Glen Canyon Dam

Long-Term Experimental and Management Plan Environmental Impact Statement

FINAL

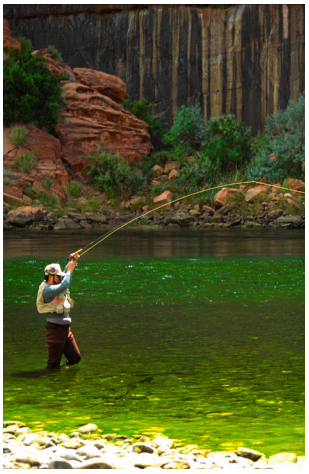
Executive Summary

U.S. Department of the Interior
Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

October 2016













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CONTENTS

ACRONYMS AND ABBREVIATIONS ..... ES-vii

EXECUTIVE SUMMARY ES-1

ES.1 Introduction ES-1
ES.2 Proposed Federal Action ES-2
ES.2.1 Purpose of and Need for Action ES-3
ES.2.2 Objectives and Resource Goals of the LTEMP ES-3
ES.3 Scope of the EIS ES-6
ES.3.1 Affected Region and Resources ES-6
ES.3.2 Impact Topics Selected for Detailed Analysis ES-6
ES.4 Laws and Regulations Related to Operations of Glen Canyon Dam and Park Management ES-8
ES.4.1 Environmental Laws and Executive Orders ES-9
ES.4.2 Cultural/Historical Laws and Executive Orders ES-10
ES.4.3 American Indian and Tribal Consultation Laws and Executive Orders ES-10
ES.4.4 Laws Establishing Criteria Related to Power Marketing ES-10
ES.4.5 Law of the River ES-11
ES.5 Related Actions ES-11
ES.5.1 Biological Opinions ES-11
ES.5.2 Environmental Impact Statements and Related Documents ES-11
ES.5.2.1 Operation of Glen Canyon Dam: Environmental Impact Statement and Record of Decision ES-11
ES.5.2.2 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead ES-12
ES.5.2.3 Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision ES-13
ES.5.2.4 Lower Colorado River Multi-Species Conservation Program—Final Programmatic Environmental Impact Statement/Environmental Impact Report ES-13
ES.5.2.5 General Management Plan for Grand Canyon National Park ES-13
ES.5.2.6 Backcountry Management Plan, Grand Canyon National Park, Arizona ES-13
ES.5.2.7 Lake Mead National Recreation Area General Management Plan—Final Environmental Impact Statement ES-14
ES.5.2.8 Glen Canyon National Recreation Area General Management Plan—Final Environmental Impact Statement ES-14

CONTENTS (Cont.)

ES.5.3 Environmental Assessments and Related Documents ES-14
ES.5.3.1 Nonnative Fish Control Environmental Assessment ES-14
ES.5.3.2 High-Flow Experiment Protocol Environmental Assessment ES-14
ES.5.3.3 Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area ES-15
ES.5.3.4 Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona ES-15
ES.5.4 Other Actions, Programs, Plans, and Projects ES-15
ES.5.4.1 Colorado River Basin Salinity Control Program ES-15
ES.5.4.2 Lake Powell Pipeline Project ES-15
ES.5.4.3 Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update ES-16
ES.5.4.4 Grand Canyon National Park Foundation Statement for Planning and Management ES-16
ES.5.4.5 Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning ES-16
ES.5.4.6 Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park ES-16
ES.5.4.7 Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge National Monument FY2007–FY2011 ..... ES-17
ES.5.4.8 Grand Canyon National Park Resource Management Plan ES-17
ES.6 Public Involvement ES-17
ES.7 Descriptions of Alternatives ES-18
ES.7.1 Development of Alternatives ES-18
ES.7.2 Descriptions of Alternatives Analyzed in the EIS ES-19
ES.7.2.1 Alternative A (No Action Alternative) ES-23
ES.7.2.2 Alternative B ES-32
ES.7.2.3 Alternative C ES-32
ES.7.2.4 Alternative D (Preferred Alternative) ES-33
ES.7.2.5 Alternative E ES-34
ES.7.2.6 Alternative F ES-35
ES.7.2.7 Alternative G ES-35
ES.8 Implementation of the LTEMP ES-36
ES.8.1 Operational Flexibility ES-36
ES.8.2 Experimental Implementation Process ES-37
ES.8.3 Descriptions of Potential Experiments ES-39

CONTENTS (Cont.)

ES.8.3.1 Sediment-Related Experiments ES-39
ES.8.3.2 Aquatic Resource-Related Experiments..... ES-40
ES.8.3.3 Experimental Vegetation Treatment ES-41
ES.8.3.4 Hydropower Improvement Flows ES-41
ES.9 Affected Environment ES-42
ES.10 Environmental Consequences ES-44
ES.11 Unavoidable Adverse Impacts..... ES-62
ES.12 Relationship between Short-Term Use and Long-Term Productivity..... ES-63
ES.13 Irreversible and Irretrievable Commitments of Resources..... ES-63
ES.14 References ES-64

FIGURES

ES-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands..... ES-7

ES-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output ES-45

TABLES

ES-1 Operational Characteristics of LTEMP Alternatives ES-24

ES-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives ES-26

ES-3 Summary of Impacts of LTEMP Alternatives on Resources ES-47

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ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
AMWG	Adaptive Management Work Group
AZGFD	Arizona Game and Fish Department
BIA	Bureau of Indian Affairs
CFMP	Comprehensive Fisheries Management Plan
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
CRSS	Colorado River Simulation System
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EA	Environmental Assessment
EIS	Environmental Impact Statement
E.O.	Executive Order
ESA	Endangered Species Act of 1973
FONSI	Finding of No Significant Impact
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
GHG	greenhouse gas
HFE	high-flow experiment
hr	hour(s)
in.	inch(es)
kaf	thousand acre-feet

LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Glen Canyon Dam Long-Term Experimental and Management Plan
maf	million acre-feet
mi	mile(s)
mi^2	square mile(s)
MLFF	Modified Low Fluctuating Flow
MW	megawatt(s)
NEPA	National Environmental Policy Act of 1969, as amended
NM	national monument
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service
NRHP	*National Register of Historic Places*
P.L.	Public Law
Reclamation	Bureau of Reclamation
ROD	Record of Decision
Secretary, the	Secretary of the Interior
SLCA/IP	Salt Lake City Integrated Projects
SO_2	sulfur dioxide
Stat.	Statute
TWG	Technical Work Group
UCRC	Upper Colorado River Commission
USC	*United States Code*
USGS	U.S. Geological Survey
WAPA	Western Area Power Administration

EXECUTIVE SUMMARY

ES.1 INTRODUCTION

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation (Reclamation) and National Park Service (NPS) proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam, the largest unit of the Colorado River Storage Project (CRSP). The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, commonly referred to as the Colorado River Ecosystem,[1] including those of importance to American Indian Tribes.

The LTEMP Environmental Impact Statement (EIS) has been prepared to identify the potential environmental effects of implementing the proposed federal action. In addition, the EIS identifies and analyzes the environmental issues and consequences associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. The alternatives addressed in this EIS include a broad range of operations and experimental actions that together allow for a full evaluation of possible impacts of the proposed action. DOI, through Reclamation and NPS, has determined these alternatives represent a reasonable range of options that may meet the purpose, need, and objectives (as described below) of the proposed action. These alternatives include a broad range of operations and actions that would accomplish the proposed federal action. This EIS has been developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), following implementing regulations developed by the President's Council on Environmental Quality (CEQ) in Title 40, *Code of Federal Regulations* (CFR), Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46.

Reclamation and NPS are joint-lead agencies for the LTEMP EIS because of their roles in operating Glen Canyon Dam (Reclamation's role) and managing the resources of Glen Canyon National Recreation Area (GCNRA), Grand Canyon National Park (GCNP), and Lake Mead National Recreation Area (LMNRA) (NPS's role). As joint leads, both agencies have been equally involved in the development of all aspects of the LTEMP EIS. There are 14 Cooperating Agencies for the LTEMP EIS, which include the Bureau of Indian Affairs (BIA), U.S. Fish and Wildlife Service (FWS), Western Area Power Administration (WAPA), Arizona Game and Fish Department (AZGFD), Colorado River Board of California, Colorado River Commission of Nevada, Upper Colorado River Commission (UCRC), Salt River Project, Utah Associated

[1] The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources (see Appendix A).

Municipal Power Systems, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni.

Major phases of LTEMP EIS development included (1) public and internal scoping, (2) identification of alternatives to be considered for evaluation and their characteristics, (3) identification of elements common to all alternatives, (4) analysis of the consequences of the alternatives, (5) government-to-government consultation with traditionally associated Tribes, (6) preparation and issuance of the Draft EIS (DEIS), (7) public review of the DEIS, and (8) issuance of this Final EIS.

The first EIS on the operation of Glen Canyon Dam was published in 1995 (Reclamation 1995). The 1996 Record of Decision (ROD) (Reclamation 1996) selected the Modified Low Fluctuating Flow Alternative as the preferred means of operating Glen Canyon Dam. The ROD incorporated the GCPA requirement that the Secretary of the Interior (hereafter referred to as the Secretary) undertake research and monitoring to determine if revised dam operations were achieving the resource protection objectives of the final EIS and the ROD. The ROD also led to the establishment of the Glen Canyon Dam Adaptive Management Program (GCDAMP), administered by Reclamation with technical expertise provided by the U.S. Geological Survey's (USGS's) Grand Canyon Monitoring and Research Center (GCMRC).

The DOI has evaluated information developed through the GCDAMP to more fully inform decisions regarding operation of Glen Canyon Dam over the next 20 years and to inform other management and experimental actions within the LTEMP. Revised dam operations and other actions will be considered and analyzed under alternatives in this EIS.

The LTEMP will incorporate information gathered since the 1996 ROD, including status reports developed in coordination with the GCDAMP and Reclamation, and NPS compliance documents supporting adaptive management efforts for the Glen Canyon Dam. These include, but are not limited to, the *Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam* (Reclamation 2011a), *Environmental Assessment for an Experimental Protocol for High-Flow Releases from Glen Canyon Dam* (Reclamation 2011b), *Colorado River Management Plan* (CRMP) (NPS 2006b), *EIS for 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Reclamation 2007a), and the *Comprehensive Fisheries Management Plan* (CFMP) (NPS 2013).

ES.2 PROPOSED FEDERAL ACTION

The proposed federal action considered in this EIS, as described in the 2011 Notice of Intent (NOI) and as further refined in this EIS, is the development and implementation of a structured, long-term experimental and management plan for operations of Glen Canyon Dam. The LTEMP and the Secretary's decision would provide a framework for adaptively managing Glen Canyon Dam operations and other management and experimental actions over the next 20 years consistent with the GCPA and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations (including hourly, daily, and monthly release patterns), non-flow actions, and appropriate experimental and management actions that

will meet the GCPA's requirements, maintain or improve hydropower production to the greatest extent practicable, consistent with improvement of downstream resources, including those of importance to American Indian Tribes. Under the LTEMP, water will continue to be delivered in a manner that is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria for (LROC) Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Section ES.4.4).

ES.2.1 Purpose of and Need for Action

The purpose of the proposed action is to provide a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with the GCPA and other provisions of applicable federal law.

The proposed action will help determine specific dam operations and actions that could be implemented to improve conditions and continue to meet the GCPA's requirements and to minimize—consistent with law—adverse impacts on the downstream natural, recreational, and cultural resources in the two park units, including resources of importance to American Indian Tribes.

The need for the proposed action stems from the need to use scientific information developed since the 1996 ROD to better inform DOI decisions on dam operations and other management and experimental actions so that the Secretary may continue to meet statutory responsibilities for protecting downstream resources for future generations, conserving species listed under the Endangered Species Act (ESA), avoiding or mitigating impacts on *National Register of Historic Properties* (NRHP)-eligible properties, and protecting the interests of American Indian Tribes, while meeting obligations for water delivery and the generation of hydroelectric power.

ES.2.2 Objectives and Resource Goals of the LTEMP

The DOI has identified several primary objectives of operating Glen Canyon Dam under the LTEMP, as well as more specific goals to improve resources within the Colorado River Ecosystem through experimental and management actions. These objectives and resource goals were considered in the formulation and development of alternatives in this EIS.

The following is a list of the objectives of the LTEMP:

- Develop an operating plan for Glen Canyon Dam in accordance with the GCPA to protect, mitigate adverse impacts to, and improve the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and to do so in such a manner as is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the U.S. Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern the allocation, appropriation, development, and exportation of the waters of the Colorado River Basin and in conformance with the Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs which are currently implemented by the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Ensure the LTEMP does not affect water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Consider potential future modifications to Glen Canyon Dam operations and other flow and non-flow actions to protect and improve downstream resources.

- Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

- Respect the interests and perspectives of American Indian Tribes.

- Make use of the latest relevant scientific studies, especially those conducted since 1996.

- Determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process.

- Ensure Glen Canyon Dam operations and non-flow actions under the LTEMP are consistent with the GCPA, ESA, National Historic Preservation Act, CRSPA, and other applicable federal laws.

Reclamation and NPS developed resource goals considering public input and desired future conditions previously adopted by the Adaptive Management Work Group (AMWG). The following resource goals were identified:

1. *Archaeological and Cultural Resources*. Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

2. *Natural Processes*. Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

3. *Humpback Chub*. Meet humpback chub (*Gila cypha*) recovery goals, including maintaining a self-sustaining population, spawning habitat, and aggregations in the Colorado River and its tributaries below the Glen Canyon Dam.

4. *Hydropower and Energy*. Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

5. *Other Native Fish*. Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

6. *Recreational Experience*. Maintain and improve the quality of recreational experiences for the users of the Colorado River Ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

7. *Sediment*. Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

8. *Tribal Resources*. Maintain the diverse values and resources of traditionally associated Tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons.

9. *Rainbow Trout Fishery*. Achieve a healthy high-quality recreational rainbow trout (*Oncorhychus mykiss*) fishery in GCNRA and reduce or eliminate downstream trout migration consistent with NPS fish management and ESA compliance.

10. *Nonnative Invasive Species*. Minimize or reduce the presence and expansion of aquatic nonnative invasive species.

11. *Riparian Vegetation*. Maintain native vegetation and wildlife habitat, in various stages of maturity, such that they are diverse, healthy, productive, self-sustaining, and ecologically appropriate.

Overlying these goals is the understanding that operations under LTEMP will continue to deliver water in a manner that is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. As such, water delivery is an overarching consideration for dam operations that will necessarily inform the actions that can be taken to achieve the resource goals set forth above.

ES.3 SCOPE OF THE EIS

ES.3.1 Affected Region and Resources

In general, the region examined in this EIS includes the area potentially directly affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead. More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. Portions of GCNRA, GCNP, LMNRA outside the Colorado River Ecosystem were also included in the affected region for certain resources due to the potential effects of LTEMP operations. In addition, for resources, such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP. Figure ES-1 portrays the project area in context with the geographic regions of northern Arizona, southwestern Utah, and southern Nevada.

ES.3.2 Impact Topics Selected for Detailed Analysis

Topics for analysis in the EIS were selected on the basis of public scoping comments, joint-lead agency guidance, meetings with Tribes and stakeholders, and relevant laws and

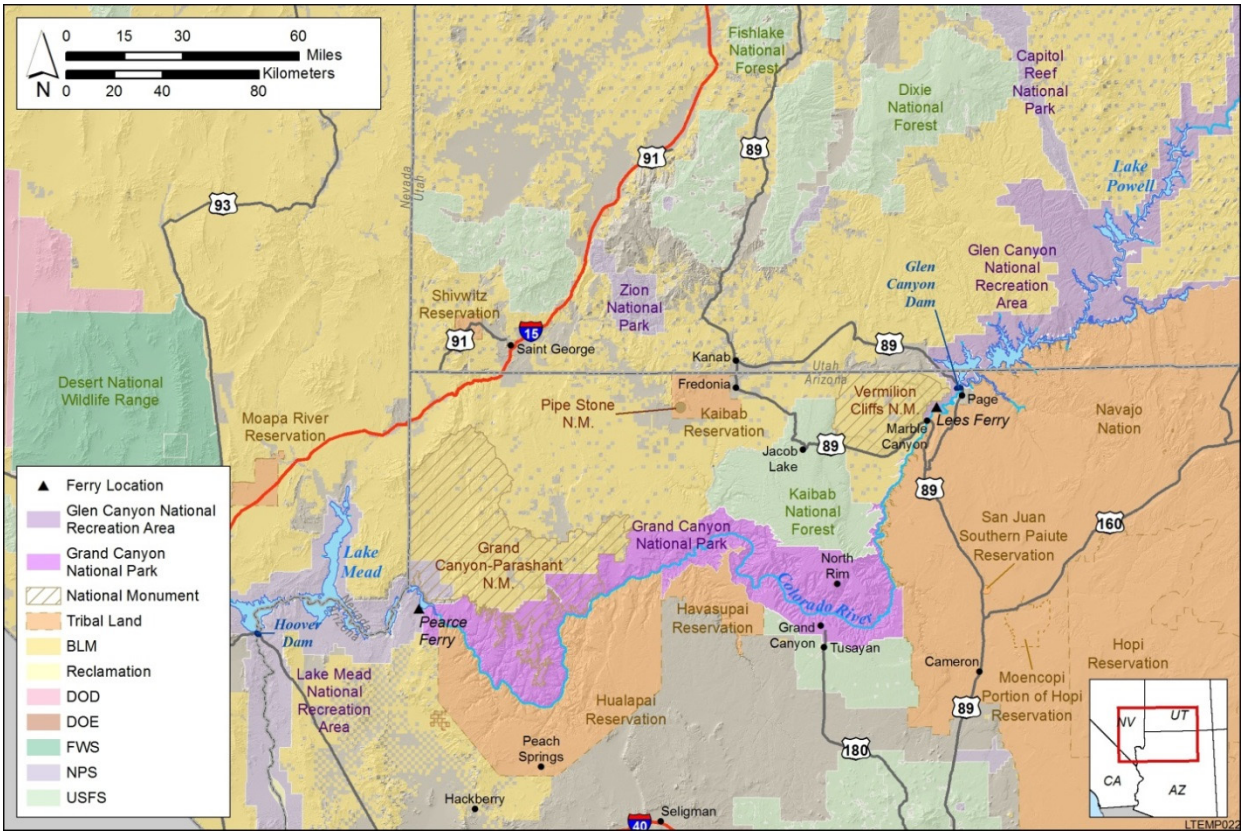

FIGURE ES-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource.)

regulations. Direct, indirect, and cumulative impacts of the effects of the proposed action, in combination with the effects of past, present, and reasonably foreseeable future projects, were analyzed in the LTEMP EIS for the following impact topics:

- Water resources, including annual, monthly, and hourly patterns of releases, water temperature, and water quality;
- Sediment resources, including sand and sandbars within the active river channel, and sand that accumulates in the Colorado River delta of Lake Mead;
- Natural processes that support ecological systems within the Colorado River Ecosystem;
- Aquatic ecology, including aquatic food base for fishes, nonnative fishes (warmwater, coolwater, and trout), native fishes (including the endangered humpback chub and razorback sucker [*Xyrauchen texanus*]), and aquatic parasites;

- Vegetation, including Old High Water Zone vegetation, New High Water Zone vegetation, wetlands, and special status plant species;

- Wildlife, including terrestrial invertebrates, amphibians and reptiles, birds, mammals, and special status wildlife species;

- Cultural resources, including archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, and ethnographic resources important to American Indian Tribes;

- Tribal resources, including vegetation, wildlife, fish, and wetlands, water rights, traditional cultural places, traditional knowledge, and continued access to important resources within Glen and Grand Canyons;

- Visual resources in GCNRA, GCNP, and LMNRA;

- Recreation, visitor use, and experience as related to fishing, boating, and camping activities in the Colorado River and on Lakes Powell and Mead;

- Wilderness and visitor wilderness experience;

- Hydropower, including the amount and value of hydropower generation at Glen Canyon Dam, marketable electrical capacity, capital and operating costs, and rate impacts;

- Socioeconomics, including recreational use values, nonuse economic value, employment and income, and environmental justice;

- Air quality effects related to changes in Glen Canyon Dam operations, including air emissions; and

- Climate change, including the effects of Glen Canyon operations on greenhouse gas (GHG) emissions and the effects of climate change on future impacts of Glen Canyon Dam operations.

ES.4 LAWS AND REGULATIONS RELATED TO OPERATIONS OF GLEN CANYON DAM AND PARK MANAGEMENT

The following laws, regulations, and treaties must be complied with for operation of Glen Canyon Dam and for park management, and may or may not specifically apply to this action. Nothing in this EIS is intended to interpret the authorities listed below.

ES.4.1 Environmental Laws and Executive Orders

- Bald and Golden Eagle Protection Act of 1940, as amended 1962 (Title 16, *United States Code*, Section 668c [16 USC 668c])
- Clean Air Act of 1970 (33 USC 1251 et seq.)
- Clean Water Act of 1972 (33 USC 1251 et seq.)
- Endangered Species Act of 1973 (16 USC 1531-1544, 87 Statute [Stat.] 884)
- Executive Order (E.O.) 11514, "Protection and Enhancement of Environmental Quality," as amended by E.O. 11991, "Relating to Protection and Enhancement of Environmental Quality" (U.S. President 1970)
- E.O. 11988, "Floodplain Management" (U.S. President 1977a)
- E.O. 11990, "Protection of Wetlands" (U.S. President 1977b)
- E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (U.S. President 1994)
- E.O. 13112, "Invasive Species" (U.S. President 1999)
- E.O. 13186, "Responsibilities of Federal Agencies to Protect Migratory Birds" (U.S. President 2001)
- Fish and Wildlife Coordination Act of 1934 (16 USC 661 et seq.)
- Grand Canyon Protection Act of 1992 (P.L. 102-575)
- Migratory Bird Treaty Act of 1918, as amended 2008 (16 USC 703)
- National Environmental Policy Act of 1969, as amended (42 USC 4321 et seq.)
- National Park Service Organic Act of 1916 (16 USC 1-4, 22, and 43, as amended)
- Redwoods National Park Expansion Act of 1978 (Redwoods Amendment) (16 USC 1a-1)
- Wild and Scenic Rivers Act of 1968 (16 USC 1271 et seq.)
- Wilderness Act of 1964 (16 USC 1131-1136)

ES.4.2 Cultural/Historical Laws and Executive Orders

- Antiquities Act of 1906 (16 USC 431-433)
- Archaeological and Historic Preservation Act of 1974 (16 USC 469 et seq.)
- Archaeological Resources Protection Act of 1979 (16 USC 470 et seq., Public Law [P.L.] 96-95)
- E.O. 11593, "Protection and Enhancement of the Cultural Environment" (U.S. President 1971)
- Historic Sites, Buildings, and Antiquities Act of 1935 (16 USC 461 et seq., as amended by P.L. 89-249)
- National Historic Preservation Act of 1966 (16 USC 470 et seq.; P.L. 89-665)

ES.4.3 American Indian and Tribal Consultation Laws and Executive Orders

- American Indian Religious Freedom Act of 1978 (P.L. 95-431, 92 Stat. 469, 42 USC 1996)
- E.O. 13007, "Indian Sacred Sites" (U.S. President 1996)
- E.O. 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000)
- Native American Graves Protection and Repatriation Act of 1990 (P.L. 101-601, 104 Stat. 3048, 25 USC 3001 et seq.)

ES.4.4 Laws Establishing Criteria Related to Power Marketing

- Colorado River Storage Project Act of 1956 (P.L. 84-485, 70 Stat. 105)
- Department of Energy Organization Act of 1977 (P.L. 95-91, 91 Stat. 565, 42 USC 7101)
- Flood Control Act of 1944 (P.L. 78-534, 58 Stat. 887)
- Reclamation Project Act of 1939 (P.L. 76-260, 53 Stat. 1187, 43 USC 485)

ES.4.5 Law of the River

The treaties, compacts, decrees, statutes, regulations, contracts, and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often referred to as the Law of the River. There is no single, universally agreed upon definition of the Law of the River, but it is useful as a shorthand reference to describe this longstanding and complex body of legal agreements governing the Colorado River. Documents generally considered to be part of the Law of the River include the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the U.S. Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern the allocation, appropriation, development, and exportation of the waters of the Colorado River Basin and in conformance with the Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs, which are currently implemented by the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

ES.5 RELATED ACTIONS

Numerous ongoing and completed plans, policies, actions, and initiatives are related to the operation of the Glen Canyon Dam and Colorado River with respect to the proposed federal action analyzed in this EIS.

ES.5.1 Biological Opinions

- Final Biological Opinion for the Proposed Adoption of Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (FWS 2007).

- Final Biological Opinion on the Operation of Glen Canyon Dam, including High-Flow Experiments and Nonnative Fish Control (FWS 2011). This replaced former Biological Opinions from 1995 to 2009.

- Final Biological Opinion on the Comprehensive Fisheries Management Plan, Coconino and Mohave Counties, Arizona (FWS 2013).

ES.5.2 Environmental Impact Statements and Related Documents

ES.5.2.1 Operation of Glen Canyon Dam: Environmental Impact Statement and Record of Decision (Reclamation 1996)

Glen Canyon Dam currently operates under provisions of the 1996 ROD (Reclamation 1996) for the Glen Canyon Dam EIS (Reclamation 1995). The Secretary accepted

the recommendation of the 1995 EIS and signed the 1996 ROD (Reclamation 1996) that selected Modified Low Fluctuating Flows (MLFF) as the operating system for the dam. A component of the final Glen Canyon Dam EIS (Reclamation 1995) and the environmental commitments identified in the 1996 ROD was the implementation of a Programmatic Agreement regarding operations of the Glen Canyon Dam. This agreement, along with subsequent monitoring and remedial action plans and the 2007 Comprehensive Treatment Plan, set a strategy for long-term management of archaeological sites affected by the operations of Glen Canyon Dam. In addition, separate, action-specific Memoranda of Agreement were established among the signatories to the agreements, primarily Reclamation, NPS, Arizona State Historic Preservation Office, and affiliated Tribes for actions related to the High Flow Experimental Protocol EA (Reclamation 2011b) and the Nonnative Fish Control EA (Reclamation 2011a). As agreed to by the signatories of the original PA, a new PA is being developed in conjunction with the LTEMP EIS based on research and monitoring along the river and the resulting new information accumulated since 1996. This draft PA currently is being developed as allowed in 36 CFR 800.14(1) (ii) when effects on historic properties cannot be fully determined prior to approval of the undertaking. The draft PA outlines general and specific measures Reclamation (as lead federal agency for operation of Glen Canyon Dam and with responsibility for the NHPA Section 106 mitigation of effects from dam operations) and the NPS will take to fulfill their responsibilities regarding the protection of historic properties under the NHPA.

ES.5.2.2 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007b)

In 2007, Reclamation developed and adopted interim operational guidelines that would address the operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. These Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. This ROD did not modify the authority of the Secretary to determine monthly, daily, hourly, or instantaneous releases from Glen Canyon Dam.

The completed Interim Guidelines determine the availability of Colorado River water for use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to conserve reservoir storage and provide water users and managers with greater certainty regarding the reduction of water deliveries during drought and other low-reservoir conditions. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as Intentionally Created Surplus (ICS), intended to minimize the severity and likelihood of potential future shortages. Nothing in this LTEMP EIS is intended to affect, or will affect, future decisions that may be made regarding the implementation of the LROC after the Interim Guidelines expire in 2026.

ES.5.2.3 Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision (NPS 2005, 2006a)

This Final EIS (NPS 2005) presents a visitor use management plan for the Colorado River corridor in the Grand Canyon. The ROD (NPS 2006a) was approved in early 2006, and the CRMP was published later in the year (NPS 2006b). The CRMP's section on research, monitoring, and mitigation for the plan focuses on the impacts of visitor use and is a consideration for the LTEMP EIS analysis.

ES.5.2.4 Lower Colorado River Multi-Species Conservation Program—Final Programmatic Environmental Impact Statement/Environmental Impact Report (DOI 2004)

This Programmatic EIS evaluates the impacts of implementing the Lower Colorado River Multi-Species Conservation Program Conservation Plan. It is intended to avoid, minimize, and fully mitigate the incidental take of the covered species from the implementation of the covered activities to the maximum extent practicable. The Conservation Plan also is intended to contribute to the recovery of species listed as threatened or endangered under the ESA and reduce the likelihood for future listing of unlisted covered species along the lower Colorado River. The ROD (DOI 2005) was approved in 2005.

ES.5.2.5 General Management Plan for Grand Canyon National Park (NPS 1995)

This plan guides the management of resources, visitor use, and general development at the park over a 10- to 15-year period. The primary purpose of the plan is to provide a foundation from which to protect park resources while providing for meaningful visitor experiences. A secondary purpose is to encourage compatible activities on adjacent lands so as to minimize adverse effects on the park.

ES.5.2.6 Backcountry Management Plan, Grand Canyon National Park, Arizona (NPS 1988)

This plan defines the primary policies that manage visitor use and resource protection for the undeveloped areas of GCNP. GCNP has started work on a Backcountry Management Plan and EIS. The park's existing Backcountry Management Plan is being updated to comply with current NPS laws and policies and the park's 1995 General Management Plan. Once completed, the revised Backcountry Management Plan will guide management decisions regarding the park's backcountry and wilderness resources into the future.

ES.5.2.7 Lake Mead National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1986)

This plan presents short-term and long-term strategies for meeting the management objectives of LMNRA. It addresses resource management, resource use, and park development challenges. The plan was intended to guide park management for 25 years or longer when it was issued. The purpose of the plan is to provide a cohesive framework for management decisions, management proposals, concession planning, and guidance for short-term decision-making.

ES.5.2.8 Glen Canyon National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1979)

This plan and wilderness recommendation lays out proposals for meeting four levels of management objectives for GCNRA, ranging from general to specific. The first-level objective is to manage GCNRA to maximize its recreational enjoyment. Objective levels 2 through 4 address increasingly specific objectives, including those for cultural, Tribal, mineral, and grazing resources and management of the reservoir. The plan presents a management zoning proposal to divide GCNRA into four management zones: natural, recreation and resource utilization, cultural, and development.

ES.5.3 Environmental Assessments and Related Documents

ES.5.3.1 Nonnative Fish Control Environmental Assessment (Reclamation 2011a)

In this assessment, Reclamation proposed to conduct research, monitoring, and specific actions to control nonnative fish in the Colorado River downstream from Glen Canyon Dam in an effort to help conserve native fish. The purpose of the action was to minimize the negative impacts of competition and predation on an endangered fish, the humpback chub. The action was needed because competition and predation by nonnative fishes, particularly rainbow trout and brown trout (*Salmo trutta*), may be contributing to a reduction in survival and recruitment of young humpback chub and threatening the potential recovery of the species. Rainbow trout and brown trout are not native to the Colorado River Basin and have been introduced into the region as sport fish. The Finding of No Significant Impact (FONSI) (Reclamation 2012b) was signed in May of 2012.

ES.5.3.2 High-Flow Experiment Protocol Environmental Assessment (Reclamation 2011b)

This experimental protocol was developed following analysis of a series of high-flow experimental releases. The protocol is intended to improve conservation of limited sediment resources in the Colorado River below Glen Canyon Dam. The FONSI (Reclamation 2012a) was signed in May of 2012.

ES.5.3.3 Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area (NPS 2013)

The NPS is implementing a CFMP, in coordination with the AZGFD, the FWS, Reclamation, and GCMRC, for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The intent of the CFMP is to maintain a thriving native fish community within GCNP and a highly valued recreational rainbow trout fishery in the Glen Canyon reach of GCNRA. NPS released a FONSI on December 9, 2013, for the CFMP.

ES.5.3.4 Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona (NPS 2009)

GCNP is using Integrated Pest Management techniques to control and contain exotic plant species within park boundaries. Exotic plant species displace natural vegetation and consequently affect long-term health of native plant and animal communities.

ES.5.4 Other Actions, Programs, Plans, and Projects

Additional actions, programs, plans, or projects involving the Colorado River may continue to operate or be contemplated during the life of the LTEMP. These items, which are not directly linked to LTEMP, include the following.

ES.5.4.1 Colorado River Basin Salinity Control Program (Reclamation 2014)

The Colorado River and its tributaries provide municipal and industrial water to about 27 million people and irrigation water to nearly 4 million ac of land in the United States. The threat of salinity is a major concern in both the United States and Mexico. In June 1974, Congress enacted the Colorado River Basin Salinity Control Act (P.L. 93-320), which directed the Secretary to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico.

ES.5.4.2 Lake Powell Pipeline Project (WCWCD 2012)

Washington, Kane, and Iron Counties in Utah are pursuing the construction of a pipeline that would run from Lake Powell, near Glen Canyon Dam, through Kane County, to Sand Hollow Reservoir, which is located approximately 10 mi east of St. George. The pipeline would then run parallel to Interstate 15 into Iron County. The pipeline would be 158 mi long and bring 70,000 ac-ft of water to Washington County, 10,000 ac-ft to Kane County, and 20,000 ac-ft to Iron County.

ES.5.4.3 Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update

The 1980 Final Wilderness Recommendation submitted to the DOI includes 1,143,918 ac proposed for wilderness designation, and includes 26,461 ac as potential wilderness pending the resolution of boundary and motorized boat use issues. The Colorado River was identified as potential wilderness. In 2010, NPS conducted internal reviews and included refinements to the proposed wilderness acreage estimates. All refinements were consistent with the intent of the original document submitted to the DOI in 1980.

ES.5.4.4 Grand Canyon National Park Foundation Statement for Planning and Management (NPS 2010)

The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Grand Canyon's natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNP and its mission, the Statement should remain relatively unchanged.

ES.5.4.5 Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning (NPS 2014)

The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Glen Canyon and Rainbow Bridge's natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNRA and its mission, the Statement should remain relatively unchanged.

ES.5.4.6 Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park (NPS 2008)

GCNP's backcountry seeps, springs, and tributaries of the Colorado River are among the most pristine watersheds and desert riparian habitats remaining in the coterminous United States. This report contains the details from the invasive plant control and monitoring efforts completed for one phase (Phase II-B) of the three-phase project. Reports for the previous two phases are also available on the NPS website.

ES.5.4.7 Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge National Monument FY2007–FY2011 (NPS 2006c)

This 5-year Strategic Plan has been written for GCNRA and Rainbow Bridge National Monument (NM). Because Rainbow Bridge NM is administered by GCNRA, this strategic plan covers both units of the NPS.

ES.5.4.8 Grand Canyon National Park Resource Management Plan (NPS 1997)

The purpose of the Resource Management Plan was to provide long-term guidance and direction for the stewardship of the natural, cultural, and recreational resources of GCNP.

ES.6 PUBLIC INVOLVEMENT

The *Federal Register* NOI to prepare an EIS and hold public scoping meetings was published on July 6, 2011, which marked the beginning of the public comment period. The scoping comment period ended January 31, 2012. Six public meetings and one web-based meeting were held in Arizona, Colorado, Nevada, and Utah in November 2011. A total of 447 individuals, groups, or organizations submitted scoping comments. Results of the public scoping process are described in the Scoping Summary Report (Reclamation and NPS 2012).

Members of the public were invited to participate in a 2-day open public meeting on preliminary alternative concepts, hosted by Reclamation and NPS. The meeting was held on April 4 and 5, 2012. More than 70 people attended the meeting, including members of the public, stakeholders, and project staff from Reclamation, NPS, and Argonne. During this meeting, alternatives being considered for inclusion in the LTEMP EIS were presented and discussed. Reclamation and NPS evaluated the feedback received at this meeting and used it to develop the final set of alternatives considered in this EIS.

Regular updates of the LTEMP EIS process were provided at public meetings of the Glen Canyon Dam AMWG. LTEMP EIS joint leads regularly presented the status of preliminary EIS-related materials (e.g., purpose and need, resource goals, and preliminary draft alternatives) and coordination activities with the Cooperating Agencies.Throughout the LTEMP development process, DOI had formal and informal consultations with Tribes.

On January 8, 2016, the LTEMP DEIS was filed with Region 9 of the U.S. Environmental Protection Agency, a Notice of Availability and Notice of Public Meetings were published in the *Federal Register* (81 FR 963), and an email notification of the availability of the DEIS for download from the project website (www.ltempeis.gov) was sent to approximately 600 members of the public. The DEIS was sent to each of the governors, senators, and representatives from relevant congressional districts of the seven Colorado River Basin States (Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming).

The original 90-day public comment period was extended an additional 32 days (122 days total) to May 9, 2016, after several requests were received from the public and Cooperating Agencies. During the comment period, two in-person meetings and two Internet-based webinars were held to provide the public with information about the content and findings of the DEIS and to receive written comments on the DEIS. More than 3,000 individual comment documents were received on the DEIS. Substantive comments within these documents were used to make changes to the DEIS when deemed appropriate and justified.

ES.7 DESCRIPTIONS OF ALTERNATIVES

Seven alternatives, including the No Action Alternative, were developed for consideration in the EIS. These alternatives were assigned letter designations of A through G, with Alternative A being the No Action Alternative.

Alternative A (the No Action Alternative) represents continued implementation of existing operations and actions as defined by existing agency decisions. The other six "action" alternatives represent various ways in which operations and actions could be modified under an LTEMP. Four of the action alternatives (C, D [the preferred alternative], F, and G) were developed by the joint-lead agencies with various levels of participation by other DOI agencies, including the BIA, FWS, and GCMRC; as well as Argonne National Laboratory, WAPA, and AZGFD; and input and comments from Cooperating Agencies and Tribes. Two of the action alternatives were developed and submitted for consideration by two stakeholder organizations, the Colorado River Energy Distributors Association (CREDA; Alternative B) and the Colorado River Basin States Representatives from Arizona, California, Colorado, Utah, Nevada, New Mexico, Wyoming, and the UCRC (Basin States; Alternative E) in response to an offer made by the DOI in April 2012 to consider alternatives submitted by Cooperating Agencies and AMWG members. Grand Canyon Trust and the Irrigation and Electrical Districts Association of Arizona submitted letters with comments on alternatives, but did not submit complete alternative proposals.

ES.7.1 Development of Alternatives

The alternative development process began with identification of the proposed action (i.e., development of a Long-Term Experimental and Management Plan), purpose and need of the LTEMP, and the resource goals and objectives of the LTEMP (Section ES.2). Once these items were defined, NPS and Reclamation worked to develop a set of alternatives that represented the full range of reasonable experimental and management actions; met the purpose, need, and objectives of the proposed action; and were considered within the constraints of existing laws, regulations, and existing decisions and agreements.

Alternative operations that either used different operational strategies (e.g., consistent monthly release pattern or condition-dependent release pattern) or had different primary objectives (e.g., native fish, sediment, or restoration of a more natural flow pattern) were developed and refined. In developing alternatives for detailed analysis, NPS and Reclamation

considered and evaluated concepts identified by the public during scoping, and alternatives that had been identified in several efforts led by the GCDAMP (USGS 2006, 2008).

Several iterations of preliminary draft alternative concepts developed by NPS and Reclamation were presented to the Cooperating Agencies and other stakeholders in workshops and webinars to explain the alternative development process, describe proposed alternative characteristics, and solicit feedback. Workshops included (1) a facilitated public workshop on April 4 and 5, 2012; (2) Cooperating Agency and Tribal meetings on August 10, 2012; (3) Tribal workshops on March 14, 2013; (4) a stakeholder workshop on August 5–7, 2013; (5) a stakeholder workshop on March 31–April 1, 2014; and (6) a stakeholder webinar on December 3, 2015. There were also monthly calls with Cooperating Agencies that included updates and information exchange related to the alternatives.

Alternative D was identified by the DOI as the preferred alternative in this EIS and received letters of support from WAPA, the Basin States, and the National Parks Conservation Association before the DEIS was published. DOI received both positive and negative feedback about this alternative from other stakeholders. Alternative D was developed by the DOI based on the results of the analysis impacts of the original set of six alternatives. Alternative D adopted many of the best-performing characteristics of Alternatives C and E. The effects of operations under these latter two alternatives were first modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance, reduce impacts, and better meet the purpose, need, and objectives of the LTEMP. The impacts of Alternative D were then evaluated using the same models used for other alternatives (Section ES.10), and these results served as the basis for the assessments presented in the EIS. Subsequent to that modeling, relatively minor modifications were made to Alternative D based on discussions with Cooperating Agencies, and with the support of additional modeling.

To aid in the alternative development process, formal decision analysis tools were used for the LTEMP EIS. Such tools are useful for this application because the LTEMP concerns the management of a very complex system with many—possibly competing—resources of interest, and it involves uncertainty about the relationships between management strategies and the responses of resources to those strategies. A structured decision analysis process for LTEMP alternative development and evaluation was facilitated by Dr. Michael Runge of the USGS to obtain multiple stakeholder viewpoints. This was accomplished through a series of workshops and webinars involving LTEMP project managers; EIS analysts; technical representatives from FWS, BIA, WAPA, Arizona Department of Water Resources, and AZGFD; and other AMWG stakeholders.

ES.7.2 Descriptions of Alternatives Analyzed in the EIS

The EIS assesses the potential environmental effects of the seven alternatives considered for detailed analysis. Operations under all of these alternatives would use only existing dam infrastructure. There are a number of experimental and management actions that would be incorporated into all of the LTEMP alternatives, except where noted:

- High flow releases for sediment conservation. Implementation of high-flow experiments (HFEs) under all alternatives are patterned after the current HFE protocol (Reclamation 2011b), but some alternatives include specific modifications related to the frequency of spring and fall HFEs, the duration of fall HFEs, the triggers for HFEs, and the overall process for implementation of HFEs, including implementation considerations and conditions that would result in discontinuing specific experiments. For Alternative D, a new HFE protocol was developed that would replace the existing protocol developed in 2011.

- Nonnative fish control actions. Implementation of control actions for nonnative brown and rainbow trout are patterned after those identified in the Nonnative Fish Control EA (Reclamation 2011a) and FONSI (Reclamation 2012b). Some alternatives, however, include specific modifications related to the area where control actions would occur, the specific actions to be implemented, and the overall process for implementation of control actions, including implementation considerations and conditions that would result in discontinuing specific experiments. Nonnative fish control actions are not included in Alternative F. For Alternative D, components of the Nonnative Fish Control EA and FONSI were modified and integrated with other actions in a tiered approach to humpback chub conservation.

- Conservation measures established by the FWS in previous Biological Opinions. Conservation measures identified in the 2011 Biological Opinion (BO) on operations of Glen Canyon Dam (FWS 2011) included the establishment of a humpback chub refuge, evaluation of the suitability of habitat in the lower Grand Canyon for the razorback sucker, and establishment of an augmentation program for the razorback sucker, if appropriate. Other measures include humpback chub translocation; Bright Angel Creek brown trout control; Kanab ambersnail (*Oxyloma haydeni kanabensis*) monitoring; determination of the feasibility of flow options to control trout, including increasing daily down-ramp rates to strand or displace age-0 trout, and high flow followed by low flow to strand or displace age-0 trout; assessments of the effects of actions on humpback chub populations; sediment research to determine effects of equalization flows; and Asian tapeworm (*Bothriocephalus acheilognathi*) monitoring. Most of these conservation measures are ongoing and are elements of existing management practices (e.g., brown trout control, humpback chub translocation, and sediment research to determine the effects of equalization flows), while others are being considered for further action under the LTEMP (e.g., trout management flows). Additional conservation measures were developed for the preferred alternative during Endangered Species Act (ESA) Section 7 consultation with the FWS.

- Non-flow experimental and management actions at specific sites, such as nonnative plant removal, revegetation with native species, and mitigation at specific and appropriate cultural sites. Included are pilot experimental riparian vegetation treatment actions planned by NPS. These actions would also have involvement from Tribes to capture concerns regarding culturally significant native plants, and would provide an opportunity to integrate Traditional Ecological Knowledge in a more applied manner into the long-term program.

- Preservation of historic properties through a program of research, monitoring, and mitigation to address erosion and preservation of archeological and ethnographic sites and minimize loss of integrity at NRHP historic properties.

- Continued adaptive management under the GCDAMP, including a research and monitoring component.

With operational flows limited to 45,000 cfs and below, the overall extent of the riparian area in the Grand Canyon is expected to continue to decrease, primarily as a result of continuing lack of water in the Old High Water Zone and continued declines at the upper edges of the New High Water Zone; however, the vegetation density within the riparian area is expected to continue to increase. Nonnative vegetation and monoculture species such as arrowweed are expected to continue to increase and key native species (e.g., Goodding's willow) are expected to continue to decrease.

Experimental riparian vegetation treatment activities would be implemented by NPS under all alternatives except for Alternative A and would modify the cover and distribution of riparian plant communities along the Colorado River. All activities would be consistent with NPS Management Policies (NPS 2006d), and would occur only within the Colorado River Ecosystem in areas that are influenced by dam operations. NPS will work with Tribal partners and GCMRC to experimentally implement and evaluate a number of vegetation control and native replanting activities on the riparian vegetation within the Colorado River Ecosystem in GCNP and GCNRA. These activities would include ongoing monitoring and removal of selected nonnative plants, species in the corridor, systematic removal of nonnative vegetation at targeted sites, and native replanting at targeted sites and subreaches, which may include complete removal of tamarisk (both live and dead) and revegetation with native vegetation. Treatments would fall into two broad categories, including the control of nonnative plant species and revegetation with native plant species. Principal elements of this experimental riparian vegetation proposal include:

- Control nonnative plant species affected by dam operations, including tamarisk and other highly invasive species;

- Develop native plant materials for replanting through partnerships and use of regional greenhouses;

- Replant native plant species to priority sites along the river corridor, including native species of interest to Tribes;

- Remove vegetation encroaching on campsites;

- Manage vegetation to assist with cultural site protection.

None of the alternatives include specific experimental tests or condition-dependent treatments for historic site preservation or Tribal cultural properties and resources other than operations and treatments intended to build and retain sandbars and targeted experimental vegetation actions in relation to cultural sites as described above. Continued evaluation of site stability and integrity would be undertaken as well as continued sediment evaluations, including those related to HFEs. Similarly, NPS's continued evaluation of Traditional Cultural Properties and resources of cultural concern would be evaluated in consultation with traditional practitioners and knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as determined necessary in consultation with Tribes.

In addition to these common elements, there are recent plans and decisions of the joint-lead agencies and DOI-identified management actions that could be implemented under all alternatives (Section ES.5). The Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a), together with existing laws and regulations (Section ES.4), were used to establish sideboards that constrain the breadth and nature of flow and non-flow actions that were in the LTEMP alternatives.

Under all alternatives, release patterns could be adjusted to provide ancillary services, including regulation and reserves for hydropower. Regulation is the minute-by-minute changes in generation needed to maintain a constant voltage within a power control area. Regulation affects instantaneous operations that deviate above and below the mean hourly flow without affecting mean hourly flow. Spinning reserves in the control area served by CRSP facilities are typically provided by power resources in the Aspinall Unit, a series of three hydropower dams on the Gunnison River. However, under some relatively rare hydrological and power resource conditions, Aspinall power resources cannot provide spinning reserves. When this occurs, the spinning reserve duty is typically placed on the Glen Canyon Powerplant. In the event that these reserves are placed on Glen Canyon and at the same time need to be deployed in response to a grid event, such as a system unit outage or downed power line, WAPA would invoke emergency exception criteria, and, within minutes or less, increase the Glen Canyon Dam power generation level up to the spinning reserve requirement. Associated turbine water release rates would increase in tandem with higher power production.

Operations described under any alternative would be altered temporarily to respond to emergencies. The North American Electric Reliability Corporation (NERC) has established guidelines for the emergency operations of interconnected power systems. A number of these guidelines apply to Glen Canyon Dam operations. These changes in operations would be of short duration (usually less than 4 hr) and would be the result of emergencies within the interconnected electrical system. Examples of system emergencies include insufficient generating capacity; transmission system overload, voltage control, and frequency; system restoration; and humanitarian situations (search and rescue).

The original NOI to prepare the LTEMP EIS identified the need to determine whether to establish a recovery implementation program for endangered fish species below Glen Canyon Dam. The LTEMP team finds that identifying the need to determine whether to establish a recovery implementation program (RIP) for endangered fish species below Glen Canyon Dam does not meet the purpose and need for the action (Section 1.2). This decision does not preclude the implementation of a RIP for endangered fish species below Glen Canyon Dam in the future. Although the GCDAMP has undertaken a number of actions that have previously been identified as necessary for the recovery of humpback chub in FWS recovery planning documents, the emphasis of that program is on mitigation and conservation actions specified in the NEPA evaluations and ESA Section 7 Biological Opinions for federal actions, not on the endangered fish species' overall needs to reach recovery.

Specific details of each of the LTEMP alternatives are described in Sections ES.6.2.1 to ES.6.2.7. Operational characteristics of LTEMP alternatives are presented in Table ES-1, and condition-dependent and experimental elements are summarized in Table ES-2.

ES.7.2.1 Alternative A (No Action Alternative)

Alternative A (No Action Alternative) represents continued operation of Glen Canyon Dam as guided by the 1996 ROD for operations of Glen Canyon Dam: MLFF, as modified by recent DOI decisions, including those specified in the 2007 ROD on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead (until 2026) (Reclamation 2007b), the HFE EA (Reclamation 2011b), and the Nonnative Fish Control EA (Reclamation 2011a) (both expiring in 2020). As is the case for all alternatives, Alternative A also includes implementation of existing and planned NPS management activities, with durations as specified in NPS management documents.

Under Alternative A, daily flow fluctuations would continue to be determined according to monthly volume brackets as follows: 5,000 cfs daily range for monthly volumes less than 600 kaf; 6,000 cfs daily range for monthly volumes between 600 kaf and 800 kaf; and 8,000 cfs for monthly volumes greater than 800 kaf.

Under Alternative A, the current HFE protocol (Reclamation 2011b) would be followed until it expired in 2020. Under this protocol, high-flow releases may be made in spring (March and April) or fall (October and November). HFE magnitude would range from 31,500 to 45,000 cfs. The duration would range from less than 1 to 96 hr. Frequency of HFEs would be determined by tributary sediment inputs, resource conditions, and a decision process carried out by the DOI. The HFE protocol uses a "store and release" approach in which sediment inputs are tracked over two accounting periods, one for each seasonal HFE: spring (December 1 through June 30) and fall (July 1 through November 30). Under the protocol, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Under Alternative A, the current nonnative fish control protocol would be followed until it expired in 2020 (Reclamation 2011a). Mechanical removal would primarily consist of the use

TABLE ES-1 Operational Characteristics of LTEMP Alternatives

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Monthly pattern in release volume	Historic monthly release volumes. Higher volumes in high electric demand months of Dec., Jan., Jul., and Aug.; volume released in Oct.–Dec. = 2.0 maf in ≥8.23-maf years and 1.5 maf in years ≤7.48 maf.	Same as Alternative A.	Highest volume in high electric demand months of Dec., Jan., and Jul.; Feb.–Jun. Volumes proportional to contract rate of delivery; lower volumes Aug.–Nov.	Comparable to Alternative E, but Aug. and Sep. volume increased, with additional volume taken from Jan.–Jul.; volume released in Oct.–Dec. = 2.0 maf in ≥8.23-maf years and 1.5 maf in years ≤7.48 maf.	Monthly volumes proportional to the contract rate of delivery, but with a targeted reduction in Aug.–Oct. volumes; volume released in Oct.–Dec. = 2.0 maf in ≥8.23-maf years and 1.5 maf in years ≤7.48 maf.	Relative to Alternative A, higher release volumes in Apr.–Jun.; lower volumes in remaining months.	Equal monthly volumes, adjusted with changes in runoff forecast.
Minimum flows (cfs)	8,000 between 7 a.m. and 7 p.m. 5,000 between 7 p.m. and 7 a.m.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	5,000	5,000
Maximum non-experimental flows (cfs)[b]	25,000	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Daily range (cfs/24 hr)[c]	5,000 for monthly volumes <600 kaf 6,000 for monthly volumes 600–800 kaf 8,000 for monthly volumes >800 kaf	Dec. and Jan.: 12,000 Feb., Jul., and Aug.: 10,000 Oct., Nov., Mar., Jun., and Sep.: 8,000 Apr. and May: 6,000	Equal to 7 × monthly volume (in kaf) in all months.	Equal to 10 × monthly volume (in kaf) in Jun.–Aug., and 9 × monthly volume (in kaf) in other months; daily range not to exceed 8,000 cfs.	Equal to 12 × monthly volume (in kaf) in Jun.–Aug., and 10 × monthly volume (in kaf) in other months.	0 cfs[d]	0 cfs[d]

TABLE ES-1 (Cont.)

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Ramp rates (cfs/hr)	4,000 up 1,500 down	4,000 up 4,000 down in Nov.–Mar. 3,000 down in other months	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 1,500 down	4,000 up 1,500 down

[a] Base operations are defined as operations in those years when no condition-dependent or experimental actions are triggered. Examples of experimental actions include HFEs, low summer flows, and trout management flows (see Table ES-2).

[b] Maximum flows presented are for normal operations and may be exceeded as necessary for HFEs, emergency operations, and equalization purposes.

[c] Values presented are the normal daily range in mean hourly flow for each alternative. Some variation in instantaneous flows within hours is allowed in all alternatives to accommodate emergency conditions, regulation requirements, and reserve requirements. For several alternatives, reduced fluctuations would be implemented after significant sediment inputs or after HFEs as described in Table ES-2.

[d] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

TABLE ES-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs)								
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE. Objective: Rebuild sandbars.	Implement when triggered through 2020 when protocol expires.	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period, but no spring HFEs in first 2 years, and no spring HFE in the same water year as an extended-duration (>96 hr) fall HFE.	Implement when triggered during entire LTEMP period, except no spring HFEs in first 10 years.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period.
Proactive spring HFE in Apr., May, or Jun., with maximum possible 24-hr release up to 45,000 cfs	Trigger: High-volume equalization year (≥10 maf). Objective: To build beaches and protect sand supply otherwise exported by high equalization release.	No.	No.	Yes, if no other spring HFE in same water year.	Yes, if no other spring HFE or extended-duration fall HFE in same water year; no proactive spring HFE in first 2 years.	No.	No.	Yes, if no other spring HFE in same water year.

TABLE ES-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs) (Cont.)								
Fall HFE (Oct. or Nov.)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE. Objective: Rebuild sandbars.	Implement when triggered through 2020 when protocol expires.	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period.	Implement when triggered during entire LTEMP period.
Fall HFEs longer than 96-hr duration	Trigger: Paria River sediment input in fall. Objective: Rebuild sandbars.	No.	No.	Yes, but HFE volume limited to that of a 45,000-cfs, 96-hr flow (357,000 ac-ft).	Yes, magnitude (up to 45,000 cfs) and duration (up to 250 hr[b]) dependent on sediment supply; limited to no more than four in a 20-year period.	No.	No.	Yes, magnitude (up to 45,000 cfs) and duration (up to 336 hr) dependent on sediment supply.
Adjustments to Base Operations								
Reduced fluctuations before HFEs ("load-following curtailment")[c]	Trigger: Significant sediment input from Paria River in Dec.–Mar. or Jul.–Oct. Objective: Conserve sediment input for spring or fall HFE.	No.	No.	Yes, in Feb. and Mar. (spring HFE) or Aug.–Oct. (fall HFE).	No.	Yes, in Aug.–Oct. (fall HFE).	No change in operations, which already feature steady flows throughout the year.	No change in operations, which already feature steady flows throughout the year.

TABLE ES-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Reduced fluctuations after HFEs ("load-following curtailment")[c]	Trigger: HFE Objective: Reduce erosion of newly built sandbars.	No.	No.	Yes, until Dec. 1 after fall HFEs, or May 1 after spring HFEs.	No.	No.	No change in operations, which already feature steady flows throughout the year.	No change in operations, which already feature steady flows throughout the year.
Low summer flows (Jul., Aug., Sep.)	Trigger: Number of adult humpback chub, temperature at Little Colorado River confluence, and release temperature. Objective: Improve recruitment of chub in mainstem.	No.	No.	Test if number of adult chub <7,000, <12°C at Little Colorado River confluence, and release temperature is sufficiently warm to achieve 13°C only if low flows are provided; within-day range 2,000 cfs.	Test in second 10 years if release temperature is sufficiently warm to achieve 14°C only if low flows are provided; within-day range 2,000 cfs. If initial test is successful, implement under same conditions when humpback chub population concerns warrant its use.	Test in second 10 years if releases have been cold, number of adult chub ≥7,000, and temperature of at least 16°C can be reached.	No change in operations, which already feature low flows during summer.	No.
Macro-invertebrate production flows	Trigger: None Objective: Increase invertebrate production especially mayflies, stoneflies, and caddisflies.	No.	No.	No.	Test, but avoid confounding effects on trout management flows. Minimum monthly flow would be held constant on Saturdays and Sundays in May through Aug.	No.	No.	No.

TABLE ES-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Hydropower improvement flows (increased fluctuation levels)	Trigger: Annual volume ≤8.23 maf. Objective: Test effect on sediment, humpback chub, and trout.	No	Maximum daily flow (held for as long as possible): 25,000 cfs (Dec.–Feb., Jun.–Aug.) 20,000 cfs (Sep.–Nov.) 15,000 cfs (Mar.–May) Minimum daily flow all months: 5,000 cfs Ramp rate up and down: 5,000 cfs/hr Test in 4 years	No.	No.	No.	No.	No.
Trout Management Actions								
Trout management flows	Trigger: Predicted high trout recruitment in Glen Canyon reach. Objective: Improve fishery, reduce emigration to Little Colorado River reach, and subsequent competition and predation on humpback chub.	Test.	Test and implement if successful.	Test and implement if successful; tests in first 5 years not dependent on high trout population.	Test and implement if successful; test may be conducted early in the 20-year period even if not triggered by high trout recruitment.[d]	2 × 2 factorial design testing with/without HFE and with/without trout management flows under warm and cold conditions.	No.	Test and implement if successful.

TABLE ES-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Non-Flow Actions								
Tier 1: Expanded translocation of humpback chub within the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below tier 1 triggers. Objective: Increase number of adult and subadult humpback chub.	No.	No.	No.	Yes.	No.	No.	No.
Tier 1: Implement head-start program for larval humpback chub	Trigger: Number of adult or sub-adult humpback chub in the Little Colorado River reach below tier 1 triggers Objective: Increase number of adult and subadult humpback chub	No.	No.	No.	Yes.	No.	No.	No.
Mechanical removal of nonnative fish in Little Colorado River reach[e]	Trigger: High trout numbers and low humpback chub numbers in Little Colorado River reach, low humpback chub numbers. Objective: Increase number of adult and subadult humpback chub	Yes, if trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented until 2020.	Yes, if trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period.	Yes, if trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period.	Yes, if trout numbers are above and humpback chub numbers are below tier 2 triggers in Little Colorado River reach.	Yes, if trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period.	No.	Yes, if trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period.

TABLE ES-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Riparian vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites.	No.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.

[a] Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

[b] The duration of extended-duration HFEs would be increased stepwise; the first test of an extended-duration HFE under Alternative D would be limited to 192 hr; depending on the results of that first test, subsequent durations could be up to 250 hr. Sediment concentration in the river would be monitored during the HFE at least during the first test.

[c] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

[d] For Alternative D, the decision to conduct trout management flows in a given year would consider the resource conditions as specified in Section ES.8.2 and would also involve considerations regarding the efficacy of the test based on those resource conditions.

[e] Trout removal in the Paria River–Badger Rapids reach was assessed in the Nonnative Fish Protocol EA, but it may not be practical based on the estimated level of effort needed to accomplish significant reductions in numbers of trout in the Little Colorado River reach when trout numbers are high in Marble Canyon (Appendix D in Reclamation 2011a).

of boat-mounted electrofishing equipment to remove all nonnative fish captured. Captured nonnative fish would be removed alive and potentially stocked into areas that have an approved stocking plan, unless live removal fails, in which case fish would be euthanized and used for later beneficial use (Reclamation 2011a).

ES.7.2.2 Alternative B

The objective of Alternative B is to increase hydropower generation while limiting impacts on other resources and relying on flow and non-flow actions to the extent possible to mitigate impacts of higher fluctuations. Alternative B focuses on non-flow actions and experiments to address sediment resources, nonnative fish control, and on native and nonnative fish communities.

Under Alternative B, monthly volumes would be the same as under current operations, but daily flow fluctuations would be higher than under current operations in most months. Compared to current operations, the hourly up-ramp rate would remain unchanged at 4,000 cfs/hr, but the hourly down-ramp rate would be increased to 4,000 cfs/hr in November through March and 3,000 cfs/hr in other months.

Alternative B includes implementation of the nonnative fish control protocol (Reclamation 2011a) and HFE protocol (Reclamation 2011b) through the entire LTEMP period, but HFEs would be limited to a maximum of one spring or fall HFE every other year. In addition to these experimental actions, Alternative B would test trout management flows and hydropower improvement flows. With trout management flows, high flows (e.g., 20,000 cfs) would be maintained for 2 or 3 days, followed by a very sharp drop in flows to a minimum level (e.g., 5,000 cfs) for the purpose of reducing annual recruitment of trout. Hydropower improvement experiments would test maximum powerplant capacity releases in up to 4 years during the LTEMP period, but only in years with annual volumes ≤8.23 maf.

ES.7.2.3 Alternative C

The objective of Alternative C is to adaptively operate Glen Canyon Dam to achieve a balance of resource objectives with priorities placed on humpback chub, sediment, and minimizing impacts on hydropower. Alternative C features a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions. The alternative uses decision trees to identify when experimental changes in base operations or other planned action is needed to protect resources. Operational changes or implementation of non-flow actions could be triggered by changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature.

Monthly release volumes under Alternative C in August through November would be lower than those under most other alternatives to reduce sediment transport rates during the monsoon period. Release volumes in the high power demand months of December, January, and July would be increased to compensate for water not released in August through November, and

volumes in February through June would be patterned to follow the monthly hydropower demand as defined by the contract rate of delivery. Under Alternative C, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to monthly volume (7× monthly volume in kaf). The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative C includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the possible duration of fall HFEs while maintaining a maximum total volume of a 96-hr 45,000-cfs release); (4) reducing fluctuations before and after HFEs; (5) mechanical removal of trout near the Little Colorado River confluence; (6) trout management flows; (7) low summer flows during the entire LTEMP period to allow greater warming; and (8) experimental vegetation treatments.

ES.7.2.4 Alternative D (Preferred Alternative)

Alternative D is the preferred alternative for the LTEMP. The objective of Alternative D is to adaptively operate Glen Canyon Dam to best meet the resource goals of the LTEMP. Like Alternative C, Alternative D features a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions. Alternative D was also considered the environmentally preferred alternative based on its relative impacts (compared to other alternatives) on the full range of environmental resources. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

After modeling of Alternative D was completed, several adjustments were made to specific operational and experimental characteristics based on discussions with Cooperating Agencies and stakeholders. These adjustments included (1) an increase in August release volume with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration (>96 hr) fall HFE. Adjustments made to Alternative D after the DEIS was published, and based on comments received from Cooperating Agencies and stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE. For most resources, these adjustments to Alternative D are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D. However, the analysis did show that the adjustments could result in some changes to the expected impacts on sediment and hydropower resources.

Under Alternative D, the pattern of monthly releases would be relatively even compared to that under Alternative A. The total monthly release volume of October, November, and December would be equal to that under Alternative A (i.e., 2 maf in years with ≥8.23 maf annual release volume) to avoid the possibility of the operational tier differing from that of Alternative A, as established in the Interim Guidelines (Reclamation 2007a). The August volume was set to 800 kaf in an 8.23-maf release year to consider both sediment conservation prior to a potential HFE and power production and capacity concerns. January through July monthly volumes were set at levels that approximate WAPA's contract rate of delivery. This produced a redistribution of monthly release volumes under Alternative D that would result in the most even distribution of flows of any alternative except for Alternative G. The allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (10 × monthly volume in kaf in the high-demand months of June, July, and August and 9 × monthly volume in kaf in other months), up to a maximum of 8,000 cfs/day. The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative D includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the duration of up to 45,000-cfs fall HFEs to as many as 250 hr depending on sediment availability; (4) mechanical removal of nonnative fish near the Little Colorado River confluence; (5) trout management flows; (6) low summer flows in the second 10 years of the LTEMP period to allow greater warming; (7) macroinvertebrate production flows; and (8) experimental vegetation treatments.

ES.7.2.5 Alternative E

The objective of Alternative E is to provide for recovery of the humpback chub while protecting other important resources, including sediment, the Glen Canyon rainbow trout fishery, aquatic food base, and hydropower resources. Alternative E features a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions.

Under Alternative E, monthly volumes would closely follow the monthly hydropower demand as defined by WAPA's contract rate of delivery. The total monthly release volume of October, November, and December, however, would be equal to that under Alternative A (i.e., 2 maf in years with ≥8.23-maf annual release volume) to minimize the possibility of the operational tier differing from that of Alternative A as established in the Interim Guidelines. In addition, lower monthly volumes (relative to Alternative A) would be targeted in August and September to reduce sediment transport during the monsoon period, when most sediment is delivered by the Paria River. The allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (12× monthly volume in kaf in high power demand months of June, July, and August, and 10× monthly volume in kaf in other months). The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under Alternative E includes testing the effects of the following actions: (1) sediment-triggered fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) sediment-triggered spring HFEs, up to 45,000 cfs and 96 hr in duration, only in the second 10 years of the LTEMP period; (3) reducing fluctuations before fall HFEs; (4) mechanical removal of trout near the Little Colorado River confluence; (5) trout management flows; (6) low summer flows in the second 10 years of the LTEMP period to allow greater warming; and (7) experimental vegetation treatments.

ES.7.2.6 Alternative F

The objective of Alternative F is to a provide flows that follow a more natural pattern of high spring, and low summer, fall, and winter flows while limiting sediment transport and providing for warming in summer months. In keeping with this objective, Alternative F does not feature some of the flow and non-flow actions of the other alternatives.

Under Alternative F, peak flows would be lower than pre-dam magnitudes to reduce sediment transport and erosion given the reduced sand supply downstream of the dam. Peak flows would be provided in May and June, which corresponds well with the timing of the pre-dam peak. The overall peak flow in an 8.23-maf year would be 20,000 cfs (scaled proportionately in drier and wetter years) and would include a 24-hr 45,000-cfs flow at the beginning of the spring peak period (e.g., on May 1) if there was no triggered spring HFE in same year, and a 168-hr (7-day) 25,000-cfs flow at the end of June. Following this peak, there would be a rapid drop to the summer base flow. The initial annual 45,000-cfs flow would serve to store sediment above the flows of the remainder of the peak, thus limiting sand transport farther downstream and helping to conserve sandbars. The variability in flows within the peak would also serve to water higher elevation vegetation. There would be no within-day fluctuations in flow under Alternative F.

Low base flows would be provided from July through January. These low flows would provide for warmer water temperatures, especially in years when releases are warm, and would also serve to reduce overall sand transport during the remainder of the year.

Experimentation under Alternative F includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 96 hr in duration, through the entire 20-year LTEMP period and (2) experimental vegetation treatments. As with other alternatives, an ongoing monitoring program would be used to determine the response of resources to operations, and adjustments to those operations would be made consistent with adaptive management.

ES.7.2.7 Alternative G

The objective of Alternative G is to maximize the conservation of sediment, in order to maintain and increase sandbar size. Under Alternative G, flows would be delivered in a steady pattern throughout the year with no monthly differences in flow other than those needed to adjust

operations in response to changes in forecast and other operating requirements such as equalization. In an 8.23-maf year, steady flow would be approximately 11,400 cfs.

Experimentation under Alternative G includes testing the effects of the following actions: (1) sediment-triggered spring and fall HFEs, up to 45,000 cfs and 96 hr in duration, through the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs, up to 45,000 cfs, in high-volume years (≥10 maf release volume); (3) extension of the duration of up to 45,000-cfs fall HFEs for as many as 250 hr depending on sediment availability; (4) mechanical removal of trout near the Little Colorado River confluence; (5) trout management flows; and (6) experimental vegetation treatments.

ES.8 IMPLEMENTATION OF THE LTEMP

Annually, Reclamation will develop a hydrograph based on the characteristics of the selected alternative. Reclamation will seek consensus on the annual hydrograph through monthly operational coordination calls with governmental entities and regular meetings of the GCDAMP Technical Working Group (TWG) and AMWG. Reclamation will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, and BIA), WAPA, and representatives from the Basin States and the UCRC. The purpose of these meetings or calls is for the participants to share and seek information on Glen Canyon Dam operations. One liaison from each Basin State and from the UCRC may participate in the monthly operational coordination meetings or calls.

ES.8.1 Operational Flexibility

Reclamation retains the authority to utilize operational flexibility at Glen Canyon Dam because hydrologic conditions of the Colorado River Basin (or the operational conditions of Colorado River reservoirs) cannot be completely known in advance. Consistent with current operations, Reclamation, in consultation with WAPA, will make specific adjustments to daily and monthly release volumes during the water year. Monthly release volumes may be rounded for practical implementation or for maintenance needs. In addition, when releases are actually implemented, minor variations may occur regularly for a number of operational reasons that cannot be projected in advance.

Reclamation also will make specific adjustments to daily and monthly release volumes, in consultation with other entities as appropriate, for a number of reasons, including operational, resource-related, and hydropower-related issues. Examples of these adjustments may include, but are not limited to, the following:

- For water distribution purposes, volumes may be adjusted to allocate water between the Upper and Lower Basins consistent with the Law of the River as a result of changing hydrology;

- For resource-related issues that may occur uniquely in a given year, release adjustments may be made to accommodate nonnative species removal, to assist with aerial photography, or to accommodate other resource considerations separate from experimental treatments under the LTEMP; and

- For hydropower-related issues, adjustments may occur to address issues such as electrical grid reliability, actual or forecasted prices for purchased power, transmission outages, and experimental releases from other CRSP dams.

In addition, Reclamation may make modifications under circumstances that may include operations that are prudent or necessary for safety of dams, public health and safety, other emergency situations, or other unanticipated or unforeseen activities arising from actual operating experience (including, in coordination with the Basin States, actions to respond to low reservoir conditions as a result of drought in the Colorado River Basin). In addition, the Emergency Exception Criteria established for Glen Canyon Dam will continue under this alternative. (See, e.g., Section 3 of the Glen Canyon Operating Criteria at 62 FR 9448, March 3, 1997.)

ES.8.2 Experimental Implementation Process

At various levels, all alternatives identify condition-dependent flow and non-flow treatments intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes to those resources (Table ES-2). These condition-dependent treatments would be implemented experimentally during the LTEMP period unless they prove ineffective or result in unanticipated and unacceptable adverse impacts on other resources.

Prior to implementation of any experiment, the relative effects of the experiment on the following resource areas will be evaluated and considered: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and WAPA's assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources. Although these key resources are listed for consideration on a regular basis, DOI intends to retain sufficient flexibility in implementation of experiments to allow for response to unforeseen circumstances or events that involve any other resources not listed here.

The proposed approach differs fundamentally from a more formal experimental design (e.g., before-after control-impact design, factorial design) that attempts to resolve uncertainties by controlling for or treating potentially influential or confounding factors. There are several reasons to avoid such a formal design and instead focus on the condition-dependent approach described here. Among these are (1) the difficulties in controlling for specific conditions in a system as complex as the Colorado River; (2) wide variability in temperature and flow conditions that are important drivers in ecological processes; (3) inherent risk of some experimentation to protected sensitive resources, in particular, endangered humpback chub; (4) conflicting multiple-use values and objectives; and (5) low expected value-of-information for

the uncertainties that could be articulated, and around which a formal experimental design would be established. For these reasons, a condition-dependent adaptive approach is proposed.

A condition-dependent adaptive design is considered preferable to a formal experimental design because of the need for a flexible and adaptive program that is responsive to learning. A more formal experimental design, while potentially beneficial in resolving specific uncertainties, would involve multiple-year tests under different conditions, and with sufficient replicates of experimental conditions to statistically test the significance of treatment effects. Such an experimental design would necessarily span a period of years, during which environmental conditions would undoubtedly vary, and thus confound interpretation of results. The duration of the experiment could be lengthened and the potential for confounding effects increased if there was a desire to test system response under specific conditions that cannot be controlled (e.g., annual volume, water temperature, sediment load, and species population levels). These factors make a formal experimental design impractical in the Grand Canyon.

In many cases, two to three replicates of an experimental treatment are considered necessary. The results of these tests would be used to determine if these condition-dependent treatments should be retained as part of the suite of long-term actions implemented under LTEMP. In other cases, following the process described elsewhere in this section, implementation of experimental treatments would continue throughout the LTEMP period if triggered (e.g., spring and fall HFEs), except in years when it was determined that the proposed experiment could result in unacceptable adverse impacts on resource conditions. For these experiments, effectiveness would be monitored and the experiments would be terminated or modified only if sufficient evidence suggested the treatment was ineffective or had unacceptable adverse impacts on other resources. All experimental treatments would be closely monitored for adverse side effects on important resources. At a minimum, an unacceptable adverse impact would include significant negative impacts on resources as a result of experimental treatments that have not been analyzed for alternatives in the LTEMP EIS.

In implementing the process described above, the DOI will exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. As an initial platform to discuss potential future experimental actions, the DOI will hold GCDAMP annual reporting meetings for all interested stakeholders; these meetings will present the best available scientific information and learning from previously implemented experiments and ongoing monitoring of resources. As a follow-up to this process, the DOI will meet with the TWG to discuss the experimental actions being contemplated for the year.

The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and representatives from the Basin States and the UCRC. Each DOI bureau will provide updates on the status of resources and dam operations. In addition, WAPA will provide updates on the status of the Basin Fund, projected purchase power prices, and its financial and operational considerations. These meetings or calls are intended to provide an opportunity for participants to share and obtain the most up-to-date information on dam operational considerations and the status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One

liaison from each Basin State and from the UCRC will be allowed to participate in the monthly operational coordination meetings or calls.

To determine whether conditions are suitable for implementing or discontinuing experimental treatments or management actions, the DOI will schedule implementation/planning meetings or calls with the DOI bureaus, WAPA, AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by the participants. The implementation/planning group will strive to develop a consensus recommendation to bring forth to the DOI considering resource issues and WAPA's assessment of the status of the Basin Fund. The Secretary of the Interior will consider the consensus recommendations of the implementation/planning group, but it retains sole discretion to decide how best to accomplish operations and experiments in any given year pursuant to the ROD and other binding obligations.

DOI will also continue separate consultation meetings with the Tribes, AZGFD, the Basin States, and UCRC upon request, or as required under existing RODs.

ES.8.3 Descriptions of Potential Experiments

The following text describes specific experiments for sediment, aquatic resources, and riparian vegetation. The overall approach attempts to strike a balance between identifying specific experiments and providing flexibility to implement those experiments when resource conditions are appropriate. Rather than proposing a prescriptive approach to experimentation, an adaptive management-based approach that is responsive and flexible would be used to adapt to changing environmental and resource conditions and new information. Given the size of the project area and the variability inherent in the system, this pragmatic approach to experimentation is warranted, and although confounding treatments are possible given the complexity of the experimental plan, they are not expected to limit learning over the life of the LTEMP.

ES.8.3.1 Sediment-Related Experiments

Under most alternatives, spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period using the same Paria River sediment input thresholds used under the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Under Alternative D, the existing HFE protocol was updated and incorporated into the LTEMP process. Changes to the existing protocol were related to implementation of the new HFEs that are included under Alternative D and an extension of the protocol to the end of the LTEMP period. This new protocol would replace the existing protocol when the LTEMP ROD is

issued. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period based on the estimated sand mass balance resulting from Paria River sediment inputs during the spring and fall accounting periods, and the dam release pattern during the accounting period. HFE releases would be 1 to 250 hr long and between 31,500 and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring or fall accounting periods, and the expected accumulation of sand, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Sand mass balance modeling would be used to ensure that the duration and magnitude of an HFE are best matched with the mass of sand present in the system during a particular release window. The magnitude and duration of HFEs would not affect the total annual release from Glen Canyon Dam. Reclamation would consider the total water to be released in the water year when determining the magnitude and duration of an HFE.

Alternatives differ with regard to inclusion of several additional experiments, including: (1) reduced within-day fluctuations (referred to as "load-following curtailment") before and/or after fall HFEs; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of extended-duration (>96-hr) HFEs, depending on sediment conditions (Table ES-2). The pattern of transferring water volumes from other months to make up the HFE volume would be addressed through a process like that described in Section ES.8.2, and, like that one, will involve consultation with DOI bureaus and Western.

For all sediment experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were potential unacceptable adverse impacts on the resources identified in Section ES7.2. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted. Annual implementation of any experiments would consider resource condition assessments and resource concerns using the interagency process described in Section ES.8.2.

ES.8.3.2 Aquatic Resource-Related Experiments

Depending on the alternative, various aquatic resource-related experiments would be triggered by either estimated numbers of rainbow trout and other nonnative fish, a combination of estimated numbers of nonnative fish and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the action under consideration. Humpback chub triggers and nonnative fish triggers for Alternative D were developed during formal Section 7 consultation with the FWS. These triggers may be modified based on experimentation conducted during the LTEMP period.

Aquatic resource experiments that may be tested under various alternatives include (1) trout management flows, (2) mechanical removal of trout, (3) low summer flows, and (3) macroinvertebrate production flows (Table ES-2). Aquatic resource experiments would seek

to refine our understanding of the impacts of water releases, HFEs, and trout management flows on these resources. The primary uncertainty surrounding HFEs revolves around the extent to which the seasonality of HFEs or the number of adult rainbow trout determines the strength of rainbow trout recruitment.

For all aquatic resource experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were potential unacceptable adverse impacts on the resources listed in Section ES.8.2. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted. Annual implementation of any experiments would consider resource condition assessments and resource concerns using the interagency process described in Section ES.8.2.

ES.8.3.3 Experimental Vegetation Treatment

Experimental riparian vegetation treatments would be implemented by NPS under all alternatives except for Alternative A and would modify the cover and distribution of riparian plant communities along the Colorado River. All activities would be consistent with NPS Management Policies (NPS 2006d), and would occur only within the Colorado River Ecosystem in areas that are influenced by dam operations. NPS will work with Tribal partners and GCMRC to experimentally implement and evaluate a number of vegetation control and native replanting activities on the riparian vegetation within the Colorado River Ecosystem in GCNP and GCNRA. These activities would include ongoing monitoring and removal of selected nonnative plants, species in the corridor, systematic removal of nonnative vegetation at targeted sites, and native replanting at targeted sites and subreaches, which may include complete removal of tamarisk (both live and dead) and revegetation with native vegetation. Treatments would fall into two broad categories, including the control of nonnative plant species and revegetation with native plant species.

ES.8.3.4 Hydropower Improvement Flows

Alternative B includes testing maximum powerplant capacity releases in up to 4 years during the LTEMP period, but only in years with annual volumes ≤8.23 maf. Under hydropower improvement flows, within-day releases during the high-demand months of December, January, February, June, July, and August would vary between 5,000 cfs at night and 25,000 cfs during the day; from September through November within-day releases would vary from 5,000 to 20,000 cfs; and from March through May within-day releases would vary from 5,000 to 15,000 cfs. Up- and down-ramp rates would be 5,000 cfs/hr throughout the year. Years with annual flows ≤8.23 maf typically require firming purchases by WAPA to meet contractual demand; thus, the experiment could mitigate some of those more costly purchases in the high-power months. The experiment is intended to evaluate the effects of maximum powerplant operations on critical resources in the Colorado River Ecosystem.

ES.9 AFFECTED ENVIRONMENT

For more than 5 million years, the forces of geologic uplift, weathering, and downcutting of the Colorado River and its tributaries have carved the Grand Canyon. The canyon is about 1 mi deep and varies in width from a few hundred feet at river level to as much as 18 mi at the rim. The erosive forces of the river cut only a narrow gorge; other geologic forces, including flowing water over the canyon walls, freezing and thawing temperatures, and abrasion of rock against rock cut the wider canyon. The Colorado River acts like a huge conveyor belt transporting finer sediment particles to the ocean.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of the Grand Canyon are part of the Colorado Plateau, a 130,000-mi^2 area covering most of the Colorado River Basin. The elevation of the canyon rim varies between about 5,000 and 8,000 ft above mean sea level, with the North Rim being about 1,000 ft higher than the South Rim.

Glen Canyon cuts through the massive Navajo Sandstone of the Mesozoic Era and is about 200 million years old. Downstream from Lees Ferry, a sequence of nearly horizontal sedimentary rocks of the Paleozoic Era appears at river level, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, the river passes through cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard, but becomes wider through the more easily eroded formations. The shelves of Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River. Farther downstream, the narrowest reaches are cut through the dense, dark-colored Vishnu Schist of the Proterozoic era (about 1.7 billion years old). In the Toroweap area, the youngest rocks in the canyon are exposed, which are remnants of lava flows that poured over the North Rim about 1 million years ago during the Cenozoic era. The hardened lava still clings to the canyon walls, and basalt boulders still affect river flow at Lava Falls Rapid. The Grand Wash Cliffs mark the southwestern edge of the Colorado Plateau and the mouth of the Grand Canyon at the headwaters of Lake Mead.

Climatic conditions in the area vary considerably with elevation. At Bright Angel Campground (elevation 2,400 ft) near Phantom Ranch, the climate is characterized by mild winters, hot summers, and low rainfall. Average high temperatures range from about 15°C (59°F) in winter to 39°C (103°F) in summer. Low temperatures range from about 4 to 24°C (39 to 76°F). Average annual precipitation, mostly in the form of rain, is about 11.2 in.

In contrast, the climate at the North Rim (elevation 7,800 to 8,800 ft) is characterized by cold winters, cool summers, and abundant precipitation with snowfall. Average high temperatures range from 4°C (39°F) in winter to 24°C (75°F) in summer; low temperatures range from about –8 to 6°C (18 to 43°F). Average annual precipitation is 33.6 in. The South Rim (elevation 7,000 ft) receives about 16 in. of precipitation annually. Average high temperatures range from 5°C (41°F) in winter to 29°C (84°F) in summer; average low temperatures range from –8°C (18°F) in winter to 12°C (54°F) in summer.

The Upper Colorado River Basin is generally classified as semiarid and the Lower Basin as arid. The climate varies from cold-humid at the headwaters in the high mountains of Colorado, New Mexico, Utah, and Wyoming to dry-temperate in the northern areas below the mountains and arid in the lower southern areas. Annual precipitation in the higher mountains occurs mostly as snow, which results in as much as 60 in. of precipitation per year. Thousands of square miles in the lower part of the basin are sparsely vegetated because of low rainfall and poor soil conditions. Rainfall in this area averages from 6 to 8 in., mostly from cloudburst storms during the late summer and early fall.

The Colorado River Ecosystem formed in a sediment-laden, seasonally flooded environment. Virtually all of the Colorado River Ecosystem resources are associated with or dependent upon water and sediment. Interactions among water volume and releases patterns, sediment transport, and downstream resources support a complex ecosystem. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. It is understood that Glen Canyon Dam collects and stores water for beneficial purposes and in the process traps sediment and associated nutrients that previously traveled down the Colorado River.

Post-dam water releases fluctuate on a daily and hourly basis to maximize the value of generated power by providing peaking power during high-demand periods. More power is produced by releasing more water through the dam's generators. Daily releases can range from 5,000 to 31,500 cfs, but actual daily fluctuations have been less than this maximum range since implementation of the 1996 ROD (Reclamation 1996). These fluctuations result in a downstream "fluctuation zone" between low and high river stages (water level associated with a given flow) that is inundated and exposed on a daily basis.

Glen Canyon Dam also affects downstream water temperature and clarity. Historically, the Colorado River and its larger tributaries were characterized by heavy sediment loads, variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide range of dissolved solids concentrations. The dam has altered these characteristics. Before the dam, water temperature varied on a seasonal basis from highs around 27°C (80°F) to lows near freezing. Now, water released from Glen Canyon Dam averages 8°C (46°F) year round, although releases temperatures vary depending on the water level in Lake Powell and other factors, and water temperature warms by about 1°C (1.8°F) for every 30 mi traveled downstream during warmer months of the year (Reclamation 1999). Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy when downstream tributaries contribute sediment, as during summer monsoon storms. These changes in temperature and turbidity have important influences on the aquatic system downstream from the dam.

Hydropower is cleaner than nonrenewable fuel resources, and if water releases are less constrained, hydropower can be more responsive to changes in load than many other forms of electrical generation. The Glen Canyon Powerplant is an important component of the electrical power system of the western United States and is the largest hydroelectric facility in the CRSP. The powerplant has eight generating units with a maximum combined capacity (i.e., the maximum electric output of the eight generating units) of 1,320 MW. When operating policies

allow, releases are scheduled to be higher during months when power demand is greatest, typically during the summer and winter.

The regulated releases from Glen Canyon Dam and Lake Powell have resulted in an altered aquatic and terrestrial ecosystem compared to that which existed before Glen Canyon Dam. Cold, clear releases support an important rainbow trout fishery in the Glen Canyon reach, while native fish, including the endangered humpback chub and razorback sucker, occur further downstream. Vegetation has become established closer to the river's edge due to the elimination of annual flood scouring, and has increasingly become dominated by nonnative plant species. Most cultural resources are located at higher elevations away from the area affected by dam operations, but at some locations, these operations may affect the availability of windblown sand that helps replenish eroded sites. Lake Powell, Lake Mead, and the Colorado River, which flows between the two reservoirs, support important recreational resources. This recreation and the hydropower produced by Glen Canyon Dam have important effects on the local and regional economy. All of these resources are of vital importance to the social and economic wellbeing of Tribes with ancestral ties to Glen and Grand Canyons.

ES.10 ENVIRONMENTAL CONSEQUENCES

The effects of alternatives result primarily from the patterns of water release from Glen Canyon Dam that are characteristic of each alternative. Monthly, daily, and hourly release rates directly affect flows and sediment distribution in the river channel and corridor, as well as water levels in Lake Powell and Lake Mead. These primary effects drive secondary effects on aquatic and terrestrial resources, historic properties, Tribal resources and values, and recreational resources. Hydropower generation and capacity are additional primary effects of release patterns, particularly the ability to adjust releases in response to changes in the demand for electric power. Alternatives also include non-flow actions such as mechanical trout removal and vegetation treatments, which would be undertaken as part of the alternative.

The quantitative analyses used for the LTEMP EIS employed an integrated multiple-resource modeling framework that incorporated a series of linked models that explicitly accounted for the effects of dam operations and the linkages among resources (Figure ES-2). The assessment of resource impacts was based on these linkages under a common conceptual model.

This conceptual model was central to the construction of the LTEMP alternatives. Operational characteristics and experimental actions of each alternative target particular resource effects. Environmental effects caused by actions included in different alternatives were modeled using historically observed resource responses to flow conditions and relationships derived from experimental results obtained since dam operations were last reviewed in 1995.

Responses of resources to operations and non-flow actions were predicted using linked models (e.g., reservoir operations model, hydropower operations models, sand budget model, and others, as depicted in Figure ES-2). The magnitude of effects was estimated using quantifiable metrics for indicators of the condition of a resource. The environmental effects of alternatives were compared quantitatively whenever possible, on the basis of the estimated effect

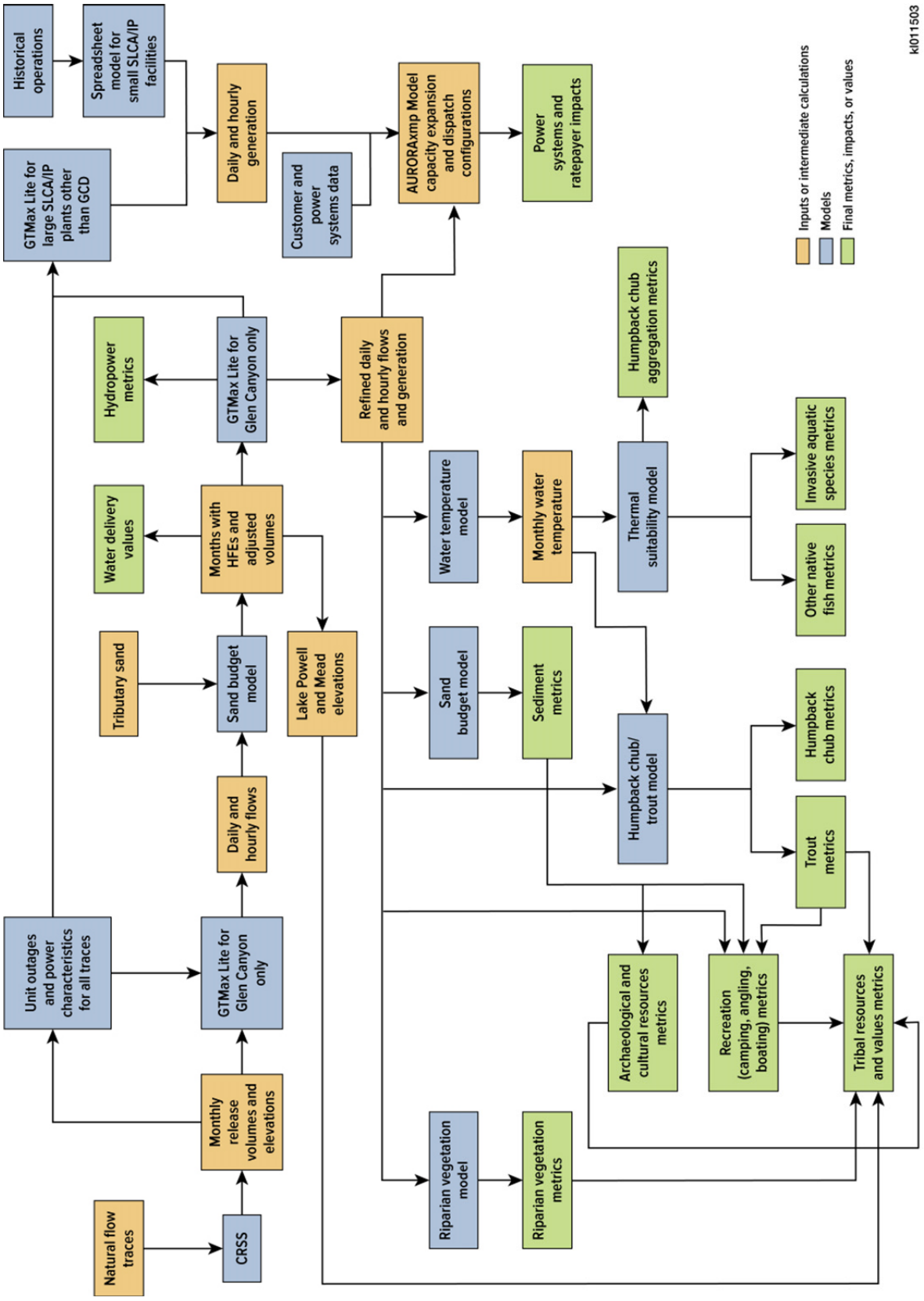

FIGURE ES-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output

on resource condition as measured by a set of resource metrics; these quantitative predictions were supported when possible by published observations and findings. It should be noted that the models used here are mainly intended to allow for relative comparisons among alternatives and not necessarily be predictive.

For those resource metrics that could be modeled quantitatively, a range of potential hydrologic conditions and sediment conditions were modeled for a 20-year period that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell in-flow scenarios (known as hydrology traces) for the 20-year LTEMP were sampled from the 105-year historic record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth sequence of 20 years to1930, and so forth. As the start of traces reach the end of the historic record, the years needed to complete a 20-year period are obtained by wrapping back to the beginning of the historical record. For instance, the trace beginning in 1996 consists of the years 1996 to 2010 and 1906 to 1910, in that order. This method produced 21 hydrology traces for analysis that represented a range of possible traces from dry to wet. Although these hydrology traces represent the range of hydrologic conditions that occurred during the period of record, they may not fully capture the driest years that could occur with climate change.

In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record (water years 1964 to 2013) were analyzed that represented low (water years 1982 to 2001), medium (water year 1996 to 1965), and high (water years 2012 to 1981). In combination, the 21 hydrology traces and 3 sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions. Models depicted in Figure ES-2 were used to generate resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. The values generated represent a range of possible outcomes.

Some resources or environmental attributes do not lend themselves to quantification because there are insufficient data or understanding to support development of a model. In these cases, the assessment includes qualitative assessments of the likely impacts on these resources and attributes. Qualitative analysis was particularly important for effects related to personal and cultural values, as well as for an assessment of impacts on resources not directly affected by river flow. In all cases, multiple lines of evidence, including consultation with subject matter experts, were used to assess impacts on resources.

Information sources used for this analysis included observational and research data collected since the start of dam operations and resulting from research programs originating under the GCDAMP established under the 1996 ROD and carried out by the GCMRC and other researchers.

Table ES-3 presents a summary of impacts anticipated under each alternative by resource topic.

TABLE ES-3 Summary of Impacts of LTEMP Alternatives on Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Water (hydrology and water quality)	No change from current condition in reservoir elevations, annual operating tiers, monthly release volumes, mean daily flows, or mean daily changes in flow (up to 8,000 cfs). No change in temperature or other water quality indicators.	Compared to Alternative A, no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months (up to 12,000 cfs). Hydropower improvement flows would cause even greater mean daily flow changes. Negligible differences in temperature or other water quality indicators.	Compared to Alternative A, some change from current condition related to reservoir elevations (<2 ft difference for each reservoir at end of Dec.), annual operating tiers (2.1% of years), monthly release volumes and mean daily flows (lower in Aug. and Sept.); lower mean daily changes in flow in all months (up to 6,200 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.2-ft difference for Lake Powell, no difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months (up to 8,000 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.3-ft difference for Lake Powell, 0.1-ft difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows (lower in Aug. and Sept.); higher mean daily changes in flow in all but Sept. and Oct. (up to 9,600 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (about a 3-ft difference for each reservoir at the end of Dec.) and annual operating tiers (2.1% of years); large changes in monthly release volumes and mean daily flows (high volume in May and June, low in other months); steady flows throughout the year. Greatest summer water temperature and increased potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.4-ft difference for Lake Powell, 1.4-ft difference for Lake Mead at end of Dec.) and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year. Some increase in summer water temperature and potential for bacteria and pathogens.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Sediment	Least HFEs of any alternative would result in lowest potential for building sandbars (highest impact of alternatives), highest sand mass balance (lowest impact of alternatives.	Compared to Alternative A, sandbar building potential would increase 10%, but higher fluctuations would result in lower sand mass balance (80% decrease).	Compared to Alternative A, sandbar building potential would increase 157%, but sand mass balance would decrease 112%.	Compared to Alternative A, sandbar building potential would increase 152%, but sand mass balance would decrease 47%.[b]	Compared to Alternative A, sandbar building potential would increase 119%, but sand mass balance would decrease 96%.	Compared to Alternative A, sandbar building potential would increase 167%, but sand mass balance would decrease 230% (highest impact of alternatives).	Compared to Alternative A, sandbar building potential would increase 176%; lowest impact of alternatives), but sand mass balance would decrease 182%.
Natural processes	Existing natural processes related to flow, water temperature, water quality, and sediment resources would continue, but replenishment of sandbars would diminish after 2020 when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be comparable nearshore habitat stability as a result of similar within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be lower nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within season variability; more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, year-round steady flows would result in the greatest nearshore habitat stability, slightly higher summer water temperatures, and the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Aquatic ecology	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Compared to Alternative A, slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows; habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced; lower trout abundance; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; habitat quality and stability for nonnative and native fish may be higher; higher trout abundance even with implementation of TMFs and mechanical removal; no difference in humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; experimental macroinvertebrate production flows (only featured in this alternative) may further increase productivity and diversity; habitat quality and stability for nonnative and native fish are expected to be slightly higher; negligible change in trout abundance with implementation of TMFs, and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base, and similar or increased drift; habitat quality and stability for nonnative and native fish would be slightly lower; lower trout abundance with implementation of TMFs and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year; positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives; higher trout abundance; slightly lower humpback chub abundance.	Compared to Alternative A, relatively high productivity of aquatic food base and long-term drift; greater habitat stability for nonnative and native fish; higher trout abundance even with implementation of TMFs and mechanical removal; slightly lower humpback chub abundance.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Vegetation	Overall index = 3.66 reflecting an adverse impact relative to current condition resulting from: narrowing of Old High Water Zone; an expected decrease in New High Water Zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Compared to Alternative A, a 6% increase in overall index reflecting an improvement in vegetation conditions (but a decline under hydropower improvement flows); impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in arrowweed, an increase in native diversity (decrease under hydropower improvement flows), an increase in native/nonnative ratio (decrease under hydropower improvement flows), and a decrease in wetland community cover.	Compared to Alternative A, a 13% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone; decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, an 8% increase in overall index reflecting an improvement in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover. Lowest impact of alternatives.	Compared to Alternative A, a 3% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, an increase in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, a 14% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative), a decrease in arrowweed, and a decrease in wetland community cover. Highest impact of alternatives.	Compared to Alternative A, a 7% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows; less decline of wetland habitat; however, hydropower improvement flows would cause a greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; least decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; increased production of aquatic insects due to more even monthly volumes could benefit species that eat insects or use nearshore areas, but benefits may be offset by higher within-day flow fluctuations.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greatest decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Cultural resources	No change from current conditions regarding the slumping of terraces in Glen Canyon during HFEs (Glen Canyon flow effects index [GFEI] = 22.7); availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (wind transport of sediment index [WTSI] = 0.16); stability of Spencer Steamboat; and visitor time off river (time off river index [TORI] = 0.82).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); no change in the stability of Spencer Steamboat or visitor time off river. Experimental hydropower improvement flows would increase the potential for slumping compared to Alternative A (1.6% increase in GFEI and a decrease in the availability of windblown sand (−9.5% decrease in WTSI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (137% increase in WTSI); negligible effect on stability of Spencer Steamboat or visitor time off river (<1% change in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (96% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (88% increase in WTSI); negligible effect on stability of Spencer Steamboat; an increase in visitor time off river (8.9% decrease in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI); negligible effect on the stability of Spencer Steamboat; a decrease in visitor time off river (2.1% increase in TORI).

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact on Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact on culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows, when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.[c]	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources (Cont.)						or mechanical trout removal. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	
Recreation, visitor use, and experience	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, few lost day-rafting visitor days (49 over 20-year period), and declining camping area.	Compared to Alternative A, a comparable number of HFEs and higher fluctuations result in more lost day-rafting visitor days (45% increase) in Glen Canyon, highest number of large trout (13% increase), lowest trout catch rates, most navigability concerns, and similar camping area (5% increase in index).	Compared to Alternative A, more HFEs and lower fluctuations result in more lost day-rafting visitor days in Glen Canyon (543% increase), similar number of large trout (3% decrease), higher trout catch rates; fewer navigation concerns, and more camping area (170% increase in index).	Compared to Alternative A, more HFEs and comparable fluctuations result in more lost day-rafting visitor days in Glen Canyon (610% increase), similar number of large trout (5% increase), similar trout catch rates, similar navigation concerns, and more camping area (158% increase in index).	Compared to Alternative A, more HFEs, higher fluctuations, and more frequent flows below 8,000 cfs result in more lost day-rafting visitor days in Glen Canyon (261% increase), more large trout (8% increase), lower trout catch rates, more navigation concerns, and more camping area (118% increase in index).	Compared to Alternative A and all other alternatives, frequent HFEs, steady flows, and lack of trout management actions result in most lost day-rafting visitor days in Glen Canyon (1,776% increase), higher trout catch rates, but fewest large trout (22% decrease); very few navigability concerns, and more camping area (191% increase in index).	Compared to Alternative A, more HFEs and steady flows result in few additional lost day-rafting visitor days in Glen Canyon (4% increase), higher trout catch rates, but fewer large trout (9% decrease); very few navigability concerns, and greatest potential increase in camping area (220% increase in index).

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wilderness	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Compared to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Compared to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Compared to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Visual resources	No change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon Dam hydropower economic and retail rate impacts	No change from current condition. Second-highest firm capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period. No change in average electric retail rate or average monthly residential electricity bill.	Compared to Alternative A, a 0.3% decrease in average daily generation (MWh) and a 3.8% increase in firm capacity (MW); a 0.02% decrease in the cost of generation, a 0.45% decrease in the cost of capacity, and a 0.04% decrease in total cost to meet electric demand over the 20-year LTEMP period; a small decrease in the average electric retail rate (−0.27%) and the average monthly residential electricity bill (−$0.27) in the year of maximum rate impact.	Compared to Alternative A, a 0.8% decrease in average daily generation (MWh) and a 17.5% decrease in firm capacity (MW); a 0.08% increase in the cost of generation, a 6.09% increase in the cost of capacity, and a 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.43%) and average monthly residential electricity bill ($0.40) in the year of maximum rate impact.[d]	Compared to Alternative A, a 1.1% decrease in average daily generation (MWh) and a 6.7% decrease in firm capacity (MW); a 0.12% increase in the cost of generation, a 3.12% increase in the cost of capacity, and a 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.39%) and average monthly residential electricity bill ($0.38) in the year of maximum rate impact.[e]	Compared to Alternative A, a 0.7% decrease in average daily generation (MWh) and a 12.2% decrease in firm capacity (MW); a 0.06% increase in the cost of generation, a 3.52% increase in the cost of capacity, and a 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.50%) and average monthly residential electricity bill ($0.47) in the year of maximum rate impact.[f]	Compared to Alternative A, a 1.9% decrease in average daily generation (MWh) and a 42.6% decrease in firm capacity (MW) (lowest of alternatives); a 0.42% increase in the cost of generation, a 4.03% increase in the cost of capacity, and a 1.17% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period; highest increase in average retail electric rate (1.21%) and average monthly residential electricity bill ($1.02) in the year of maximum rate impact.	Compared to Alternative A, a 1.7% decrease in average daily generation (MWh) and a 24.2% decrease in firm capacity (MW); a 0.34% increase in the cost of generation, a 7.39% increase in the cost of capacity, and a 0.73% increase in total cost to meet electric demand over 20-year LTEMP period; a small increase in average retail electric rate (0.64%) and average monthly residential electricity bill ($0.59) in the year of maximum rate impact.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Hoover Dam hydropower economic impacts	No change in the value of generation.	Compared to Alternative A, no change in the value of generation.	Compared to Alternative A, a 2.0% increase in the value of generation.	Compared to Alternative A, a 1.0% increase in the value of generation.	Compared to Alternative A, a 1.2% increase in the value of generation.	Compared to Alternative A, a 4.1% increase in the value of generation.	Compared to Alternative A, a 1.4% increase in the value of generation.
Socioeconomics	No change from current conditions in use values or economic activity, with no change in reservoir levels or river conditions. Lowest non-use value of alternatives.	Compared to Alternative A, no change in use values and economic activity associated with Lake Powell recreation, and declines in use values (up to 5.2%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Minimal decrease in use values (<0.1%), and no change in economic activity associated with Lake Mead recreation. Minimal increase in economic activity	Compared to Alternative A, declines (0.7%) in use values and economic activity (0.6%) associated with Lake Powell recreation, and in use values (up to 11.5%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 11.7%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity	Compared to Alternative A, declines in use values (0.5%) and economic activity (0.5%) associated with Lake Powell recreation, and in use values (up to 14.0%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from	Compared to Alternative A, declines in use values (1.1%) and economic activity (1.1%) associated with Lake Powell recreation, and in use values (up to 8.9%) associated with most forms of river recreation. An increase in use values (0.5%) associated with Upper and Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.5%) and economic activity (0.5%) associated with	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 13.2%) associated with most forms of river recreation. An increase in use values (0.3%) associated with Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Socioeconomics (Cont.)		(<0.1%) from lower residential electric bills compared to Alternative A. Annual increase in non-use value of $1,511 million at the national level.	minimal decrease in economic activity from higher residential electric bills (< 0.1%). Annual increase in non-use value of $3,985 million at the national level.	expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Highest non-use value of alternatives. Annual increase in non-use value of $4,486 million at the national level.	capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,963 million at the national level.	Lake Mead recreation. Increased economic activity from capacity expansion (up to 9.3%), and minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $2,353 million at the national level.	in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,524 million at the national level.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Environmental justice	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and <1 year, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 6 years and 0–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 8 years and 2–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and 0–2 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in 11 years and 3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Air quality	No change from current conditions in air quality or visibility.	Compared to Alternative A, a negligible increase (0.01%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.01%) in SO_2 emissions and no change in NO_x emissions; no change in visibility.	Compared to Alternative A, no change in SO_2 emissions and negligible increase in NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible increase (<0.005%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.04%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.03%) in SO_2 and negligible increase in NO_x emissions; no change in visibility.
Climate change	No change from current conditions.	Compared to Alternative A, a 0.011% increase in GHG emissions.	Compared to Alternative A, a 0.033% increase in GHG emissions.	Compared to Alternative A, a 0.042% increase in GHG emissions.	Compared to Alternative A, a 0.030% increase in GHG emissions.	Compared to Alternative A, a 0.081% increase in GHG emissions.	Compared to Alternative A, a 0.074% increase in GHG emissions.
Cumulative impacts	Contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.	Compared to Alternative A, similar sandbar building, lower trout numbers, slightly higher humpback chub numbers, greater value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly higher humpback chub numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, similar trout numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, much higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.

Footnotes on next page.

TABLE ES-3 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G

[a] The quantitative results presented here are from modeling conducted prior to making several adjustments to Alternative D, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and an adjustment in the monthly release volumes such that releases in August would be 50 kaf higher (800 kaf instead of 750 kaf) and releases in May and June would each be 25 kaf lower. The actual number of HFEs would be about 19.8 (1.3 fewer). As described in Section 4.1 of the EIS, for most resources, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. In addition, for all resources but hydropower, the relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. Potentially noticeable effects are identified for sediment and hydropower in footnotes (b) and (e).

[b] Impacts on sediment presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]). The actual number of HFEs would be lower and would result in a slightly lower sand load index (SLI) and higher sand mass balance index (SMBI). Change in monthly release volumes would result in a slight increase in sediment transport (1.2%), resulting in a lower SLI and a lower SMBI. Elimination of load-following curtailment would result in a 0.6% decrease in SMBI. The relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. See Section 4.1 for more detail.

[c] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the impacts on Hualapai docks under Alternative D.

[d] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative C compared to Alternative A, estimated at $148 million, by about $24.5 million resulting in a total cost difference of about $173 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.41% increase in cost to a 0.48% increase in cost. The relative ranking of Alternative C compared to other alternatives would not change as a result of adding the cost of experimental low summer flows.

[e] Impacts on hydropower resources presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]), and they do not include the cost of experimental low summer flows. Experimental low summer flows would increase costs by $15 million, while the adjustments would reduce costs by $58.9 million. Combined, the cumulative effect of these adjustments may reduce the relative cost of Alternative D compared to Alternative A, estimated at $104 million, by approximately $44 million over a 20-year period; the resulting difference from Alternative A would be $60 million. These adjustments reduce the percent difference relative to Alternative A from a 0.29% increase in cost to a 0.17% increase in cost. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost. These adjustments would also result in slight reductions to the retail rate costs. See Section 4.13.3.4 for more detail.

[f] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative E compared to Alternative A, estimated at $91 million, by about $9.95 million resulting in a total cost difference of about $101 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.25% increase in cost to a 0.28% increase in cost. The relative ranking of Alternative E compared to other alternatives would change from third to fourth lowest cost.

ES.11 UNAVOIDABLE ADVERSE IMPACTS

On the basis of the assessments conducted and summarized in Table ES-3, each of the alternatives is expected to result in some unavoidable adverse impacts on resources. These adverse impacts result from the flow and non-flow actions included in each alternative and could be minimized through adaptive management and implementation of mitigation measures.

All of the alternatives, including Alternative A, would result in continued reductions (for continued compliance with the GCPA) in hydropower production relative to pre-1996-ROD operations that more closely match generation with electrical demand due to restrictions on maximum and minimum flow, within-day fluctuation levels, and ramping rates. Steady flow alternatives (Alternatives F and G) would result in the greatest adverse impacts on hydropower value. Alternative B would result in an increase in hydropower energy and capacity compared to Alternative A; Alternatives D and E would produce less energy and capacity than Alternative A; Alternative C would produce less than Alternatives D and E, but more than Alternatives F and G. Alternative F would produce less energy and capacity than any of the alternatives.

Under all of the alternatives, sediment availability in the river channel below the dam would continue to be limited due to the presence of the dam. No operational alternative can reverse the reduction in sediment availability. Because of this sediment-depleted condition, all of the alternatives would continue to produce a net loss of sand from the Colorado River Ecosystem. Alternatives C, D, E, F, and G retain more sandbars than Alternative A or Alternative B.

Implementation of mechanical removal of trout and trout management flows would represent an unavoidable adverse impact on certain Tribes if these actions are needed to manage the trout fishery and mitigate trout impacts on humpback chub, because these actions are not in keeping with important Tribal values. The adverse impacts of mechanical removal could be mitigated with the provision of beneficial use (e.g., making euthanized fish available for human consumption). Any other mitigation to avoid adverse impacts would need to be identified in discussion with the Tribes.

The remaining unavoidable adverse impacts on certain resources are those associated not with the alternatives themselves; instead, they are consequences of existing operational rules (i.e., requirements of the Law of the River and the 2007 Interim Guidelines; Reclamation 2007a), the 1996 Glen Canyon Dam ROD (Reclamation 1996), and the presence of Glen Canyon Dam and current dam infrastructure. For example, temperature and sediment impacts of all alternatives are related to the inability of operations themselves to provide for warmer temperatures or restore sediment supplies. Infrastructure changes, which are not within the scope of the LTEMP EIS, could mitigate those impacts; however, without that infrastructure, these adverse impacts are unavoidable.

ES.12 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Under all alternatives, different restrictions on flow fluctuations result in trade-offs between peak hydropower production and productivity of the environment, which are largely related to increased nearshore habitat stability, aquatic food base productivity, and sandbar building downstream from the dam. For example, alternatives that have increased flow fluctuations or uneven monthly release volumes, such as Alternatives A and B, benefit peak hydropower energy and capacity and other resources (such as humpback chub) but result in less habitat stability and sandbar building. Alternatives with steady flows, such as Alternatives F and G, have the greatest reduction in peak hydropower energy and capacity, but result in more habitat stability and sandbar building downstream from the dam, and corresponding benefits for other resources such as recreation, aquatic food base, and trout. As a result, each of the alternatives presents a different balance between impacts on resources that appear to benefit from increased fluctuations and those that benefit from reduced fluctuations. Alternatives C, D, and E represent alternatives with more even monthly release volumes, and in the case of Alternatives C and D, fluctuation levels that are comparable to or lower than those under Alternative A. These alternatives were designed to strike a more even balance among resource impacts. However, regardless of the alternative, experimental flow and non-flow actions associated with alternatives (e.g., HFEs, trout management flows, and mechanical trout removal) would be tested in an attempt to maintain a balance that improves long-term productivity of the environment downstream of Glen Canyon Dam. Similarly, experimental elements of the alternatives are designed to improve our understanding of how resources respond to operations and how management actions can be best used to avoid, minimize, or mitigate impacts on resources and the long-term productivity of resources.

ES.13 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Any experiment or operation that bypasses Glen Canyon Dam generators (e.g., HFEs that exceed powerplant capacity through generator bypass) would cause an irretrievable loss of hydropower production. Hydropower production forgone on a given day due to due to flows that reduce flexibility (e.g., lower summer flow or reduced fluctuations under certain alternatives) would create an irretrievable loss (see Table ES-3).

There could be some small differences among alternatives in total air emissions (<0.1% difference in emissions of SO_2, NO_x, or GHGs) that are related to differences among alternatives in the amount of energy and capacity that would be provided by Glen Canyon Dam. As part of an integrated electric grid, any loss of generation or capacity from Glen Canyon Dam must be offset by generation from a mix of other sources, including renewable energy sources and fossil-fuel-fired powerplants. The portion of the energy that comes from fossil-fuel-fired powerplants would produce these small differences in emissions (see Table ES-3).

Archeological sites by their nature are non-renewable; therefore any loss due to dam operations would be irretrievable. See Table ES-3 for the relative performance of alternatives in comparison to Alternative A.

No other instances of irreversible or irretrievable commitments of resources are expected under any of the alternatives. Although operations, flow actions, non-flow actions, and experiments could result in unexpected impacts on natural and cultural resources, a long-term monitoring program implemented as part of the ongoing GCDAMP would be used to inform the need for changes in operations and actions to minimize impacts and improve downstream resources in accordance with the objectives of this EIS. Safeguards have been incorporated into alternatives, including implementation considerations that would preclude taking specific actions if implementation would result in unacceptable adverse impacts, and off-ramps that would be used to alter operations or stop actions to prevent irreversible losses.

ES.14 REFERENCES

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Glen Canyon Dam

Long-Term Experimental and Management Plan Environmental Impact Statement

FINAL

Volume 1—Chapters 1-8

U.S. Department of the Interior
Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

October 2016













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GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN FINAL ENVIRONMENTAL IMPACT STATEMENT

Joint-Lead Agencies
Bureau of Reclamation
National Park Service

Cooperating Agencies
Department of the Interior
Bureau of Indian Affairs
U.S. Fish and Wildlife Service
U.S. Department of Energy
Western Area Power Administration
Arizona Game and Fish Department
Colorado River Board of California
Colorado River Commission of Nevada
Upper Colorado River Commission
Havasupai Tribe
Hopi Tribe
Hualapai Tribe
Kaibab Band of Paiute Indians
Navajo Nation
Pueblo of Zuni
Salt River Project
Utah Associated Municipal Power Systems

ABSTRACT

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation and National Park Service (NPS), proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, including those of importance to American Indian Tribes.

The Final Environmental Impact Statement (FEIS) was developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), and followed the implementing regulations developed by the President's Council on Environmental Quality in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46. The FEIS analysis draws on the scientific information that has been collected under the Glen Canyon Dam Adaptive Management Program over the last 20 years to identify the potential environmental effects associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. Seven alternatives were considered and analyzed for the LTEMP EIS—a no action alternative (Alternative A), a hydropower-focused alternative (Alternative B), three condition-dependent alternatives (Alternatives C, D, and E), and two steady flow alternatives (Alternatives F and G). These alternatives incorporated a broad range of operations and experimental actions that together allowed for a full evaluation of possible impacts of the

proposed action. Based on the impact analyses conducted, DOI has chosen Alternative D as both the preferred and the environmentally preferred alternative. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

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CONTENTS

ABSTRACT iii

ACRONYMS AND ABBREVIATIONS lxiii

1 INTRODUCTION 1-1

1.1 Description of the Proposed Action 1-4
1.2 Purpose of and Need for Action 1-5
1.3 Lead and Cooperating Agencies and Consulting Tribes 1-9
1.3.1 Lead Agencies 1-9
1.3.2 Cooperating Agencies and Consulting Tribes 1-9
1.4 Objectives and Resource Goals of the LTEMP 1-10
1.5 Scope of the EIS 1-13
1.5.1 Affected Region and Resources 1-13
1.5.2 Impact Topics Selected for Detailed Analysis 1-14
1.5.3 Impact Topics Dismissed from Detailed Analysis 1-15
1.6 Role of Adaptive Management 1-16
1.6.1 History of the Existing Adaptive Management Program 1-16
1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations 1-17
1.7 Role of Decision Analysis in the EIS Process 1-17
1.8 History, Location, and Setting 1-18
1.8.1 History and Purpose of Glen Canyon Dam 1-18
1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area 1-19
1.8.3 Operation of the Glen Canyon Dam 1-20
1.8.4 History, Purpose, and Significance of the National Park System Units 1-22
1.8.4.1 Grand Canyon National Park 1-22
1.8.4.2 Glen Canyon National Recreation Area 1-24
1.8.4.3 Lake Mead National Recreation Area 1-24
1.8.5 Tribal Lands 1-25
1.8.5.1 Fort Mojave Tribe 1-26
1.8.5.2 Havasupai Tribe 1-26
1.8.5.3 Hopi Tribe 1-27
1.8.5.4 Hualapai Tribe 1-27
1.8.5.5 Navajo Nation 1-27
1.8.5.6 Pueblo of Zuni 1-28
1.8.5.7 Southern Paiute Tribes 1-28
1.9 Laws and Regulations Related to Operations of Glen Canyon Dam and Park Management 1-29
1.9.1 Environmental Laws and Executive Orders 1-29
1.9.2 Cultural/Historical Laws and Executive Orders 1-30

CONTENTS (Cont.)

1.9.3 American Indian and Tribal Consultation Laws and Executive Orders ... 1-31
1.9.4 Laws Establishing Criteria Related to Power Marketing ... 1-31
1.9.5 Law of the River ... 1-31
1.10 Related Actions ... 1-31
1.10.1 Biological Opinions ... 1-33
1.10.2 Environmental Impact Statements and Related Documents ... 1-33
1.10.3 Environmental Assessments and Related Documents ... 1-35
1.10.4 Other Actions, Programs, Plans, and Projects ... 1-36

2 DESCRIPTION OF ALTERNATIVES ... 2-1

2.1 Development of Alternatives ... 2-2
2.2 Descriptions of Alternatives Considered in Detail ... 2-4
2.2.1 Alternative A (No Action Alternative) ... 2-8
2.2.2 Alternative B ... 2-20
2.2.3 Alternative C ... 2-23
2.2.3.1 Base Operations under Alternative C ... 2-25
2.2.3.2 Implementation Process for Experiments under Alternative C ... 2-27
2.2.3.3 Sediment-Related Experiments To Be Evaluated under Alternative C ... 2-37
2.2.3.4 Aquatic Resource-Related Experiments To Be Evaluated under Alternative C ... 2-38
2.2.4 Alternative D (Preferred Alternative) ... 2-41
2.2.4.1 Base Operations under Alternative D ... 2-44
2.2.4.2 Operational Flexibility under Alternative D ... 2-46
2.2.4.3 Implementation Process for Experiments under Alternative D ... 2-48
2.2.4.4 Communication and Consultation Process for Alternative D ... 2-57
2.2.4.5 Sediment-Related Experiments To Be Evaluated under Alternative D ... 2-58
2.2.4.6 Aquatic Resource-Related Experiments To Be Evaluated under Alternative D ... 2-62
2.2.4.7 Conservation Measures under Alternative D ... 2-72
2.2.5 Alternative E ... 2-72
2.2.5.1 Base Operations under Alternative E ... 2-72
2.2.5.2 Experimental Framework for Alternative E ... 2-75
2.2.6 Alternative F ... 2-80
2.2.7 Alternative G ... 2-81
2.3 Alternatives Considered and Eliminated from Detailed Study ... 2-84
2.3.1 Modified Low Fluctuating Flows with Extended Protocols ... 2-84

CONTENTS (Cont.)

2.3.2 Naturally Patterned Flow Alternative 2-85
2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative 2-85
2.3.4 Grand Canyon First! Alternative 2-86
2.3.5 Species Community and Habitat-Based Alternative 2-86
2.3.6 Stewardship Alternative 2-86
2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives 2-87
2.3.8 Decommission Glen Canyon Dam Alternative 2-87
2.3.9 Fill Lake Mead First Alternative 2-88
2.3.10 Full-Powerplant Capacity Operations Alternative 2-88
2.3.11 Run-of-the-River Alternative 2-88
2.4 Alternative Elements Eliminated from Detailed Study 2-89
2.4.1 New Infrastructure 2-89
2.4.2 Flow and Non-Flow Actions 2-90
2.5 Summary Comparison of Alternatives 2-91

3 AFFECTED ENVIRONMENT 3-1

3.1 Project Area 3-1
3.1.1 Colorado River Setting 3-1
3.1.2 Geologic Setting 3-3
3.1.2.1 Tribal Perspectives on Geologic Setting 3-3
3.1.3 Climatic Setting 3-4
3.1.4 Glen Canyon Dam Releases and Flow 3-5
3.1.5 Colorado River Ecosystem Resource Linkages 3-6
3.2 Water Resources 3-6
3.2.1 Hydrology 3-7
3.2.1.1 Lake Powell Hydrology 3-8
3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam 3-11
3.2.1.3 Lake Mead Hydrology 3-13
3.2.1.4 Seeps and Springs 3-14
3.2.2 Water Quality 3-16
3.2.2.1 Lake Powell Water Quality 3-16
3.2.2.2 Colorado River Water Quality 3-19
3.2.2.3 Lake Mead Water Quality 3-27
3.2.3 Tribal Perspectives on Water Resources 3-29
3.2.4 Hydrology and Climate Change 3-32
3.2.4.1 Basis for Runoff Estimates 3-32
3.2.4.2 Water Variability and Availability 3-33
3.2.4.3 Seasonal Timing Shifts 3-34
3.2.4.4 Water Quality 3-35
3.3 Sediment Resources 3-35
3.3.1 Background: Geomorphology of the Colorado River 3-35

CONTENTS (Cont.)

3.3.1.1 Geomorphic Features of the Colorado River 3-37
3.3.1.2 Glen Canyon Geomorphology 3-40
3.3.1.3 Marble and Grand Canyon Geomorphology 3-41
3.3.2 Sediment Characteristics and Transport Mechanisms 3-43
3.3.2.1 Particle Size and Sediment Supply 3-45
3.3.2.2 Sediment Transport Capacity 3-46
3.3.2.3 River Stage 3-46
3.3.3 Sediment Sources 3-46
3.3.3.1 Gaged Tributaries 3-48
3.3.3.2 Ungaged Tributaries 3-48
3.3.4 Sediment Transport and Storage 3-50
3.3.4.1 Sediment Transport 3-50
3.3.4.2 Sediment Storage 3-51
3.3.4.3 High-Flow Experiments 3-51
3.3.4.4 Sediment Supply Limitation 3-53
3.3.4.5 Sandbar Deposition and Retention 3-53
3.3.5 Lake Deltas 3-56
3.4 Natural Processes 3-57
3.5 Aquatic Ecology 3-59
3.5.1 Aquatic Food Base 3-59
3.5.1.1 Periphyton and Rooted Aquatic Plants 3-61
3.5.1.2 Plankton 3-63
3.5.1.3 Macroinvertebrates 3-63
3.5.1.4 Nonnative Invasive Species 3-66
3.5.1.5 Food Web Dynamics 3-69
3.5.2 Native Fish 3-70
3.5.2.1 Special Status Fish Species 3-72
3.5.2.2 Other Native Species 3-86
3.5.3 Nonnative Fish 3-90
3.5.3.1 Coldwater Nonnative Species 3-94
3.5.3.2 Warmwater Nonnative Species 3-100
3.5.3.3 Interactions with Native Species 3-101
3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions 3-104
3.6 Vegetation 3-109
3.6.1 Historic and Remnant Riparian Plant Communities 3-110
3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam 3-111
3.6.2.1 Tribal Perspectives on Vegetation 3-119
3.6.3 Special Status Plant Species 3-121
3.7 Wildlife 3-124
3.7.1 Invertebrates 3-125
3.7.2 Amphibians and Reptiles 3-126
3.7.3 Birds 3-127

CONTENTS (Cont.)

3.7.4 Mammals ... 3-129
3.7.5 Special Status Wildlife Species ... 3-131
3.7.5.1 Invertebrates ... 3-132
3.7.5.2 Amphibians and Reptiles ... 3-136
3.7.5.3 Birds ... 3-136
3.7.5.4 Mammals ... 3-142
3.7.6 Tribal Perspectives on Wildlife ... 3-142
3.8 Cultural Resources ... 3-144
3.8.1 Area of Potential Effect ... 3-146
3.8.2 Description of Cultural Resources and Site Types ... 3-149
3.8.2.1 Archaeological Resources ... 3-149
3.8.2.2 Historic Resources ... 3-153
3.8.2.3 Cultural Landscapes ... 3-155
3.8.2.4 Traditional Cultural Properties and Ethnographic Resources ... 3-156
3.9 Tribal Resources ... 3-156
3.9.1 Fort Mojave Indian Tribe ... 3-157
3.9.2 Havasupai ... 3-158
3.9.3 Hopi ... 3-158
3.9.4 Hualapai ... 3-159
3.9.5 Navajo Nation ... 3-162
3.9.6 Pueblo of Zuni ... 3-164
3.9.7 Southern Paiute Tribes ... 3-167
3.9.8 Indian Trust Assets and Trust Responsibility ... 3-168
3.10 Recreation, Visitor Use, and Experience ... 3-168
3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area ... 3-169
3.10.1.1 Lees Ferry Recreational Fishery ... 3-169
3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach ... 3-174
3.10.2 The Colorado River in Grand Canyon National Park ... 3-178
3.10.2.1 Campsites in Grand Canyon National Park ... 3-179
3.10.2.2 River Flow and Fluctuation ... 3-183
3.10.2.3 Hualapai Tribe Recreation Program ... 3-186
3.10.3 Recreation Use on Lake Mead and Lake Powell ... 3-187
3.10.3.1 Lake Mead National Recreation Area ... 3-187
3.10.3.2 Lake Powell, Glen Canyon National Recreation Area ... 3-187
3.10.4 Park Operations and Management ... 3-187
3.11 Wilderness ... 3-188
3.11.1 Law and Policy ... 3-189
3.11.2 Defining Wilderness Character ... 3-190
3.12 Visual Resources ... 3-192
3.12.1 Glen Canyon National Recreation Area ... 3-193

CONTENTS (Cont.)

3.12.2 Grand Canyon and the Colorado River 3-195
3.12.3 Lake Mead National Recreation Area 3-198
3.13 Hydropower 3-198
3.13.1 Power Operations 3-199
3.13.1.1 Hydropower Generation 3-199
3.13.1.2 Basin Fund 3-200
3.13.1.3 Operational Flexibility 3-201
3.13.1.4 Scheduling 3-202
3.13.1.5 Load/Generation Following and Regulation 3-203
3.13.1.6 Capacity Reserves 3-205
3.13.1.7 Disturbances and Emergencies and Outage Assistance 3-205
3.13.1.8 Transmission System 3-206
3.13.2 Power Marketing 3-206
3.13.2.1 Wholesale Rates 3-209
3.13.2.2 Retail Rates 3-209
3.14 Socioeconomics and Environmental Justice 3-209
3.14.1 The Six-County Region of Influence 3-210
3.14.1.1 Population 3-210
3.14.1.2 Income 3-211
3.14.1.3 Employment 3-211
3.14.1.4 Unemployment 3-213
3.14.1.5 Environmental Justice 3-213
3.14.2 The Seven-State Region of Influence 3-221
3.14.2.1 Population 3-221
3.14.2.2 Income 3-222
3.14.2.3 Employment 3-224
3.14.2.4 Unemployment 3-226
3.14.2.5 Environmental Justice 3-226
3.14.3 Non-Use Value 3-228
3.15 Air Quality 3-229
3.15.1 Local Air Quality 3-229
3.15.2 Regional Air Quality 3-231
3.15.3 Regional Air Emissions 3-234
3.16 Climate Change 3-236

4 ENVIRONMENTAL CONSEQUENCES 4-1

4.1 Overall Analysis and Assessment Approach 4-1
4.2 Water Resources 4-9
4.2.1 Analysis Methods 4-10
4.2.1.1 Hydrology 4-10
4.2.1.2 Water Quality 4-13
4.2.2 Summary of Impacts 4-14

CONTENTS (Cont.)

4.2.2.1 Hydrology 4-14
4.2.2.2 Water Quality 4-37
4.2.3 Alternative-Specific Impacts 4-47
4.2.3.1 Alternative A (No Action Alternative) 4-48
4.2.3.2 Alternative B 4-49
4.2.3.3 Alternative C 4-53
4.2.3.4 Alternative D (Preferred Alternative) 4-55
4.2.3.5 Alternative E 4-58
4.2.3.6 Alternative F 4-60
4.2.3.7 Alternative G 4-62
4.3 Sediment Resources 4-65
4.3.1 Analysis Methods 4-66
4.3.2 Summary of Impacts 4-70
4.3.3 Alternative-Specific Impacts 4-72
4.3.3.1 Alternative A (No Action Alternative) 4-75
4.3.3.2 Alternative B 4-77
4.3.3.3 Alternative C 4-80
4.3.3.4 Alternative D (Preferred Alternative) 4-81
4.3.3.5 Alternative E 4-84
4.3.3.6 Alternative F 4-85
4.3.3.7 Alternative G 4-86
4.4 Natural Processes 4-87
4.4.1 Analysis Methods 4-88
4.4.2 Summary of Impacts 4-88
4.4.3 Alternative-Specific Impacts 4-97
4.4.3.1 Alternative A (No Action Alternative) 4-97
4.4.3.2 Alternative B 4-97
4.4.3.3 Alternative C 4-98
4.4.3.4 Alternative D (Preferred Alternative) 4-99
4.4.3.5 Alternative E 4-99
4.4.3.6 Alternative F 4-100
4.4.3.7 Alternative G 4-101
4.5 Aquatic Ecology 4-102
4.5.1 Analysis Methods 4-102
4.5.1.1 Aquatic Food Base 4-102
4.5.1.2 Nonnative Fish 4-103
4.5.1.3 Native Fish 4-106
4.5.1.4 Aquatic Parasites 4-107
4.5.2 Summary of Impacts 4-107
4.5.2.1 Aquatic Food Base 4-107
4.5.2.2 Nonnative Fish 4-119
4.5.2.3 Native Fish 4-127
4.5.2.4 Aquatic Parasites 4-135

CONTENTS (Cont.)

4.5.3 Alternative-Specific Impacts on Aquatic Resources 4-137
4.5.3.1 Alternative A (No Action Alternative)..... 4-137
4.5.3.2 Alternative B 4-140
4.5.3.3 Alternative C 4-143
4.5.3.4 Alternative D (Preferred Alternative)..... 4-148
4.5.3.5 Alternative E..... 4-154
4.5.3.6 Alternative F..... 4-157
4.5.3.7 Alternative G..... 4-160
4.6 Vegetation 4-163
4.6.1 Analysis Methods..... 4-164
4.6.2 Summary of Impacts..... 4-168
4.6.2.1 Impacts on Old High Water Zone Vegetation..... 4-177
4.6.2.2 Impacts on New High Water Zone..... 4-179
4.6.2.3 Wetlands..... 4-185
4.6.2.4 Special Status Plant Species..... 4-187
4.6.3 Alternative-Specific Impacts 4-190
4.6.3.1 Alternative A (No Action Alternative)..... 4-191
4.6.3.2 Alternative B 4-192
4.6.3.3 Alternative C 4-194
4.6.3.4 Alternative D (Preferred Alternative)..... 4-196
4.6.3.5 Alternative E..... 4-197
4.6.3.6 Alternative F..... 4-199
4.6.3.7 Alternative G..... 4-201
4.7 Wildlife..... 4-203
4.7.1 Analysis Methods..... 4-203
4.7.2 Summary of Impacts..... 4-204
4.7.2.1 Terrestrial Invertebrates 4-204
4.7.2.2 Amphibians and Reptiles..... 4-210
4.7.2.3 Birds 4-212
4.7.2.4 Mammals..... 4-214
4.7.2.5 Special Status Species 4-216
4.7.3 Alternative-Specific Impacts on Wildlife 4-227
4.7.3.1 Alternative A (No Action Alternative)..... 4-227
4.7.3.2 Alternative B 4-229
4.7.3.3 Alternative C 4-230
4.7.3.4 Alternative D (Preferred Alternative)..... 4-231
4.7.3.5 Alternative E..... 4-232
4.7.3.6 Alternative F..... 4-233
4.7.3.7 Alternative G..... 4-234
4.8 Cultural Resources 4-235
4.8.1 Compliance with Federal Regulations..... 4-235
4.8.2 Analysis Methods..... 4-235
4.8.3 Summary of Impacts..... 4-238

CONTENTS (Cont.)

4.8.4 Alternative-Specific Impacts 4-246
4.8.4.1 Alternative A (No Action Alternative)..... 4-246
4.8.4.2 Alternative B 4-246
4.8.4.3 Alternative C 4-247
4.8.4.4 Alternative D (Preferred Alternative)..... 4-248
4.8.4.5 Alternative E..... 4-248
4.8.4.6 Alternative F..... 4-249
4.8.4.7 Alternative G..... 4-250
4.9 Tribal Resources..... 4-251
4.9.1 Tribal Resource Goals..... 4-251
4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons 4-252
4.9.1.2 Protect and Preserve Sites of Cultural Importance..... 4-254
4.9.1.3 Preserve and Enhance Respect for Canyon Life 4-256
4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons..... 4-258
4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons..... 4-259
4.9.1.6 Economic Opportunity 4-259
4.9.1.7 Maintain Tribal Water Rights and Supply 4-260
4.9.1.8 LTEMP Process..... 4-261
4.9.2 Analysis Methods..... 4-261
4.9.3 Summary of Impacts..... 4-262
4.9.4 Alternative-Specific Impacts 4-268
4.9.4.1 Alternative A (No Action Alternative)..... 4-268
4.9.4.2 Alternative B 4-270
4.9.4.3 Alternative C 4-271
4.9.4.4 Alternative D (Preferred Alternative)..... 4-273
4.9.4.5 Alternative E..... 4-274
4.9.4.6 Alternative F..... 4-276
4.9.4.7 Alternative G..... 4-277
4.10 Recreation, Visitor Use, and Experience..... 4-279
4.10.1 Analysis Methods..... 4-279
4.10.2 Summary of Impacts..... 4-281
4.10.2.1 Glen Canyon Fishing..... 4-281
4.10.2.2 Glen Canyon Day Rafting 4-290
4.10.2.3 Glen Canyon Recreational Facilities..... 4-291
4.10.2.4 Whitewater Boating..... 4-291
4.10.2.5 Reservoir Activities and Facilities 4-292
4.10.2.6 Tribal Recreation Operations 4-293
4.10.2.7 Pearce Ferry..... 4-296
4.10.2.8 Park Operations and Management 4-296

CONTENTS (Cont.)

4.10.3 Alternative-Specific Impacts 4-297
4.10.3.1 Alternative A (No Action Alternative) 4-297
4.10.3.2 Alternative B 4-298
4.10.3.3 Alternative C 4-300
4.10.3.4 Alternative D (Preferred Alternative) 4-301
4.10.3.5 Alternative E 4-303
4.10.3.6 Alternative F 4-304
4.10.3.7 Alternative G 4-306
4.11 Wilderness 4-307
4.11.1 Analysis Methods 4-307
4.11.2 Summary of Impacts 4-308
4.11.3 Alternative-Specific Impacts 4-313
4.11.3.1 Alternative A (No Action Alternative) 4-314
4.11.3.2 Alternative B 4-314
4.11.3.3 Alternative C 4-315
4.11.3.4 Alternative D (Preferred Alternative) 4-316
4.11.3.5 Alternative E 4-317
4.11.3.6 Alternative F 4-317
4.11.3.7 Alternative G 4-318
4.12 Visual Resources 4-319
4.13 Hydropower 4-322
4.13.1 Analysis Methods 4-322
4.13.1.1 Hydropower Resource and Capacity Expansion Impacts 4-323
4.13.1.2 Wholesale Rate Impacts 4-330
4.13.1.3 Retail Rate Impacts 4-332
4.13.1.4 Hoover Dam Impacts 4-333
4.13.2 Summary of Hydropower Impacts 4-334
4.13.2.1 Monthly Water Release Impacts 4-334
4.13.2.2 Hydropower Power Generation and Capacity Impacts 4-340
4.13.2.3 Economic Impacts 4-343
4.13.2.4 Change in FES Wholesale Rates 4-349
4.13.2.5 Retail Rate and Bills Impacts 4-350
4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics 4-351
4.13.3 Alternative-Specific Impacts 4-353
4.13.3.1 Alternative A (No Action Alternative) 4-353
4.13.3.2 Alternative B 4-353
4.13.3.3 Alternative C 4-354
4.13.3.4 Alternative D (Preferred Alternative) 4-355
4.13.3.5 Alternative E 4-358
4.13.3.6 Alternative F 4-359
4.13.3.7 Alternative G 4-360

CONTENTS (Cont.)

4.14 Socioeconomics and Environmental Justice 4-362
4.14.1 Analysis Methods 4-362
4.14.1.1 Recreational Use and Environmental Non-Use Values 4-362
4.14.1.2 Recreational Economic Impacts 4-364
4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts 4-364
4.14.1.4 Environmental Justice 4-365
4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice 4-365
4.14.2.1 Recreational Use Values 4-365
4.14.2.2 Environmental Non-Use Values 4-378
4.14.2.3 Recreational Economic Impacts 4-379
4.14.2.4 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts 4-382
4.14.2.5 Environmental Justice Impacts 4-384
4.14.3 Alternative-Specific Impacts 4-390
4.14.3.1 Alternative A (No Action Alternative) 4-390
4.14.3.2 Alternative B 4-391
4.14.3.3 Alternative C 4-393
4.14.3.4 Alternative D (Preferred Alternative) 4-395
4.14.3.5 Alternative E 4-396
4.14.3.6 Alternative F 4-398
4.14.3.7 Alternative G 4-400
4.15 Air Quality 4-402
4.15.1 Analysis Methods 4-402
4.15.2 Summary of Impacts 4-403
4.15.3 Alternative-Specific Impacts 4-409
4.15.3.1 Alternative A (No Action Alternative) 4-409
4.15.3.2 Alternative B 4-409
4.15.3.3 Alternative C 4-410
4.15.3.4 Alternative D (Preferred Alternative) 4-410
4.15.3.5 Alternative E 4-410
4.15.3.6 Alternative F 4-411
4.15.3.7 Alternative G 4-411
4.16 Climate Change 4-411
4.16.1 Analysis Methods 4-412
4.16.1.1 Effects of LTEMP Alternatives on Climate Change 4-412
4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources 4-413
4.16.2 Summary of Impacts 4-414
4.16.2.1 Effects of LTEMP Alternatives on Climate Change 4-414
4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources 4-419

CONTENTS (Cont.)

4.16.3 Alternative-Specific Impacts 4-421
4.16.3.1 Alternative A (No Action Alternative)..... 4-421
4.16.3.2 Alternative B 4-424
4.16.3.3 Alternative C 4-424
4.16.3.4 Alternative D (Preferred Alternative)..... 4-424
4.16.3.5 Alternative E..... 4-425
4.16.3.6 Alternative F..... 4-425
4.16.3.7 Alternative G..... 4-426
4.17 Cumulative Impacts..... 4-426
4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts..... 4-426
4.17.1.1 Past and Present (Ongoing) Actions..... 4-427
4.17.1.2 Reasonably Foreseeable Future Actions 4-442
4.17.2 Climate-Related Changes..... 4-445
4.17.3 Cumulative Impacts Summary by Resource..... 4-446
4.17.3.1 Water Resources..... 4-446
4.17.3.2 Sediment Resources 4-457
4.17.3.3 Natural Processes 4-458
4.17.3.4 Aquatic Ecology..... 4-458
4.17.3.5 Vegetation 4-461
4.17.3.6 Wildlife..... 4-463
4.17.3.7 Cultural Resources 4-466
4.17.3.8 Tribal Resources..... 4-467
4.17.3.9 Recreation, Visitor Use, and Experience..... 4-468
4.17.3.10 Wilderness..... 4-469
4.17.3.11 Visual Resources..... 4-470
4.17.3.12 Hydropower..... 4-471
4.17.3.13 Socioeconomics and Environmental Justice 4-472
4.17.3.14 Air Quality and Climate Change..... 4-472
4.18 Unavoidable Adverse Impacts..... 4-474
4.19 Relationship between Short-Term Use and Long-Term Productivity..... 4-475
4.20 Irreversible and Irretrievable Commitments of Resources..... 4-475

5 CONSULTATION AND COORDINATION 5-1

5.1 Consultation and Coordination with Other Agencies and Programs 5-1
5.1.1 U.S. Department of the Interior 5-1
5.1.2 Cooperating Agencies..... 5-1
5.1.3 American Indian Tribes 5-2
5.1.4 Other Consultations 5-6
5.1.4.1 National Historic Preservation Act..... 5-6
5.1.4.2 State and Local Water and Power Agency Coordination..... 5-7
5.1.4.3 U.S. Fish and Wildlife Service..... 5-7

CONTENTS (Cont.)

5.2 Public Involvement 5-8
5.2.1 Public Scoping Process and Comments Received 5-8
5.2.2 Public Meetings on Alternatives 5-10
5.2.3 Glen Canyon Dam Adaptive Management Working Group 5-11
5.2.4 Public Involvement on the LTEMP DEIS 5-11

6 REFERENCES 6-1

7 LIST OF PREPARERS 7-1

8 GLOSSARY 8-1

APPENDIX A: Adaptive Management Working Group Desired Future Conditions A-1

A.1 Desired Future Conditions: Colorado River Ecosystem A-5
A.1.1 DFC Description A-5
A.1.2 DFC Background and Legislation A-6
A.1.3 Why the Colorado River Ecosystem DFCs Are Important A-6
A.1.4 Colorado River Ecosystem DFCs A-6
A.1.4.1 Sediment-Related Resources DFCs A-6
A.1.4.2 Water Quality DFCs A-7
A.1.4.3 Colorado River Ecosystem Aquatic Resource DFCs A-7
A.1.4.4 Colorado River Ecosystem Riparian Resource DFCs A-9
A.1.5 Colorado River Ecosystem DFCs Additional Information A-9
A.1.5.1 Colorado River Ecosystem Linkages A-9
A.1.5.2 Colorado River Ecosystem Metrics A-10
A.2 Power Desired Future Conditions A-10
A.2.1 Power DFC Description A-10
A.2.2 Power DFC Background and Legislation A-10
A.2.3 Why the Power DFC Is Important A-11
A.2.4 Power DFCs A-11
A.2.5 Power DFC Additional Information A-12
A.2.5.1 Power Linkages A-12
A.2.5.2 Power Metrics A-12
A.3 Cultural Resources Desired Future Conditions A-13
A.3.1 Cultural Resources DFC Description A-13
A.3.2 DFC Background and Legislation A-13
A.3.3 Why the Cultural Resources DFCs Are Important A-13
A.3.4 NRHP Eligible Historic Properties DFCs A-14
A.3.4.1 Prehistoric Archaeological Sites and Historic Sites A-14
A.3.4.2 Traditional Cultural Properties A-14
A.3.5 NRHP Eligible Historic Properties DFC Additional Information A-15
A.3.5.1 NRHP Eligible Historic Properties Linkages A-15

CONTENTS (Cont.)

A.3.5.2 NRHP Eligible Historic Properties Metrics A-16
A.3.6 Resources of Traditional Cultural Significance but Not NRHP Eligible A-16
A.3.7 Resources of Traditional Cultural Significance DFCs A-16
A.3.8 Resources of Traditional Cultural Significance Linkages A-17
A.3.9 Resources of Traditional Cultural Significance Metrics A-17
A.4 Recreation Desired Future Conditions A-17
A.4.1 Recreation DFC Description A-17
A.4.2 DFC Background and Legislation A-17
A.4.3 Why the Recreation DFC Is Important A-18
A.4.3.1 Grand Canyon National Park A-18
A.4.3.2 Glen Canyon National Recreation Area A-18
A.4.4 Recreation DFCs A-18
A.4.4.1 River Recreation in Grand Canyon National Park A-18
A.4.4.2 River Recreation in Glen Canyon National Recreation Area A-19
A.4.4.3 Blue Ribbon Trout Fishery in Glen Canyon National Recreation Area A-19
A.4.4.4 River Corridor Stewardship A-19
A.4.5 Recreation DFC Additional Information A-20
A.4.6 Recreation Linkages A-20
A.4.7 Recreation Metrics A-20
A.5 Reference A-21

APPENDIX B: Performance Metrics Used to Evaluate Alternatives B-1

B.1 Aquatic Ecology B-3
B.1.1 Humpback Chub B-3
B.1.2 Other Native Fish B-5
B.1.3 Trout Fishery B-5
B.1.4 Nonnative Aquatic Species B-6
B.2 Archaeological and Cultural Resources B-7
B.3 Hydropower and Energy B-9
B.4 Natural Processes B-10
B.5 Recreational Experience B-11
B.5.1 Grand Canyon Metrics B-11
B.5.2 Glen Canyon Metrics B-15
B.6 Riparian Vegetation B-16
B.7 Sediment B-18
B.8 Tribal Resources B-18
B.9 Water Delivery B-24
B.10 References B-25

CONTENTS (Cont.)

APPENDIX C: Decision Analysis to Support Development of the Glen Canyon Dam Long-Term Experimental and Management Plan C-1

APPENDIX D: Hydrology Technical Information and Analysis D-1

D.1 Analysis Methods D-3
D.1.1 Background D-3
D.1.2 Initial Conditions D-4
D.1.3 Reservoir Operations D-4
D.1.3.1 Upper Basin Reservoirs above Lake Powell D-4
D.1.3.2 Lake Powell and Lake Mead D-5
D.1.3.3 Lake Mohave and Lake Havasu D-9
D.1.4 Representation of the Different Alternatives in CRSS D-9
D.1.4.1 Experimental Components Modeled in CRSS D-22
D.1.5 Input Hydrology D-23
D.1.6 Input Demands D-26
D.1.7 Other Key Assumptions D-26
D.2 Supplemental Information on Impact Modeling D-27
D.2.1 Low Summer Flows D-27
D.2.2 Modeled Annual Releases Extending beyond the End of the Water Year D-28
D.2.3 Lake Elevation D-29
D.3 References D-36

APPENDIX E: Sediment Resources Technical Information and Analysis E-1

E.1 Introduction E-3
E.1.1 Analysis Period E-3
E.1.2 General Scope E-3
E.2 Methods E-4
E.2.1 Sand Budget Model E-4
E.2.1.1 Model Description E-4
E.2.1.2 Sand Budget Model Modifications E-5
E.2.1.3 Modified Sand Budget Model Inputs E-6
E.2.2 Sediment Metrics E-8
E.2.2.1 Sand Load Index E-9
E.2.2.2 Standard Deviation of High Flows E-9
E.2.2.3 Sand Mass Balance Index E-10
E.3 Results E-10
E.3.1 HFEs Determined by Alternative E-10
E.3.2 Metrics E-11
E.3.2.1 Sand Load Index E-12
E.3.2.2 Standard Deviation of High Flows E-12

CONTENTS (Cont.)

E.3.3 Sand Mass Balance Index E-12
E.3.4 Alternative Performance under Climate Change Scenarios E-13
E.3.5 Relative Impacts of Dam Operations and Hydrology on Performance E-13
E.4 Lake Deltas E-15
E.5 Limitations and Known Issues E-17
E.5.1 Geographic Scope E-17
E.5.2 Modeling Improvements E-17
E.6 References E-18

APPENDIX F: Aquatic Resources Technical Information and Analysis F-1

F.1 Introduction F-3
F.2 Aquatic Food Base Assessment F-4
F.2.1 Description of the Aquatic Food Base Downstream from Glen Canyon Dam F-4
F.2.1.1 The Aquatic Food Base Prior to Construction of Glen Canyon Dam F-5
F.2.1.2 The Aquatic Food Base of the Colorado River Downstream from Glen Canyon Dam F-5
F.2.1.3 Influence of New Zealand Mudsnail on the Aquatic Food Base F-13
F.2.2 Impacts of LTEMP Alternatives on the Aquatic Food Base F-14
F.2.2.1 Flow Effects on the Aquatic Food Base F-15
F.2.2.2 Temperature Effects on the Aquatic Food Base F-23
F.2.3 Conclusion F-26
F.3 Modeling Effects of LTEMP Alternatives on Rainbow Trout and Humpback Chub F-28
F.3.1 Model Overview F-28
F.3.1.1 Glen Canyon Trout Submodel F-29
F.3.1.2 Trout Movement Submodel F-36
F.3.1.3 Humpback Chub Population Submodel F-40
F.3.2 Results for LTEMP Alternatives F-52
F.3.2.1 Rainbow Trout Performance Measures F-52
F.3.2.2 Humpback Chub Performance Measures F-60
F.4 Modeling the Effects of LTEMP Alternatives on Temperature Suitability F-62
F.4.1 Model Overview F-64
F.4.2 Humpback Chub Aggregations F-67
F.4.2.1 Historic Temperature Suitability for Humpback Chub F-69
F.4.2.2 Results for LTEMP Alternatives F-70
F.4.3 Other Native Fish F-71
F.4.3.1 Historic Temperature Suitability for Native Fish F-73
F.4.3.2 Results for LTEMP Alternatives F-73

CONTENTS (Cont.)

F.4.4 Nonnative Fish F-78
F.4.4.1 Historic Temperature Suitability for Nonnative Fish F-79
F.4.4.2 Results for LTEMP Alternatives F-79
F.4.5 Aquatic Parasites F-81
F.4.5.1 Historic Temperature Suitability for Aquatic Parasites F-84
F.4.5.2 Results for LTEMP Alternatives F-86
F.5 References F-90

APPENDIX G: Vegetation Technical Information and Analysis G-1

G.1 Analysis Methods G-3
G.1.1 Old High-Water Zone Analysis G-4
G.1.2 New High-Water Zone G-5
G.1.2.1 Native Cover Metric G-6
G.1.2.2 Native Diversity Metric G-7
G.1.2.3 Native/Nonnative Ratio Metric G-7
G.1.2.4 Arrowweed Metric G-8
G.1.2.5 Overall Score G-8
G.1.3 Wetlands G-9
G.2 Alternative-Specific Impacts G-10
G.2.1 Alternative A (No Action Alternative) G-10
G.2.2 Alternative B G-10
G.2.3 Alternative C G-10
G.2.4 Alternative D (Preferred Alternative) G-11
G.2.5 Alternative E G-11
G.2.6 Alternative F G-12
G.2.7 Alternative G G-12
G.3 Summary G-12
G.4 References G-13

APPENDIX H: Cultural Resources Technical Information and Analysis H-1

H.1 Wind Transport of Sediment H-3
H.1.1 Wind Transport of Sediment—Methods H-4
H.1.2 Wind Transport of Sediment—Results H-5
H.2 Flow Effects on Cultural Resources in Glen Canyon H-8
H.2.1 Flow Effects on Cultural Resources in Glen Canyon—Methods H-9
H.2.2 Flow Effects on Cultural Resources in Glen Canyon—Results H-10
H.3 Time Off River H-13
H.3.1 Time Off River—Methods H-13
H.3.2 Time Off River—Results H-14
H.4 References H-16

CONTENTS (Cont.)

APPENDIX I: Tribal Resources Technical Information and Analysis I-1

I.1 Quantifiable Measures Used to Assess Impacts on Tribal Resources..... I-4
I.1.1 Riparian Diversity..... I-4
I.1.2 Wetland Abundance..... I-8
I.1.3 Trout Management Flows..... I-10
I.1.4 Mechanical Removal of Trout..... I-12
I.1.5 Water Levels at Lake Powell..... I-14
I.1.6 Access to Resources..... I-17
I.2 References..... I-18

APPENDIX J: Recreation, Visitor Use, and Experience Technical Information and Analysis..... J-1

J.1 Recreational Experience Metrics..... J-3
J.1.1 Grand Canyon Metrics..... J-4
J.1.2 Glen Canyon Metrics..... J-4
J.2 Metric Definitions, Analysis Methods, and Results..... J-5
J.2.1 Camping Area Index..... J-5
J.2.1.1 Camping Area Index—Methods..... J-6
J.2.1.2 Camping Area Index—Results..... J-7
J.2.2 Navigational Risk Index..... J-8
J.2.2.1 Navigational Risk Index—Methods..... J-9
J.2.2.2 Navigational Risk Index—Results..... J-10
J.2.3 Fluctuation Index..... J-11
J.2.3.1 Fluctuation Index—Methods..... J-12
J.2.3.2 Fluctuation Index—Results..... J-13
J.2.4 Time Off River..... J-14
J.2.4.1 Time Off River Index—Methods..... J-14
J.2.4.2 Time Off River Index—Results..... J-15
J.2.5 Glen Canyon Rafting Use..... J-15
J.2.5.1 Glen Canyon Rafting Use Metric—Methods..... J-17
J.2.5.2 Glen Canyon Rafting Use Metric—Results..... J-18
J.2.6 Glen Canyon Inundation Metric..... J-18
J.2.6.1 Glen Canyon Inundation Metric—Methods..... J-19
J.2.6.2 Glen Canyon Inundation Metric—Results..... J-21
J.3 Lake Powell and Lake Mead Dock Access..... J-21
J.4 Summary..... J-26
J.5 References..... J-26

CONTENTS (Cont.)

APPENDIX K: Hydropower Systems Technical Information and Analysis K-1

K.1 Economic Value of Glen Canyon Dam Powerplant Capacity and Energy Production K-3
K.1.1 Power Systems Background K-3
K.1.2 Glen Canyon Dam, Reservoir, and Powerplant Background K-5
K.1.3 Power Systems Geographic Scope K-8
K.1.3.1 Top Tier: General Western Interconnection Perspective Modeling K-9
K.1.3.2 Middle Tier: LTF Customer Utility Systems K-11
K.1.3.3 Bottom Tier: WAPA SLCA/IP Hydropower Resources K-15
K.1.4 Overview of Power Systems Methods K-16
K.1.5 Description of Individual Power System Models K-20
K.1.5.1 Colorado River Simulation System Model K-20
K.1.5.2 Representative Trace Tool K-21
K.1.5.3 Hydropower Outage Model K-21
K.1.5.4 Generation and Transmission Maximization-Lite K-21
K.1.5.5 Sand Budget Model K-29
K.1.5.6 Large SLCA/IP Powerplant Spreadsheets K-29
K.1.5.7 Small SLCA/IP Powerplant Spreadsheet K-30
K.1.5.8 Loads Shaping Algorithm K-30
K.1.5.9 AURORA K-31
K.1.5.10 LMP Calibration Spreadsheet K-34
K.1.5.11 Firm Capacity Spreadsheet K-35
K.1.6 SLCA/IP Market System, Data Sources, and Model K-38
K.1.6.1 Historical Data Sources K-38
K.1.6.2 AURORA Model Dispatch Results for 2013 ..... K-42
K.1.6.3 SLCA/IP Market System Projections K-43
K.1.7 Glen Canyon Dam Powerplant Capacity Cost and Benefit Methodology K-59
K.1.7.1 Treatment of Glen Canyon Dam Capital and Fixed O&M Costs K-61
K.1.7.2 WAPA's SLCA/IP LTF Obligations and Glen Canyon Dam Replacement Capacity K-61
K.1.7.3 WAPA SLCA/IP Firm Hydropower Capacity K-62
K.1.7.4 Firm Capacity Curves for LTEMP Power Systems Analyses for the Peak Month of August K-79
K.1.7.5 AURORA Capacity Expansion Reserve Margin Targets and Capacity Additions K-82
K.1.7.6 Dispatch Performed by AURORA Model Capacity Expansion Runs K-86
K.1.7.7 Rationale for the Selection of Hydrology Conditions Used for Capacity Expansion Runs K-90

CONTENTS (Cont.)

K.1.8 Glen Canyon Dam Energy Economic Benefits Methodology K-90
K.1.9 Net Present Value Calculations and Study Period Adjustments K-94
K.1.10 Power Systems Results K-96
K.1.10.1 Main Drivers of Differences among Alternatives K-97
K.1.10.2 Capacity Expansion Modeling K-101
K.1.10.3 Economic Impacts K-108
K.1.10.4 Sensitivity of Results to Exceedance Level K-116
K.1.10.5 Sensitivity of Results to Discount Rate K-121
K.1.10.6 Sensitivity of Results to the Base Capacity Expansion Path K-121
K.1.10.7 Sensitivity of Results to the Assumed Future Hydrological Conditions K-123
K.1.10.8 Sensitivity of Results to Changes in Ancillary Services K-125
K.1.10.9 Sensitivity of Results to Customer Capacity Expansion Assumptions K-129
K.1.10.10 Summary of Economic Ranking K-131
K.2 WAPA's SLCA/IP Firm Electric Service Rate Impacts K-131
K.2.1 Relationship between the Economic Impacts of LTEMP Alternatives and Impacts on SLCA/IP FES Rates K-133
K.2.2 Temporal Scope of the Analysis and Input Data K-133
K.2.3 SLCA/IP Rate Setting K-134
K.2.4 Calculation of Net Electrical Energy Expense K-135
K.2.4.1 SLCA/IP Electrical Production K-135
K.2.4.2 Sustainable Hydropower and Available Hydropower Capacity and Energy K-135
K.2.5 Calculation of Capacity Expenses and Total Net Costs K-139
K.2.6 WAPA Replacement Resources K-143
K.2.7 Post-2024 Marketing Period K-144
K.2.8 Power Repayment Studies to Determine Rate Impacts K-146
K.2.8.1 PRS Expenses K-146
K.2.8.2 PRS Revenue Distribution K-149
K.2.8.3 The SLCA/IP PRS K-149
K.2.8.4 Standard PRS Rate-Setting Method Versus the Method Used in This Analysis K-150
K.2.9 Results K-150
K.2.9.1 Pinch-Point Year K-152
K.2.10 Definitions Used in Section K.2 ..... K-153
K.3 Impacts on Retail Electricity Rates K-154
K.3.1 Analysis Approach K-154
K.3.1.1 Database of Sales, Rates, and SLCA/IP Allocation for Retail Utility Systems K-156
K.3.1.2 Incorporation of Power Systems Analysis and Capital Recovery Factors K-158

CONTENTS (Cont.)

K.3.1.3 Inflation Rates, Sales Growth, and Interest Rates from EIA K-161
K.3.1.4 Calculation Process for Computing Rate and Bill Impacts K-162
K.3.2 Results K-167
K.3.2.1 Grid Cost Changes Relative to WAPA Wholesale Revenues K-168
K.3.2.2 Retail Rate Changes for Individual Systems and SLCA/IP Power Relative to Total Resources K-169
K.3.2.3 Using Regression Equations to Approximate Retail Rate Changes for Systems Not Included in the Database K-171
K.3.3 Summary of Impacts K-172
K.3.3.1 Average Rate Impacts under LTEMP Alternatives over the 20-Year LTEMP Period K-172
K.3.3.2 Average Year-by-Year Rate Impacts K-174
K.3.3.3 Individual System Impacts and Summary Descriptions of LTEMP Alternatives K-179
K.3.4 Impacts on Small Systems K-185
K.3.5 Alternative-Specific Impacts K-187
K.3.5.1 Alternative A K-187
K.3.5.2 Alternative B K-187
K.3.5.3 Alternative C K-188
K.3.5.4 Alternative D K-189
K.3.5.5 Alternative E K-189
K.3.5.6 Alternative F K-190
K.3.5.7 Alternative G K-190
K.4 Financial Impacts of LTEMP Alternatives on American Indian Tribes K-190
K.4.1 Contractual Requirements for Calculating and Delivering Benefits to Tribes K-192
K.4.2 Calculation of Tribal Benefit Baseline under Alternative A (No Action Alternative) K-193
K.4.3 Calculation of Change in Tribal Benefit as a Result of LTEMP EIS Alternatives K-193
K.4.4 Impacts on Tribes through a Change in the Retail Rate of the Electrical Supplier to Tribal Lands K-194
K.4.5 Calculation of Tribal Impacts for Tribes That Are Direct SLCA/IP Recipients K-195
K.4.6 Total Impact of LTEMP EIS Alternatives: Benefit Change and Rate Effect K-196
K.4.7 Total Impact on Tribes and Tribal Members Versus Retail Rate Changes to Households K-202
K.4.8 Conclusions K-202
K.5 Impacts of LTEMP Alternatives on Lake Mead and the Hoover Dam Powerplant K-206

CONTENTS (Cont.)

K.5.1 Hoover Analysis Methods, Model, and Supporting Data K-209
K.5.2 Hoover Monthly Energy Production and Water-to-Power Conversion K-210
K.5.3 Hoover Maximum Operational Capacity and Firm Capacity K-213
K.5.4 Economic Value of Hoover Powerplant Energy K-213
K.5.5 Sensitivity of Model Results K-214
K.6 References K-215
Attachment K.1: Geographic Scope of the Analysis K-219
Attachment K.2: AURORA Western Interconnection Spot Market Energy Prices Adjustments K-223
Attachment K.3: Selection of Representative Trace K-226
Attachment K.4: Discounting Procedures K-244
Attachment K.5: Forced Outage Scenario Generation for Hydroelectric Power Facilities K-247
Attachment K.6: Forecast of Monthly Peak Loads and Energy by SLCA/IP Long-Term Firm Customer K-250
Attachment K.7: Analysis of the Timing of the Peak Load K-252
Attachment K.8: Analysis of Capacity Determinations — Comparing Results Using a Range of Exceedence Levels and Two Summer Peak Months K-258
Attachment K.9: Results of a Survey of Electric Utility Integrated Resource Plans K-260
Attachment K.10: Indices Used for Converting Dollars from One Year to Another K-270
Attachment K.11: Summary IRP of Capacity Additions in the Joint System and Surrounding Utility Systems through the End of CY2034 ..... K-275
Attachment K.12: Annual SLCA/IP Allocations to American Indian Tribes and Benefit Information K-277

APPENDIX L: Socioeconomic Technical Information and Analysis L-1

L.1 Recreation Economic Analyses L-3
L.1.1 Recreation Use Values L-3
L.1.1.1 Lake_Full Utility Model L-4
L.1.1.2 GCRec_Full Utility Model L-5
L.1.2 Recreation Non-Use Values L-6
L.1.3 Regional Recreation Economic Impacts L-10
L.1.4 Estimates of Recreational Economic Impacts L-12
L.2 Regional Electricity Analyses L-13
L.2.1 Regional Electricity Price Impacts L-13
L.2.2 Regional Electricity Generating Capacity Expansion Impacts L-15
L.3 Additional Socioeconomic Data L-15
L.3.1 Urban Population in the Six-County Region L-15
L.3.2 Urban Income in the Six-County Region L-20
L.4 References L-21

CONTENTS (Cont.)

APPENDIX M: Air Quality and Climate Change Technical Information and Analysis M-1

M.1 Analysis Methods M-4
M.1.1 System Power Generation M-4
M.1.2 Spot Market M-5
M.1.3 Generation Type M-6
M.2 Results M-6
M.2.1 SO_2 and NO_X M-6
M.2.2 GHG Emissions M-8
M.3 References M-9

APPENDIX N: Government-to-Government and National Historic Preservation Act Consultation N-1

N.1 Government-to-Government Consultation N-3
N.2 Consultation with the State Historic Preservation Office N-31
N.3 Reference N-31
Attachment N.1 ..... N-33
Attachment N.2 ..... N-75
Attachment N.3 ..... N-137

APPENDIX O: Biological Assessment for the Glen Canyon Dam Long-Term Experimental and Management Plan O-1

APPENDIX P: High-Flow Experiment Protocol for the Preferred Alternative P-1

P.1 Decision-Making Process P-3
P.1.1 Planning P-4
P.1.2 Modeling P-5
P.1.3 Decision and Implementation P-8
P.2 Operation of Glen Canyon Dam under the HFE Protocol P-9
P.2.1 Potential Operation of Glen Canyon Dam during the Fall HFE Implementation Window P-10
P.2.2 Potential Operation of Glen Canyon Dam during the Spring HFE Implementation Window P-10
P.3 High Flow Experiments to be Evaluated under the Preferred Alternative P-11
P.3.1 Sediment-Triggered Spring HFEs P-11
P.3.2 Proactive Spring HFEs P-12
P.3.3 Sediment-Triggered Fall HFEs P-13
P.3.4 Extended-Duration Fall HFEs P-13
REFERENCES P-14

APPENDIX Q: Responses to Public Comments on the Glen Canyon Dam Long-Term Experimental and Management Plan Draft Environmental Impact Statement Q-1

FIGURES

1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands 1-5

1-2 Glen Canyon Dam..... 1-6

1-3 Map of the Colorado River between Lake Powell and Lake Mead 1-20

1-4 Indian Reservations within or Adjacent to the LTEMP EIS Project Area..... 1-25

2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an 8.23-maf Year Based on Values Presented in Table 2-3 2-18

2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year 2-18

2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-19

2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4 2-21

2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year 2-22

2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-22

2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year 2-24

2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year..... 2-24

2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B for a Week in July in an 8.23-maf Year 2-25

2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5.... 2-26

2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year 2-28

2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-28

2-13 Decision Tree for Sediment-Related Actions under Alternative C..... 2-29

FIGURES (Cont.)

2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C 2-30

2-15 Example Implementation of a Two-Cycle TMF in June and July with Resumption of Normal Fluctuations between Cycles and Afterward 2-40

2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-6 2-42

2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8 2-45

2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year 2-47

2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-47

2-20 Decision Tree for Implementation of Sediment-Related Experimental Treatments under Alternative D..... 2-55

2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental Treatments under Alternative D..... 2-56

2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative D in an 8.23-maf Year Based on the Values Presented in Table 2-10 2-69

2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11 2-74

2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year..... 2-74

2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-75

2-26 Decision Tree for Sediment-Related Actions under Alternative E 2-76

2-27 Decision Tree for Trout-Related Actions under Alternative E..... 2-77

2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12 2-82

FIGURES (Cont.)

2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an 8.23-maf Year Based on Values Presented in Table 2-13 2-83

3.1-1 LTEMP Project Area and Surrounding Lands 3-2

3.2-1 Map of Lake Powell and Associated Major Tributaries 3-8

3.2-2 Pattern of Annual Historic Flows at Lees Ferry 3-12

3.2-3 Map of Lake Mead and Associated Major Tributaries 3-13

3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River 3-16

3.2-5 Water Temperature at Lees Ferry 3-18

3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 3-21

3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge 3-22

3.3-1 Geomorphic Features of the Colorado River 3-36

3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River 3-38

3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building 3-38

3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River 3-40

3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam 3-42

3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 3-42

3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River 3-44

3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers 3-49

3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE 3-52

FIGURES (Cont.)

3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates 3-54

3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE 3-55

3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 3-57

3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam 3-71

3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead 3-74

3.5-3 Estimated Adult Humpback Chub Abundance from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age 3-75

3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 3-76

3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence, 1995 to Present 3-81

3.5-6 Mean Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 3-96

3.5-7 Mean Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 3-99

3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam ... 3-114

3.7-1 Riparian Zones Used by Nesting Birds 3-124

3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor 3-135

3.8-1 Spencer Steamboat 3-148

3.8-2 A Roasting Pit Feature in a Grand Canyon Dune 3-148

FIGURES (Cont.)

3.8-3 An Archaic Period Site on the Colorado River in GCNP 3-151

3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA 3-151

3.8-5 Puebloan Era Architecture along the Colorado River in GCNP 3-152

3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA 3-155

3.10-1 Glen Canyon Reach Rainbow Trout 3-170

3.10-2 Mean Rainbow Trout Catch Per Unit Effort of Both Boat Anglers and Shore-Line Anglers from Creel Surveys at Lees Ferry 3-171

3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 and 2009..... 3-172

3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 3-173

3.10-5 Designated Campsite Areas in the Glen Canyon Reach 3-175

3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite 3-176

3.10-7 Pontoon Raft Operated by Colorado River Discovery..... 3-176

3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month 3-179

3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP..... 3-181

3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 3-182

3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006..... 3-182

3.12-1 Glen Canyon Viewed from the Colorado River 3-194

3.12-2 Horseshoe Bend 3-194

3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip 3-196

3.12-4 Colorado River and Granaries at Nankoweap..... 3-196

FIGURES (Cont.)

3.12-5 Entrance to Havasu Canyon 3-197

3.12-6 Vasey's Paradise 3-197

3.14-1 Minority Population Groups in the 11-County Area 3-219

3.14-2 Low-Income Population Groups in the 11-County Area 3-220

3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area 3-233

3.15-2 PSD Class I Areas in the 11-State Affected Area 3-235

3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand 3-238

4-1 Integrated Multiple-Resource Modeling Framework Showing Inputs, Intermediate Calculations, and Output 4-3

4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values 4-6

4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes 4-22

4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-24

4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-27

4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios..... 4-29

4.2-5 Lake Powell and Lake Mead End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives 4-32

4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces and Seven Alternatives 4-33

FIGURES (Cont.)

4.2-7 Percentage of Time in Different Operating Tier than Alternative 4-34

4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces..... 4-35

4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces..... 4-36

4.2-10 Frequency of Occurrence of Modeled Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives 4-37

4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases 4-39

4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives..... 4-40

4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives 4-42

4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry 4-46

4.3-1 Conceptual Depiction of the Sand Load Index 4-67

4.3-2 Conceptual Depiction of the Sand Mass Balance Model..... 4-68

4.3-3 Variation in Lake Powell Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-75

4.3-4 Variation in Lake Mead Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-76

4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives..... 4-77

4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-78

4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-79

4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem..... 4-89

FIGURES (Cont.)

4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios 4-121

4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives 4-123

4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives 4-124

4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-125

4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-127

4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations 4-129

4.5-7 Mean Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence and at Pumpkin Spring under Each Alternative..... 4-130

4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives 4-131

4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-135

4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam..... 4-136

4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam..... 4-177

FIGURES (Cont.)

4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-178

4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-179

4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model 4-187

4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives 4-243

4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives 4-245

4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives 4-288

4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS 4-326

4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives 4-341

4.13-3 Total NPV of Hoover Powerplant Energy over a 20-Year Period under LTEMP Alternatives 4-352

4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period 4-407

4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change 4-415

4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces 4-416

4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives 4-420

D-1 Operating Tiers as Specified by the 2007 Interim Guidelines for the Operations of Lake Powell and Lake Mead D-7

D-2 Monthly Releases for Each Alternative in an 8.23-maf Release Year D-21

FIGURES (Cont.)

D-3 Locations of CRSS 29 Natural Flow Nodes D-24

D-4 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell Annual Inflow, Lake Powell Water-Year Release Volume, and Lake Powell Monthly Release Volume D-25

D-5 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell End-of-December Water Elevations at the 10th, 50th, and 90th Percentiles D-25

D-6 Occurrences of Low Summer Flows in Applicable Alternatives D-28

D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the End of the Water Year per 20-yr Trace for Each of the Alternatives D-29

D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the Water-Year Releases by Trace for Each of the Alternatives D-30

D-9 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and B D-30

D-10 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and C D-31

D-11 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and D D-31

D-12 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and E D-32

D-13 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and F D-32

D-14 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and G D-33

D-15 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and B D-33

D-16 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and C D-34

FIGURES (Cont.)

D-17 Percentage of Traces below Lake Powell's Minimum Power and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and D D-34

D-18 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and E D-35

D-19 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and F D-35

D-20 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and G D-36

E-1 Comparison of Calendar, Water, and Sediment Years E-20

E-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output E-21

E-3 Conceptual Schematic of the Sand Budget Model E-22

E-4 Historical Paria Sediment Load per Accounting Period and the 20.5-year Load for the Trace That Begins in Each Fall Accounting Period E-22

E-5 Sediment Traces s1, s2, and s3 for the Paria River Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-6 Little Colorado River Sediment Traces for s1, s2, and s3 Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-7 Conceptual Representation of the Sand Mass Balance Index E-24

E-8 Average Sediment and Hydrology Triggered HFE Count by Type for Each Long-Term Strategy E-24

E-9 Average HFE Count for Sediment Traces s1, s2, and s3 for Each Long-Term Strategy E-25

E-10 Definition of the Statistics Represented by the Box and Whisker Plots Used in This Analysis E-25

FIGURES (Cont.)

E-11 Sand Load Index Statistics from 63 Simulations for Each Long-Term Strategy..... E-26

E-12 Standard Deviation of High Flows Statistics from 63 Simulations for Each Long-Term Strategy E-26

E-13 Correlation between SDHF and SLI E-27

E-14 Sand Mass Balance Index Statistics from 63 Simulations for Each Long-Term Strategy E-27

E-15 Correlation between SMBI and SLI E-28

E-16 Sand Load Index for Long-Term Strategies Using Climate Change Weights..... E-28

E-17 Comparison of the Sand Load Index between Climate Change and Historical Weights E-29

E-18 Standard Deviation of High Flows Using Climate Change Weights..... E-29

E-19 Comparison of the Standard Deviation of High Flows between Climate Change and Historical Weights E-30

E-20 Sand Mass Balance Index Using Climate Change Weights E-30

E-21 Comparison of the Sand Mass Balance Index between Climate Change and Historical Weights E-31

E-22 Comparison of Long-Term Strategies C1 and C2 for Hydrology Trace 1, Sediment Trace 3 ..... E-31

E-23 SMBI for Alternative E Plotted against Alternative C E-32

E-24 SLI for Alternative E Plotted against Alternative C E-32

E-25 Load-Following Curtailment Effects on SLI and SMBI..... E-33

E-26 Low Summer Flows for WY 2014, Hydrology Trace 1, Sediment Trace 1 ..... E-34

E-27 Hydrology Impacts on the Sand Load Index E-35

E-28 Hydrology Impacts on the Sand Mass Balance Index E-35

E-29 Conceptual Diagram of Water Surface Elevation Affecting Delta Location..... E-36

FIGURES (Cont.)

E-30 Historical Cumulative Sand Load Leaving Marble Canyon and Reaching the Gage above Diamond Creek E-36

E-31 Hydrology Impacts of Lake Powell Pool Elevations by Month across Alternatives E-37

E-32 Hydrology Impacts of Lake Mead Pool Elevations by Month across Alternatives E-37

F-1 Fit of Regressions Predicting the Log of Recruitment of Rainbow Trout in the Glen Canyon Reach Estimated by the Korman et al. Stock Synthesis Model as a Function of the Annual Release Volume from Glen Canyon Dam, the Range of Mean Daily Flows during May–August, and the Maximum Flow Each Year.... F-31

F-2 Relationship between Annual Estimates of the Asymptotic Length of Rainbow Trout in Lees Ferry Predicted by the Stock Synthesis Model as a Function of the Estimated Abundance for Fish >150 mm Each Year..... F-32

F-3 The Relationship between Annual Recruitment of Rainbow Trout in Lees Ferry Estimated by the Korman et al. Stock Synthesis Model and the Number of Trout That Emigrate from Lees Ferry into Marble Canyon the Following Year F-35

F-4 Fit of the Glen Canyon Rainbow Trout Simulation Model to Predictions of Recruitment, Asymptotic Length, and the Number of Out-migrants Predicted by the Korman et al. Stock Synthesis Model F-37

F-5 Predicted and Observed Annual Catch of Rainbow Trout by Year and River Reach..... F-41

F-6 Best-Fitting Distributions Describing Monthly Movement of Rainbow Trout in Marble Canyon Assuming Either a Normal or Cauchy Distribution..... F-43

F-7 Visual Summary of Humpback Chub Population Model Structure..... F-44

F-8 Modeled Effects of Trout Abundance and Temperature on Humpback Chub Survival and Growth F-48

F-9 Simulated Adult Abundances from Backcasted Model Compared to Patterns Reported in Coggins and Walters F-51

F-10 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under LTEMP Alternatives and Long-Term Strategies F-54

FIGURES (Cont.)

F-11 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-55

F-12 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and the Mean Number of Rainbow Trout Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-56

F-13 Modeled Mean Annual Angler Catch Rate for Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-57

F-14 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and Mean Angler Catch Rates during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies..... F-58

F-15 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-59

F-16 Modeled Frequency of Triggered Mechanical Removal for Rainbow Trout in the Little Colorado River Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-61

F-17 Modeled Minimum Population Size for Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-62

F-18 Relationship between Modeled Mean Numbers of Rainbow Trout Out-migrants from the Glen Canyon Reach and the Modeled Mean Minimum Abundance of Adult Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-63

F-19 Suitability for Spawning, Egg Incubation, and Growth of Humpback Chub as a Function of Water Temperature F-68

F-20 Months for Which Annual Temperature Suitability for Specific Life History Aspects of Humpback Chub Were Calculated..... F-68

F-21 Modeled Historic Water Temperatures in the Colorado River at Humpback Chub Aggregation Locations, Water Years 1990–2012 ..... F-70

FIGURES (Cont.)

F-22 Output from the Temperature Suitability Model for Humpback Chub Aggregation Locations Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-71

F-23 Mainstem Temperature Suitability for Humpback Chub Aggregation Locations under LTEMP Alternatives and Long-Term Strategies F-72

F-24 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Native Fish Species F-74

F-25 Months for Which Temperature Suitability for Specific Life History Aspects Were Considered for Native Fish Species F-74

F-26 Modeled Historic Water Temperatures in the Colorado River Downstream of Glen Canyon Dam, Water Years 1990–2012 ..... F-75

F-27 Annual Temperature Suitability Scores for Growth, Spawning, and Egg Incubation of Native Fish Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-76

F-28 Annual Temperature Suitability Scores for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-29 Mean Annual Overall Temperature Suitability for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-30 Mean Annual Mainstem Temperature Suitability for Native Fish under LTEMP Alternatives and Long-Term Strategies at RM 61, RM 157, and RM 225, and Overall Mean for RM 61–225 ..... F-78

F-31 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Nonnative Fish Species F-80

F-32 Months during Which Temperature Suitability for Specific Life History Aspects Were Calculated for Nonnative Fish Species F-81

F-33 Annual Temperature Suitability Scores for Spawning, Incubation, and Growth of Nonnative Fish Species at RM 225 Based on Modeled Temperatures for Water Years 1990 to 2012 ..... F-82

F-34 Mean Annual Temperature Suitability Scores for Nonnative Fish Species and for Temperature Groups by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-83

FIGURES (Cont.)

F-35 Mean Annual Overall Temperature Suitability Scores for Coldwater and Warmwater Nonnative Fish Species Groups Based on Modeled Historic Temperatures for Water Years 1990–2012 ..... F-83

F-36 Mean Annual Mainstem Temperature Suitability for Coldwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 15, RM 61, RS 157, and RM 225 ..... F-84

F-37 Mean Annual Mainstem Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 0, RM 61, RM 157, and RM 225 ..... F-85

F-38 Suitability of Various Water Temperatures for Host Activity and Infestation Rates of Parasite Species F-86

F-39 Annual Temperature Suitability Scores for Parasite Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-40 Mean Annual Temperature Suitability Scores for Parasite Species by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-41 Overall Means of Annual Suitability Scores for Parasite Species across All River Locations during the 1990–2012 Water Years F-88

F-42 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives and Long-Term Strategies for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam F-89

G-1 Native Cover Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-2 Native Cover Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-3 Native Diversity Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-4 Native Diversity Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-5 Native/Nonnative Ratio Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-48

FIGURES (Cont.)

G-6 Native/Nonnative Ratio Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term G-48

G-7 Arrowweed Metric for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less G-49

G-8 Arrowweed Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less Arrowweed G-49

G-9 Overall Combined Score for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-10 Overall Combined Score under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-11 Relative Change in Wetland Cover for the LTEMP Alternatives and Associated Long-Term Strategies G-51

G-12 Relative Change in Wetland Cover under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-51

H-1 Wind Transport of Sediment Index Values for the LTEMP Alternatives and Associated Long-Term Strategies H-6

H-2 Average Number of HFEs in the 20-Year LTEMP Period H-7

H-3 Daily Maximum Discharge in a Typical 8.23-maf Water Volume Release Year from the Glen Canyon Dam during the Windy Season of March–June H-8

H-4 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives and Long-Term Strategies H-10

H-5 Average Number of Days of an HFE Event per Year H-11

H-6 Modeled Glen Canyon Dam Discharge for the Same Year H-12

H-7 Time Off River Index Values for All LTEMP Alternatives and Associated Long-Term Strategies H-14

H-8 Daily Average Discharge for Representative Long-Term LTEMP Strategies H-15

I-1 Riparian Diversity for the LTEMP Alternatives and Associated Long-Term Strategies I-6

FIGURES (Cont.)

I-2 Riparian Diversity under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-7

I-3 Wetland Abundance for the LTEMP Alternatives and Associated Long-Term Strategies I-9

I-4 Wetland Abundance under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-10

I-5 Frequency of Trout Management Flows for the LTEMP Alternatives and Associated Long-Term Strategies I-12

I-6 Frequency of Trout Management Flows under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-13

I-7 Frequency of Mechanical Removal for the LTEMP Alternatives and Associated Long-Term Strategies I-14

I-8 Frequency of Mechanical Removal under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-15

I-9 Lake Powell Water Levels for the LTEMP Alternatives and Associated Long-Term Strategies I-16

I-10 Lake Powell Water Levels under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-17

J-1 Camping Area Index for LTEMP Long-Term Strategies J-8

J-2 Sand Load Index for LTEMP Long-Term Strategies J-9

J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies J-11

J-4 Fluctuation Index for LTEMP Long-Term Strategies J-14

J-5 Time Off River Index for LTEMP Long-Term Strategies J-16

J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP Alternatives J-16

J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies J-19

FIGURES (Cont.)

J-8 Average Number of HFEs in the 20-Year LTEMP Period for LTEMP Long-Term Strategies J-20

J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies J-22

J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Summer Season J-24

J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Fall and Spring Seasons J-24

J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Summer Season J-25

J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Fall and Spring Seasons J-25

K.1-1 Network Topology Used by the AURORA Western Interconnection Model K-10

K.1-2 Percentage of Total Generation Resources Owned by Individual Customers K-12

K.1-3 Simplified Network Topology of the SLCA/IP Market System K-13

K.1-4 Percentage of SLCA/IP Federal Hydropower Nameplate Capacity by Facility K-16

K.1-5 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS K-18

K.1-6 Illustration of a Typical GTMax-Lite Result for a 24-Hour Period K-24

K.1-7 GTMax-Lite Network Topology for the Large SLCA/IP Hydropower Resources Other Than Glen Canyon Dam K-26

K.1-8 Illustration of Temporal Modeling Method Used in the GTMax-Lite Five Large SLCA/IP Plant Configuration K-28

K.1-9 Example of the Load Scaling Algorithm LDC K-31

K.1-10 Example of the Load Scaling Algorithm Chronological Hourly Loads K-32

K.1-11 Projected Annual Average Calibrated AURORA LMPs at the Palo Verde Market Hub K-36

FIGURES (Cont.)

K.1-12 Historical Palo Verde On- and Off-Peak Electricity Prices Compared to Natural Gas Prices K-36

K.1-13 2014 AEO Projected Delivered Utility Natural Gas Prices K-37

K.1-14 Comparison of Modeled and Actual Annual Aggregated Generation Levels for Natural Gas, Coal, and Nuclear Powerplants under the No Action Alternative K-43

K.1-15 Total Non-coincidental Peak Loads for the SLCA/IP Market System K-49

K.1-16 Total Monthly Loads for the SLCA/IP Market System K-49

K.1-17 Projected 2014 AEO Natural Gas Prices at the Henry Hub K-56

K.1-18 2014 AEO Electricity Market Module Regions and the Mapping of States to Regions K-57

K.1-19 Projected AEO 2014 Coal Prices by Electricity Market Module Region K-59

K.1-20 WAPA SLCA/IP Hydropower Powerplants K-63

K.1-21 SLCA/IP Federal Hydropower Capacity Uses and Variability Factors K-64

K.1-22 Reductions in Operating Range when Providing Ancillary Services K-66

K.1-23 Illustration of the Trapezoidal Method Used to Compute Capacity at Flaming Gorge Dam K-72

K.1-24 Illustration of Ramping Time Increase as a Function of Increasing Water Volumes at Flaming Gorge Dam K-73

K.1-25 Capacity Values at Flaming Gorge Dam Calculated over a Wide Range of Daily Water Releases Using the Trapezoidal Method K-74

K.1-26 Average Historical Non-coincidental Annual Peak Loads for the Eight Large Customers and Percentages Relative to the Total K-75

K.1-27 Historical Coincidental Annual and Average Peak Loads for the Eight Large Customers during the CY 2006 through CY 2009 Time Period K-76

K.1-28 Historical Coincidental Annual and Average Peak Loads for Six Large Customers during the CY 2010 through CY 2012 Time Period K-77

FIGURES (Cont.)

K.1-29 SLCA/IP Models Used for Estimating SHP Capacity K-78

K.1-30 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in July K-80

K.1-31 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in August K-80

K.1-32 Comparison of Firm Marketable Capacity Determinations across Alternatives, Exceedance Levels, and Summer Peak Months..... K-81

K.1-33 Timing of Capacity Additions in AURORA K-83

K.1-34 Annual Average Hydropower Generation for the Glen Canyon Dam Powerplant and the Aggregate Generation for All Other SLCA/IP Resources K-88

K.1-35 Average Daily Glen Canyon Dam Powerplant Hydropower Generations by Month Based on the Average of All 21 CRSS/SBM Hydrology Traces K-89

K.1-36 Average Annual Glen Canyon Dam Powerplant Generation for the Representative CRSS/SBM Hydrology Trace K-92

K.1-37 Representative Trace Average Daily Glen Canyon Dam Powerplant Generations by Month..... K-93

K.1-38 Average Daily Generation by Month for Each Alternative K-97

K.1-39 Palo Verde Average Daily Electricity Market Price Statistics by Month during the 20-Year LTEMP Period K-98

K.1-40 Typical Hourly Winter/Summer Price Patterns in the Western United States K-99

K.1-41 Average Number of HFEs by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-42 Average Amount of Non-Power Water Releases by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-43 Average Annual Number of Hours the Lake Powell Elevation Is below the Penstock Intake by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-101

K.1-44 2014 Annual Energy Outlook Projections of Capacity Additions in the Western Interconnection over the LTEMP Period..... K-104

FIGURES (Cont.)

K.1-45 Cumulative Capacity Additions for Alternative A K-106

K.1-46 Cost Difference of Alternatives Compared to Alternative A at 50% Exceedance Level and 3.375% Discount Rate K-119

K.1-47 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate K-119

K.1-48 Cost Difference of Alternatives Compared to Alternative A at 99% Exceedance Level and 3.375% Discount Rate K-120

K.1-49 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 1.4% Discount Rate K-122

K.1-50 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combustion Turbines K-123

K.1-51 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combined Cycle K-124

K.1-52 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate Assuming Average Hydropower Conditions K-125

K.2-1 Determination of Energy Hourly Expense or Revenue K-140

K.2-2 Determination of Total Net Expense or Revenue by Year for Each Alternative..... K-142

K.3-1 Flowchart Diagram of Rate Impact Analysis Process K-156

K.3-2 Projected Carrying Charge Rates Used in Rate Impact Analysis K-161

K.3-3 Flowchart Diagram of Allocation Process K-162

K.3-4 Load Factors of SLCA/IP Power K-165

K.3-5 Scatter Plot of Preference Ratio and Annual Retail Sales K-169

K.3-6 Scatter Plots of Percent Retail Rate Change and the Preference Ratio..... K-171

K.3-7 Retail Rate Distribution under Alternative A K-173

FIGURES (Cont.)

K.3-8 Monthly Residential Bill Distribution under Alternative A K-173

K.3-9 Average Retail Rate Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-10 Average Residential Bill Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-11 Average Retail Percent Revenue Increase Relative to Alternative A K-176

K.3-12 Average Monthly Residential Bill Changes Relative to Alternative A K-177

K.3-13 Retail Rates under Alternative A K-188

K.4-1 Calculation of Change in Tribal Benefit Resulting from LTEMP EIS Alternatives K-194

K.4-2 Financial Impacts under Alternative B Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-3 Financial Impacts under Alternative C Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-4 Financial Impacts under Alternative D Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-5 Financial Impacts under Alternative E Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-6 Financial Impacts under Alternative F Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.4-7 Financial Impacts under Alternative G Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.5-1 Change in Lake Powell Monthly Water Release Volumes under LTEMP Alternatives K-207

K.5-2 Average Lake Mead EOM Pool Elevations under LTEMP Alternatives K-207

K.5-3 Average Monthly Difference in Turbine Water Releases Relative to Alternative A K-212

FIGURES (Cont.)

K.5-4 Average Monthly Hoover Powerplant Generation for All Power Systems under Primary LTEMP EIS Alternatives K-212

K.5-5 NPV of Hoover Powerplant Benefits Relative to Alternative A Resulting from LTEMP Alternatives K-214

L-1 Elements of the Lake_Full Utility Model L-5

L-2 Elements of the GCRec_Full Utility Model L-6

L-3 Elements of the Regional Recreation Impacts Analysis L-11

L-4 Elements of the Regional Electricity Price Impacts Analysis L-16

L-5 Elements of the Regional Electricity Generating Capacity Expansion Impacts Analysis L-17

P-1 Average Monthly Sand Load from the Paria River and Little Colorado River Showing the Fall and Spring HFE Accounting Periods and Implementation Windows P-4

TABLES

1-1	Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows	1-21
1-2	Selected Documents Included in the Law of the River	1-32
2-1	Operational Characteristics of LTEMP Alternatives	2-9
2-2	Condition-Dependent and Experimental Elements of LTEMP Alternatives	2-11
2-3	Flow Parameters under Alternative A in an 8.23-maf Year	2-17
2-4	Flow Parameters under Alternative B in an 8.23-maf Year	2-21
2-5	Flow Parameters under Alternative C in an 8.23-maf Year	2-26
2-6	Implementation Criteria for Experimental Treatments of Alternative C	2-31
2-7	Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year	2-42
2-8	Flow Parameters under Alternative D in an 8.23-maf Year	2-45
2-9	Implementation Criteria for Experimental Treatments of Alternative D	2-50
2-10	Flow Parameters for a Year with Low Summer Flows under Alternative D in an 8.23-maf Year	2-68
2-11	Flow Parameters under Alternative E in an 8.23-maf Year	2-73
2-12	Flow Parameters under Alternative F in an 8.23-maf Year	2-82
2-13	Flow Parameters under Alternative G in an 8.23-maf Year	2-83
2-14	Summary of Impacts of LTEMP Alternatives on Resources	2-93
3.5-1	Native Fish of the Colorado River through Glen and Grand Canyons	3-72
3.5-2	Nonnative Fish Found in the Colorado River through Glen and Grand Canyons	3-91
3.5-3	Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009	3-94
3.5-4	Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed	3-102

TABLES (Cont.)

3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins 3-113

3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead 3-122

3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead 3-133

3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013 3-177

3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders 3-184

3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013 3-208

3.14-1 Population in the Six-County Region 3-210

3.14-2 Income in the Six-County Region 3-212

3.14-3 Employment in the Six-County Region 3-213

3.14-4 Employment by Sector in 2011 3-214

3.14-5 Unemployment Rates in the Six-County Region 3-215

3.14-6 Minority and Low-Income Populations in the 11-County Area 3-217

3.14-7 Population in the Seven-State Region of Influence 3-222

3.14-8 Income in the Seven-State Region of Influence 3-223

3.14-9 Employment in the Seven-State Region of Influence 3-224

3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence 3-225

3.14-11 Unemployment in the Seven-State Region of Influence 3-226

3.14-12 State Minority and Low-Income Populations, 2010 3-227

3.15-1 Clean Air Act Prevention of Significant Deterioration Designations 3-230

TABLES (Cont.)

3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011 3-231

3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection 3-236

4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative 4-4

4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality 4-15

4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek 4-50

4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources 4-73

4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative 4-90

4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources 4-92

4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology 4-109

4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base 4-116

4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels 4-165

4.6-2 Vegetation States and Corresponding Mapped Vegetation Types 4-169

4.6-3 Summary of Impacts of LTEMP Alternatives on Vegetation 4-170

4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions 4-181

4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor 4-185

4.6-6 Summary of Impacts of LTEMP Alternatives on Special Status Plant Species 4-188

4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife 4-205

TABLES (Cont.)

4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species 4-217

4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons 4-239

4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover 4-253

4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources 4-263

4.10-1 Summary of Impacts of LTEMP Alternatives on Recreation, Visitor Use, and Experience 4-282

4.10-2 Amount of Sediment Transported Out of Marble Canyon under the LTEMP Alternatives over the 20-Year LTEMP Period 4-295

4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience 4-310

4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources 4-335

4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice 4-366

4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP Alternatives 4-376

4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012 4-380

4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives 4-380

4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives 4-381

4.14-6 Seven-State Economic Impacts under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033 4-383

4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A 4-384

4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers 4-389

TABLES (Cont.)

4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality 4-404

4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative 4-408

4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions 4-417

4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions 4-422

4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area 4-428

4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives 4-447

5.1-1 Summary of Cooperating Agency Involvement 5-3

B-1 Tolerable Flow Fluctuations for Recreational River Use B-13

D-1 Initial Reservoir Conditions D-5

D-2 Monthly Release Volumes by Water-Year Release for Alternative A D-11

D-3 Monthly Release Volumes by Water-Year Release for Alternative B D-12

D-4 Monthly Release Volumes by Water-Year Release for Alternative C D-13

D-5 Monthly Release Volumes by Water-Year Release for Alternative C with Low Summer Flows D-14

D-6 Monthly Release Volumes by Water-Year Release for Alternative D D-15

D-7 Monthly Release Volumes by Water-Year Release for Alternative D with Low Summer Flows D-16

D-8 Monthly Release Volumes by Water-Year Release for Alternative E D-17

D-9 Monthly Release Volumes by Water-Year Release for Alternative E with Low Summer Flows D-18

D-10 Monthly Release Volumes by Water-Year Release for Alternative F D-19

TABLES (Cont.)

D-11 Monthly Release Volumes by Water-Year Release for Alternative G D-20

D-12 Minimum Release Constraints Used for Each Alternative D-21

D-13 Input Demands by State D-27

E-1 Sources for Historical Tributary Sediment Load Data E-38

E-2 Historical Periods Used for Paria Sediment Traces s1, s2, and s3 ..... E-38

E-3 Historical Periods Used for Little Colorado River Sediment Traces s1, s2, and s3 ..... E-38

E-4 List of HFEs Available for Sediment-Triggered Experiments E-39

F-1 Average Mean Habitat-Weighted Invertebrate Biomass at Select Sites in the Colorado River, July 2006–June 2009 ..... F-8

F-2 Average Mean Habitat-Weighted Invertebrate Production at Select Sites in the Colorado River, July 2006–June 2009 ..... F-9

F-3 Average Mean Habitat-Weighted Invertebrate Abundance at Select Sites in the Colorado River, July 2006–June 2009 ..... F-10

F-4 Distribution, Ecological Importance, and Favorable Temperature Range for Select Primary Producers F-11

F-5 Temperature Requirements for Common Zooplankton F-24

F-6 Distribution, Importance to Higher Trophic Levels, and Temperature Range for Common Benthic Macroinvertebrates Downstream of Glen Canyon Dam F-25

F-7 Temperature Requirements for the Asian Tapeworm, Anchor Worm, and Trout Nematode F-26

F-8 Summary of Metrics Values from the Rainbow Trout-Humpback Chub Model F-53

F-9 Description of Input Parameters for the LTEMP Temperature Suitability Model F-66

F-10 Humpback Chub Aggregation Locations F-67

F-11 Locations Used for Temperature Suitability Modeling of Native Fish, Nonnative Fish, and Parasites F-73

TABLES (Cont.)

G-1 Vegetation States, Plant Associations, and Corresponding Submodels G-15

G-2 Hydrologic Events Considered in the Riparian Vegetation Model G-16

G-3 Riparian Vegetation Model Transition Rules G-17

G-4 New High-Water Zone and Old High-Water Zone Vegetation Classes Mapped from Lees Ferry to Diamond Creek G-22

G-5 Vegetation States and Corresponding Mapped Vegetation Types G-24

G-6 Example Results for the Native Cover Metric G-25

G-7 Example Results for the Arrowweed Metric G-25

G-8 Results for Alternative A G-26

G-9 Results for Alternative B, Long-Term Strategy B1 ..... G-27

G-10 Results for Alternative B, Long-Term Strategy B2 ..... G-28

G-11 Results for Alternative C, Long-Term Strategy C1 ..... G-29

G-12 Results for Alternative C, Long-Term Strategy C2 ..... G-30

G-13 Results for Alternative C, Long-Term Strategy C3 ..... G-31

G-14 Results for Alternative C, Long-Term Strategy C4 ..... G-32

G-15 Results for Alternative D, Long-Term Strategy D1 ..... G-33

G-16 Results for Alternative D, Long-Term Strategy D2 ..... G-34

G-17 Results for Alternative D, Long-Term Strategy D3 ..... G-35

G-18 Results for Alternative D, Long-Term Strategy D4 ..... G-36

G-19 Results for Alternative E, Long-Term Strategy E1 ..... G-37

G-20 Results for Alternative E, Long-Term Strategy E2 ..... G-38

G-21 Results for Alternative E, Long-Term Strategy E3 ..... G-39

TABLES (Cont.)

G-22 Results for Alternative E, Long-Term Strategy E4 ..... G-40

G-23 Results for Alternative E, Long-Term Strategy E5 ..... G-41

G-24 Results for Alternative E, Long-Term Strategy E6 ..... G-42

G-25 Results for Alternative F G-43

G-26 Results for Alternative G G-44

G-27 The Effects of LTEMP Long-Term Strategies on Wetlands G-45

I-1 Federal Regulations and Executive Orders Pertaining to Consultation with Tribes I-3

I-2 Vegetation States I-5

J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial Motor Guides, Commercial Oar Guides, and Private Trip Leaders Who Have Experienced Daily Fluctuations of at Least 15,000 cfs in the Grand Canyon J-12

J-2 Recreation Response to Daily Maximum Flow J-20

J-3 Summary of Recreation, Visitor Use, and Experience Metrics J-26

K.1-1 Cost and Performance Characteristics of Capacity Expansion Candidates K-51

K.1-2 Cumulative Annual Percentage Increase in Natural Gas Prices at the Henry Hub K-55

K.1-3 Cumulative Annual Percent Increase in Regional Coal Prices K-58

K.1-4 Cumulative Annual Percentage Increase in Regional Distillate Fuel Prices K-60

K.1-5 Assumed Ancillary Services Provided by SLCA/IP Hydropower Facilities from 2013 to 2030 ..... K-65

K.1-6 Summary of Utility IRPs for Four Large SLCA/IP Customers and Other Large Utilities in Areas Neighboring the SLCA/IP System K-87

K.1-7 SLCA/IP Marketable Capacity at the 90% Exceedance Level K-102

K.1-8 Difference in Cumulative Capacity Additions of Each Alternative Relative to Alternative A K-105

TABLES (Cont.)

K.1-9 Comparison of the Amount and Timing of New Capacity Additions for Alternatives A and F K-107

K.1-10 Total Economic Impacts by Alternative at the 90% Exceedance Level K-109

K.1-11 Estimated Cost of LTEMP Experiments K-116

K.1-12 Comparison of Marketable Capacity, Replacement Capacity, and Capacity Additions by Exceedance Level K-117

K.1-13 Firm SLCA/IP Federal Hydropower Capacity at Various Exceedance Levels at Glen Canyon Dam by Alternative and Ancillary Service Scenarios K-127

K.1-14 Comparison of Capacity and Energy Values at Glen Canyon Dam by Alternative and Ancillary Services Scenarios at the 90% Exceedance Level K-128

K.1-15 Difference Relative to Alternative A K-128

K.1-16 Alternative Cost Increase Estimates for Mixed NGCC/CT Technology Capacity Replacement Relative to CT Only Replacement as Estimated Using GTMax-Lite K-130

K.1-17 Summary of Economic Rankings for Baseline and All Sensitivity Scenarios K-132

K.2-1 SHP Contractual Obligations and Project Use Required Deliveries by Month K-136

K.2-2 SHP Hourly Load Shapes by Month and Type of Day K-137

K.2-3 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year K-141

K.2-4 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year Expressed as the Difference from Alternative A K-143

K.2-5 Total Net Purchase Power Expenses by Year and Alternative for the Continuous Current Obligations Scenario K-147

K.2-6 Total Net Purchase Power Expenses by Year and Alternative for the Reduced Obligations to Match Resource Scenario K-148

K.2-7 SLCA/IP Rate Impact by Alternative K-151

K.3-1 Energy Allocations for Systems Receiving Indirect SLCA/IP Allocations K-157

TABLES (Cont.)

K.3-2 Coverage of Retail Information from EIA Database Relative to SLCA/IP Preference Power Allocation K-159

K.3-3 Average Annual Grid Cost Relative to SLCA/IP Wholesale Revenues Relative to Alternative A K-168

K.3-4 Summary Table of Comparative Values K-178

K.3-5 Individual Systems with the Largest Percent Retail Rate Impacts Relative to Alternative A K-180

K.3-6 Individual Systems with the Smallest Percent Retail Rate Impacts Relative to Alternative A K-182

K.3-7 Individual Systems with the Largest Monthly Residential Bill Impacts Relative to Alternative A K-183

K.3-8 Individual Systems with the Smallest Monthly Residential Bill Impacts Relative to Alternative A K-184

K.3-9 Size and Preference Ratio for Utility Systems with Large Rate Impacts K-186

K.3-10 Rate Impacts for Selected Groups in Maximum Impact Year K-186

K.4-1 Monthly Change in Residential Electric Utility Bill for Tribes by Alternative K-197

K.4-2 Total Dollar Annual Impact on Tribes under LTEMP Alternatives Relative to Alternative A K-199

L-1 Total Regional Economic Impacts of Non-Local Recreation Expenditures, 2013 ..... L-13

L-2 Urban Population, Income, and Poverty in the Six-County Region L-18

M-1 Emission Factors by Plant for System Power Generation and Spot Market M-10

M-2 Power Generation Averaged over the 20-Year LTEMP Period by Alternative M-12

M-3 Summary of Potential Impacts of LTEMP Alternatives on Visibility and Regional Air Quality M-15

M-4 Annual SO_2 Emissions Averaged over the 20-Year LTEMP Period by Alternative M-16

TABLES (Cont.)

M-5 Annual NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative M-19

M-6 Summary of Impacts of LTEMP Alternatives on SO_2 and NO_x Emissions M-22

M-7 Annual Greenhouse Gas Emissions under LTEMP Alternatives M-23

M-8 Summary of Impacts of LTEMP Alternatives on CO_2e Emissions M-26

N-1 Summary of Tribal Participation Status N-5

N-2 Summary of Tribal Correspondence N-6

N-3 Summary of Major Face-to-Face Meetings, Webinars, and Conference Calls Involving Tribes N-25

N-4 Summary of Individual Tribal Consultation Meetings to Date N-27

N-5 Index of Project Tribal Government Consultation and Coordination Correspondence N-29

P-1 List of HFEs Available for Sediment-Triggered Experiments under the Preferred Alternative P-7

Q-1 Comment Issues and Location in the Report Q-6

Q-2 Commenter Distribution by State Q-10

Q-3 Commenter, Affiliation, and Location Where Responses Are Found Q-88

ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
ACHP	Advisory Council on Historic Preservation
AML	abandoned mine land
AMSL	above mean sea level
AMWG	Adaptive Management Work Group
AOP	Annual Operation Plan for Colorado River Reservoirs
APE	Area of Potential Effect
Argonne	Argonne National Laboratory
ASMR	Age-Structured Mark Recapture Model
AZGFD	Arizona Game and Fish Department
AZ-SGCN	Arizona Species of Greatest Conservation Need
BA	Balancing Authority (in Chapter 3 only) Biological Assessment (in all other sections)
BGEPA	Bald and Golden Eagle Protection Act of 1940
BIA	Bureau of Indian Affairs
BO	Biological Opinion
C	Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
CCC	Civilian Conservation Corps
CEQ	Council on Environmental Quality
CFMP	*Comprehensive Fisheries Management Plan*
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUE	catch per unit effort
CRBC	Colorado River Board of California
CRCN	Colorado River Commission of Nevada
CRD	Colorado River Discovery
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
CRSS	Colorado River Simulation System
CSU	Colorado Springs Utilities

DEIS	Draft Environmental Impact Statement
Deseret	Deseret Generation and Transmission Cooperative
DFC	desired future condition
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DPS	Distinct Population Segment
EA	Environmental Assessment
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ELCOM	Estuary, Lake and Coastal Ocean Model
EMS	emergency medical services
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ESA	Endangered Species Act of 1973, as amended
F	Fahrenheit
FCPP	Four Corners Power Plant
FES	Firm Electric Service
FONSI	Finding of No Significant Impact
FR	*Federal Register*
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCM	general circulation model
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
GHG	greenhouse gas
GMP	General Management Plan
GW	gigawatt(s)
GWh	gigawatt-hour(s)
GWP	global warming potential
H_2S	hydrogen sulfide
HBC	humpback chub
HFC	hydrofluorocarbon
HFE	high-flow experiment
hr	hour(s)

HRR	Hualapai River Runners
in.	inch(es)
IPM	Integrated Pest Management
IRP	integrated resource plan
ISM	Indexed Sequential Method
kaf	thousand acre-feet
kWh	kilowatt-hour(s)
lb	pound(s)
LCRMSCP	Lower Colorado River Multi-Species Conservation Program
LMM	Lake Mead Model
LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Long-Term Experimental and Management Plan
LTEP	Long Term Experimental Plan
LTF	long-term firm
maf	million acre-feet
MAMB	miscellaneous algae, macrophytes, and bryophytes
MBTA	Migratory Bird Treaty Act
MCL	maximum contaminant level
mi	mile(s)
MLFF	Modified Low Fluctuating Flow
MMt	million metric tons
MOA	Memorandum of Agreement
MT	metric ton(s)
MW	megawatt(s)
MWh	megawatt-hour(s)
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAU	Northern Arizona University
NC	no change
NEPA	National Environmental Policy Act of 1969, as amended
NERC	North American Electric Reliability Corporation
NEV	net economic use value
NGO	nongovernmental organization
NHPA	National Historic Preservation Act
NM	national monument
NO_2	nitrogen dioxide
NO_3	nitrate-nitrogen
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service

NPV	net present value
NRHP	*National Register of Historic Places*
NTUA	Navajo Tribal Unit Authority
O&M	operation and maintenance
O_3	ozone
OPAC	Office of Planning and Compliance
OSMRE	Office of Surface Mining Reclamation and Enforcement
PA	Programmatic Agreement
Pb	lead
PEPC	Planning, Environment, and Public Comment
PFC	perfluorocarbon
P.L.	Public Law
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
PM_{10}	particulate matter ≤10 μm in aerodynamic diameter
POM	particulate organic matter
PSAR	preventative search and rescue
PSD	Prevention of Significant Deterioration
RA	resource available
Reclamation	Bureau of Reclamation
RM	river mile
RMP	Resource Management Plan
ROD	Record of Decision
RSG	Reserve Sharing Group
SAAQS	State Ambient Air Quality Standards
SBM	Sand Budget Model
SCP	Salinity Control Project
SD	standard deviation
SDA	Structured Design Analysis
SE	standard error
Secretary, the	Secretary of the Interior
SF_6	sulfur hexaflouride
SHPO	State Historic Preservation Officer
SLCA/IP	Salt Lake City Area Integrated Projects
SO	Secretarial Order
SO_2	sulfur dioxide
SPC	Southern Paiute Consortium
SRP	Salt River Project
SRSG	Southwest Reserve Sharing Group
TCD	temperature control device
TCP	traditional cultural property

TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer
TL	total length
TMF	trout management flow
Tri-State	Tri-State Generation and Transmission Association
TWG	Technical Working Group
UAMPS	Utah Associated Municipal Power Systems
UBWR	Utah Board of Water Resources
UCRC	Upper Colorado River Commission
UMPA	Utah Municipal Power Agency
USC	*United States Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACM	Western Area Colorado-Missouri Region
WALC	Western Area Lower Colorado Region
WAUW	Western Area Upper Great Plains West Region
WECC	Western Electricity Coordinating Council
Western	Western Area Power Administration
YOY	young-of-year
yr	year(s)
ZHHPO	Zuni Heritage and Historic Preservation Office

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1 INTRODUCTION

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation (Reclamation) and National Park Service (NPS) proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam, the largest unit of the Colorado River Storage Project (CRSP). The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, commonly referred to as the Colorado River Ecosystem,[1] including those of importance to American Indian Tribes.

This LTEMP Environmental Impact Statement (EIS) has been prepared to identify the potential environmental effects of implementing the proposed federal action. In addition, this EIS identifies and analyzes the environmental issues and consequences associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. The alternatives addressed in this EIS include a broad range of operations and experimental actions that together allow for a full evaluation of possible impacts of the proposed action. DOI, through Reclamation and NPS, has determined these alternatives represent a reasonable range of options that may meet the purpose, need, and objectives (as described below) of the proposed action. This EIS has been developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), following implementing regulations developed by the President's Council on Environmental Quality (CEQ) in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46.

Reclamation and NPS are joint-lead agencies for the LTEMP EIS because of their roles in operating Glen Canyon Dam (Reclamation's role) and managing the resources of Glen Canyon National Recreation Area (GCNRA), Grand Canyon National Park (GCNP), and Lake Mead National Recreation Area (LMNRA) (NPS's role). As joint leads, both agencies have been equally involved in the development of all aspects of the LTEMP EIS. Major phases of LTEMP EIS development included (1) public and internal scoping, (2) identification of alternatives to be considered for evaluation and their characteristics, (3) identification of elements common to all alternatives, (4) analysis of the consequences of the alternatives, (5) government-to-government consultation with traditionally associated Tribes, (6) preparation and issuance of the Draft EIS (DEIS), (7) public review of the DEIS, and (8) issuance of this Final EIS.

[1] The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources (see Appendix A).

The first EIS on the operation of Glen Canyon Dam was published in 1995 (Reclamation 1995). The 1996 Record of Decision (ROD) (Reclamation 1996) selected the Modified Low Fluctuating Flow Alternative as the preferred means of operating Glen Canyon Dam. The ROD incorporated the GCPA requirement that the Secretary of the Interior (hereafter referred to as the Secretary) undertake research and monitoring to determine if revised dam operations were achieving the resource protection objectives of the final EIS and the ROD. The ROD also led to the establishment of the Glen Canyon Dam Adaptive Management Program (GCDAMP), administered by Reclamation with technical expertise provided by the U.S. Geological Survey's (USGS's) Grand Canyon Monitoring and Research Center (GCMRC).

The following passages were included in the 1995 EIS for the purposes of providing background and context to the public. This section provides relevant content and context for this LTEMP EIS and is therefore reproduced here for public information:

> The underlying project purpose(s) is defined by section 1 of the Colorado River Storage Project Act of 1956 (43 United States Code (U.S.C.) 620), which authorized the Secretary to "construct, operate, and maintain" Glen Canyon Dam:
>
> "...for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes..."
>
> In 1968, Congress enacted the Colorado River Basin Project Act (43 U.S.C. 1501 et seq.). This act provided for a program for further comprehensive development of Colorado River Basin water resources. Section 1501(a) states:
>
> "This program is declared to be for the purposes, among others, of regulating the flow of the Colorado River; controlling flood; improving navigation; providing for the storage and delivery of waters of the Colorado River for reclamation of lands, including supplemental water supplies, and for municipal, industrial, and other beneficial purposes; improving water quality; providing for basic public outdoor recreation facilities; improving conditions for fish and wildlife, and the generation and sale of electrical power as an incident of the foregoing purposes."
>
> In addition, the Criteria for Coordinated Long Range Operation of Colorado River Reservoirs (including Glen Canyon Dam) were mandated by section 1552 of the Colorado River Basin Project Act. Article 1.(2) of these criteria requires that the Annual Operating Plan for Colorado River reservoirs:
>
> "...shall reflect appropriate consideration of the uses of the reservoirs for all purposes, including flood control, river regulation, beneficial consumptive uses,

power production, water quality control, recreation, enhancement of fish and wildlife, and other environmental factors."

The Colorado River Compact (1922) and the Upper Colorado River Basin Compact (1948) do not affect obligations to Native American interests. Article VII and Article XIX, Part A, respectively, of the 1922 and 1948 compacts provide that:

"Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian Tribes."

The Colorado River Storage Project Act of 1956, the Colorado River Basin Project Act of 1968, and the associated Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (Long-Range Operating Criteria) did not alter these compact provisions.

In addition to the Secretary's decision calling for a reevaluation, Congress subsequently enacted the Grand Canyon Protection Act of 1992. Section 1802 (a) of the act requires the Secretary to operate Glen Canyon Dam:

"... in accordance with the additional criteria and operating plans specified in section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreational Area were established, including, but not limited to natural and cultural resources and visitor use."

Section 1802(b) of the act further requires that the above mandate be implemented in a manner fully consistent with existing law[2]. Section 1802(c) states that the purposes for which Grand Canyon National Park and Glen Canyon National Recreation Area were established are unchanged by the act. Section 1804 (a) of the act requires the Secretary to complete an EIS no later than October 30, 1994, following which, under section 1804 (c), the Secretary is to 'exercise other authorities under existing law, so as to ensure that Glen Canyon Dam is operated in a manner consistent with section 1802.' Section 1804 (c) also requires that the criteria and operating plans are to be 'separate from and in addition to those specified in section 602 (b) of the Colorado River Basin Project Act of 1968.'

Glen Canyon Dam was completed by the Bureau of Reclamation (Reclamation) in 1963, prior to enactment of the National Environmental Policy Act of 1969 (NEPA). Consequently, no EIS was filed regarding the construction or operation

2 The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968, that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

of Glen Canyon Dam. Since the dam has long been completed, alternatives to the dam itself have been excluded from the scope of the analysis.

The DOI has evaluated information developed through the GCDAMP to more fully inform decisions regarding operation of Glen Canyon Dam over the next 20 years and to inform other management and experimental actions within the LTEMP. Revised dam operations and other actions will be considered and analyzed under alternatives in this EIS.

The LTEMP will incorporate information gathered since the 1996 ROD, including status reports developed in coordination with the GCDAMP and Reclamation and NPS compliance documents supporting adaptive management efforts for the Glen Canyon Dam. These include, but are not limited to, the *Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam* (Reclamation 2011a), *Environmental Assessment for an Experimental Protocol for High-Flow Releases from Glen Canyon Dam* (Reclamation 2011b), Colorado River Management Plan (CRMP) (NPS 2006b), *EIS for 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Reclamation 2007a), and the *Comprehensive Fisheries Management Plan* (CFMP) (NPS 2013e).

A previous planning process, called the Long Term Experimental Plan (LTEP) for the operation of Glen Canyon Dam, commenced in late 2006. In February 2008, the LTEP EIS was put on hold until the completion of environmental compliance on a 5-year plan of experimental flows (2008–2012), including a high-flow test completed in March 2008 and yearly fall steady flows conducted each year in September and October from 2008 to 2012. As stated in the Notice of Intent (NOI) in the *Federal Register* on July 6, 2011 (DOI 2011b), the LTEMP EIS supersedes the LTEP EIS. This LTEMP EIS draws on the environmental documentation and updated information developed for the LTEP EIS.

1.1 DESCRIPTION OF THE PROPOSED ACTION

The proposed federal action considered in this EIS, as described in the 2011 NOI and as further refined in this EIS, is the development and implementation of a structured, long-term experimental and management plan for operations of Glen Canyon Dam. The LTEMP and the Secretary's decision would provide a framework for adaptively managing Glen Canyon Dam operations and other management and experimental actions over the next 20 years consistent with the GCPA and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations (including hourly, daily, and monthly release patterns), non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements, maintain or improve hydropower production to the greatest extent practicable, consistent with improvement of downstream resources, including those of importance to American Indian Tribes. The locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and adjacent lands are shown in Figure 1-1. Glen Canyon Dam is shown in Figure 1-2.

This LTEMP EIS analyzes alternative-specific monthly, daily, and hourly releases from Glen Canyon Dam. Under the LTEMP, water will continue to be released in a manner that is

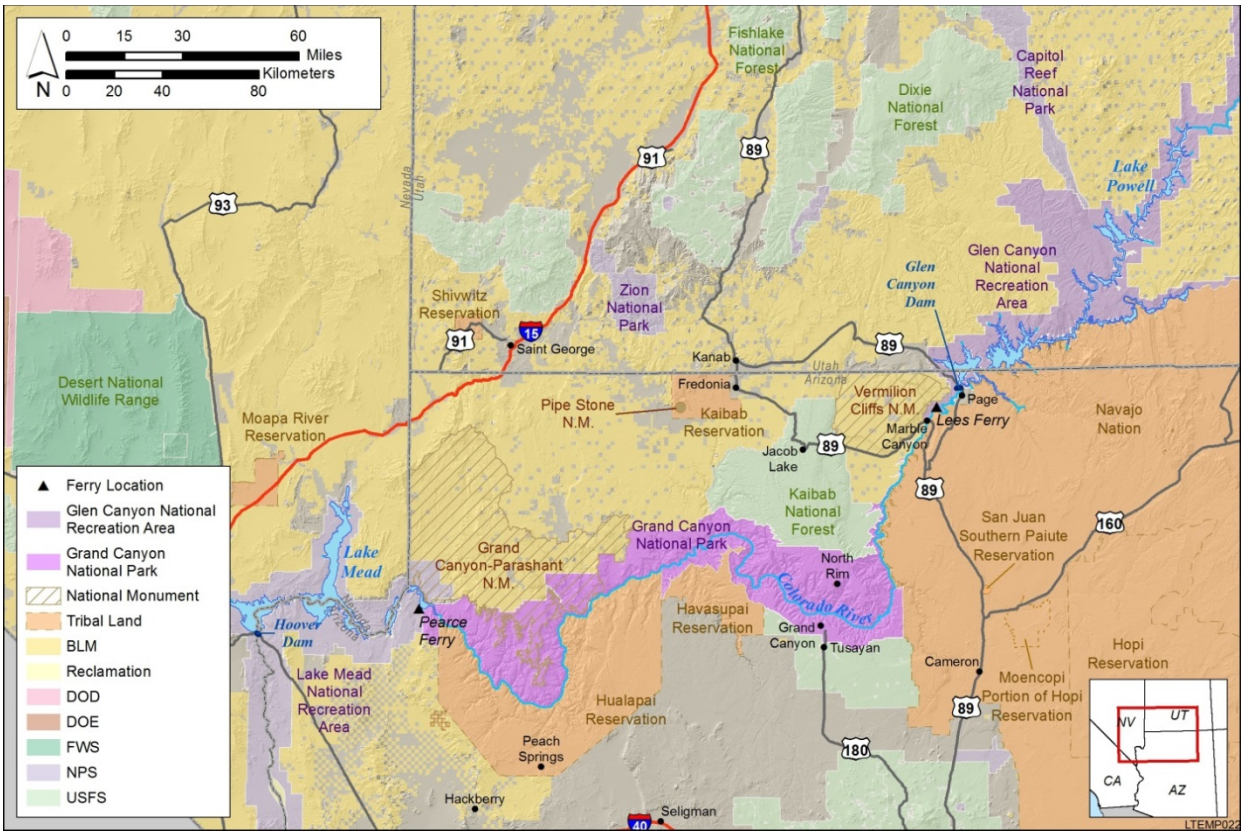

FIGURE 1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource and is addressed in Chapters 3 and 4.)

fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 (CRSPA) and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria for (LROC) Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

1.2 PURPOSE OF AND NEED FOR ACTION

The purpose of the proposed action is to provide a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with the GCPA and other provisions of applicable federal law.



FIGURE 1-2 Glen Canyon Dam

The proposed action will help determine specific dam operations and actions that could be implemented to improve conditions and continue to meet the GCPA's requirements and to minimize—consistent with law—adverse impacts on the downstream natural, recreational, and cultural resources in the two park units, including resources of importance to American Indian Tribes.

The need for the proposed action stems from the need to use scientific information developed since the 1996 ROD to better inform DOI decisions on dam operations and other management and experimental actions so that the Secretary may continue to meet statutory responsibilities for protecting downstream resources for future generations, conserving species listed under the Endangered Species Act (ESA), avoiding or mitigating impacts on *National Register of Historic Places* (NRHP)-eligible properties, and protecting the interests of American Indian Tribes, while meeting obligations for water delivery and the generation of hydroelectric power.

The purpose and need statement described above was modified from the July 6, 2011, *Federal Register* notice based on public and Cooperating Agency comments. The ESA Recovery Implementation Program was removed from the objectives in Section 1.4 and eliminated from further consideration for this EIS, as described in Section 2.2; other refinements to the purpose and need statement were not substantively different from those described in the original notice.

Several key issues related to resources downstream of Glen Canyon Dam, and new scientific information related to them, are summarized below:

- *Continued loss of sandbars*. The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and many types of ongoing dam releases further deplete sediment delivered to the main channel by causing erosion. However, high-flow releases, between approximately 30,000 and 45,000 cubic feet per second (cfs) that are triggered when there is sufficient sediment from the Paria River, mobilize sand stored in the river channel and redeposit it as sandbars and beaches and associated backwater and riparian habitats (Melis 2011). This LTEMP EIS uses current comprehensive scientific data and modeling to consider possible improvements related to the use of high-flow experiments (HFEs), as well as possible intervening flow operations that may help better achieve the goal of building and retaining sandbars.

- *Humpback chub.* Since the 1995 EIS, the status of the humpback chub (*Gila cypha*), listed as an endangered species, has continued to be an issue of concern since the population in Grand Canyon, the largest in existence, declined during the late 1990s, coincident with higher flow volumes, cooler water temperatures, and high nonnative trout abundance, but has since partially rebounded over the last decade when water temperatures were warmer and trout abundance lower (Yackulic et al. 2014; Yard et al. 2011). Uncertainty in future humpback chub population response to interactions among flows, nonnative trout, food base, and water temperatures remains. This EIS explicitly examines the scientific uncertainties related to the relationships among trout, temperature, and the humpback chub population and considers both flow (e.g., trout management flows) and non-flow options (e.g., mechanical removal) and adaptive and experimental actions to improve the status of humpback chub.

- *Rainbow trout fishery*. Rainbow trout (*Oncorhynchus mykiss*) are the basis of the recreational fishery at Lees Ferry. Since 1964, the tailwaters of Glen Canyon Dam have supported a recreational rainbow trout fishery that has grown in importance and reputation to anglers locally, nationally, and internationally. Anglers from around the world travel to Lees Ferry to fish for high-quality rainbow trout. This blue-ribbon recreational sport fishery has become a financial and economic mainstay for the community of Marble Canyon, the City of Page, and Coconino County, as well as contributing to the statewide economy. This EIS evaluates the effects of flow and non-flow actions of LTEMP alternatives and adapative and experimental actions on the Glen Canyon rainbow trout fishery.

- *Other native and nonnative fish*. In addition to humpback chub, the razorback sucker (*Xyrauchen texanus*), also listed as endangered, and three other native fish still occur in the Colorado River below Glen Canyon Dam. Razorback

sucker were thought to be extirpated from the Grand Canyon but have recently been found in western Grand Canyon. Populations of bluehead and flannelmouth suckers have fluctuated since the 1995 EIS. Numerous nonnative fish species are also found in the Colorado River and tributaries, and are numerically dominated by rainbow trout above the Little Colorado River. Brown trout (*Salmo trutta*), channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*), and other species occur in many locations in lower numbers. There is concern that the nonnative fish compete with or prey upon the native or endangered fish to varying degrees. The effects of dam operations were examined in the 1995 EIS, and much additional information has been accumulated about the effects of dam operations on native and nonnative fish. This EIS applies the best available science and modeling methods to further consider the impacts of a variety of dam operations and non-flow actions on native and nonnative fish and guide future experimentation regarding these flow regimes to reduce the negative interactions of nonnative fish with native fish.

- *Cultural resources*. Cultural resources occur along the river corridor downstream from Glen Canyon Dam in Glen, Marble, and Grand Canyons. In this EIS, cultural and natural resources are treated separately; however, it is recognized that many Tribes view these resources as being interconnected and view the river system as an integral component of the cultural landscape. These resources are found both within the area directly affected by river flows as well as on elevated terraces that have not been inundated by flows since construction of the dam. Research conducted since the 1995 EIS on the relationship between sand deposits and wind processes continues to provide data that suggest that windblown sand changes the surface of some sites of archaeological and cultural concern where sand supply and wind are active agents (Draut and Rubin 2008; Draut 2012b; Sankey and Draut 2014). Additional research downstream from the dam is examining the relationship between dam operations and ongoing erosion in areas of limited sand supply (Collins et al. 2014). This LTEMP EIS reexamines these relationships in light of the most recent scientific studies.

- *Riparian vegetation*. Vegetation along the river corridor is affected by the magnitude and seasonal pattern of river flows. Vegetation studies conducted since 1995 indicate that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. This EIS considers approaches to protecting, mitigating adverse impacts on, and improving vegetation within the Colorado River Ecosystem.

- *Hydropower.* Power generated by Glen Canyon Dam serves 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. Since 1995, new modeling tools have been created to better analyze dam operations for hydropower and the impacts of altering operations on electrical generation and capacity. This LTEMP EIS applies peer-reviewed

science and modeling methods to further consider the impacts of a variety of dam operations on power generation and capacity, and considers operations that can maintain or increase hydropower generation while protecting and improving downstream resources. The status of the Basin Fund would be considered prior to implementing experiments as explained in Section 2.2.4.3.

Additional concerns related to dam operations were raised by the public at scoping meetings and in comments submitted during the scoping of the EIS. Such concerns included restoration of the downstream Colorado River Ecosystem; reestablishment of ecosystem patterns and processes to their pre-dam range of natural variability; elimination or minimization of further beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the integrity of cultural and archeological resources; elimination of adverse impacts and other direct, indirect, and cumulative impacts on native species and assistance in their recovery; nonnative fish management; assistance in repropagation of the native riparian plant communities; and improving the hydropower resource. Public scoping is discussed further in Section 1.5.

1.3 LEAD AND COOPERATING AGENCIES AND CONSULTING TRIBES

Federal agencies having management objectives include Reclamation, NPS, U.S. Fish and Wildlife Service (FWS), Bureau of Indian Affairs (BIA), and Western Area Power Administration (WAPA).

1.3.1 Lead Agencies

The DOI, through Reclamation and NPS, prepared this LTEMP EIS with assistance from Argonne National Laboratory (Argonne). Reclamation is primarily responsible for operating Glen Canyon Dam. NPS is primarily responsible for conservation of the natural and cultural resources and visitor experience in GCNP, GCNRA, and LMNRA. Reclamation and NPS are joint-lead agencies in this process and have cooperated on all aspects of the production of this LTEMP EIS, including the overall NEPA/EIS process, communication and consultation with Cooperating Agencies and other stakeholders, and project schedule.

1.3.2 Cooperating Agencies and Consulting Tribes

Reclamation and NPS initially invited 25 federal, Tribal, state, and local government agencies to participate as Cooperating Agencies. Regular meetings with Cooperating Agencies have been held during the LTEMP EIS development process.

In addition, 43 Tribes were formally invited to enter into government-to-government consultation. In accordance with the requirements identified in Executive Order (E.O.) 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000); the President's memorandum of April 29, 1994, "Government-to-Government Relations with Native American Tribal Governments" (U.S. President 1994a); "Department of the Interior Policy on

Consultation with Indian Tribes;" the President's memorandum of November 5, 2009, "Tribal Consultation" (U.S. President 2009); agency-specific guidance on Tribal interactions; and applicable natural and cultural resource laws and regulations (e.g., NEPA, ESA, National Historic Preservation Act [NHPA], and Migratory Bird Treaty Act); Reclamation and NPS coordinate and consult with federally recognized Tribes whose interests might be affected by activities being considered in the LTEMP EIS. Regular meetings have been held with Tribes who indicated an interest in consultation in the LTEMP EIS development process.

The Cooperating Agencies include BIA, FWS, WAPA, Arizona Game and Fish Department (AZGFD), Colorado River Board of California, Colorado River Commission of Nevada, Upper Colorado River Commission, Salt River Project, Utah Associated Municipal Power Systems, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni. Two additional Tribes—the Fort Mojave Indian Tribe and the Gila River Indian Community—accepted the invitation to participate as consulting parties. Nine others—the Pueblo of Santa Ana, the Fort Yuma Quechan, the Pueblo of Nambe, the Pueblo of Santa Clara, the Pueblo of Zia, the Southern Ute Indian Tribe, the Ute Mountain Ute Indian Tribe, the Paiute Indian Tribe of Utah, and Yavapai-Apache Nation—preferred to be on the mailing list and kept informed regarding the LTEMP EIS.

1.4 OBJECTIVES AND RESOURCE GOALS OF THE LTEMP

The DOI has identified several primary objectives of operating Glen Canyon Dam under the LTEMP, as well as more specific goals to improve resources within the Colorado River Ecosystem through experimental and management actions. These objectives and resource goals were considered in the formulation and development of alternatives in this EIS.

The following is a list of the objectives of the LTEMP:

- Develop an operating plan for Glen Canyon Dam in accordance with the GCPA to protect, mitigate adverse impacts to, and improve the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and to do so in such a manner as is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the U.S. Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern the allocation, appropriation, development, and exportation of the waters of the Colorado River Basin (see Section 1.9.4) and in conformance with the Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs which are currently implemented by the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Ensure the LTEMP does not affect water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made

pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Consider potential future modifications to Glen Canyon Dam operations and other flow and non-flow actions to protect and improve downstream resources.

- Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

- Respect the interests and perspectives of American Indian Tribes.

- Make use of the latest relevant scientific studies, especially those conducted since 1996.

- Determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process.

- Ensure Glen Canyon Dam operations and non-flow actions under the LTEMP are consistent with the GCPA, ESA, NHPA, CRSPA, and other applicable federal laws.

Reclamation and NPS developed resource goals considering public input and desired future conditions (DFCs) previously adopted by the Adaptive Management Work Group (AMWG). The following resource goals were identified:

1. *Archaeological and Cultural Resources*. Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

2. *Natural Processes*. Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

3. *Humpback Chub*. Meet humpback chub recovery goals, including maintaining a self-sustaining population, spawning habitat, and aggregations in the Colorado River and its tributaries below the Glen Canyon Dam.

4. *Hydropower and Energy*. Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and

minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

5. *Other Native Fish*. Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

6. *Recreational Experience*. Maintain and improve the quality of recreational experiences for the users of the Colorado River Ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

7. *Sediment*. Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

8. *Tribal Resources*. Maintain the diverse values and resources of traditionally associated Tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons.

9. *Rainbow Trout Fishery*. Achieve a healthy high-quality recreational rainbow trout fishery in GCNRA and reduce or eliminate downstream trout migration consistent with NPS fish management and ESA compliance.

10. *Nonnative Invasive Species*. Minimize or reduce the presence and expansion of aquatic nonnative invasive species.

11. *Riparian Vegetation*. Maintain native vegetation and wildlife habitat, in various stages of maturity, such that they are diverse, healthy, productive, self-sustaining, and ecologically appropriate.

Overlying these goals is the understanding that operations under LTEMP will continue to deliver water in a manner that is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of CRSPA and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin, and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. As such, water delivery is an overarching consideration for dam operations that will necessarily inform the actions that can be taken to achieve the resource goals set forth above.

1.5 SCOPE OF THE EIS

On December 10, 2009, then Secretary of the Interior Ken Salazar announced the need to develop the LTEMP for Glen Canyon Dam. The Secretary emphasized the inclusion of stakeholders, particularly those in the GCDAMP, in the development of the LTEMP. This decision triggered the NEPA process and the need to conduct public scoping in preparation of this LTEMP EIS.

The *Federal Register* NOI to prepare an EIS and hold public scoping meetings was published on July 6, 2011, which marked the beginning of the public comment period. The scoping comment period ended January 31, 2012. A total of six public meetings and one web-based meeting were held in Arizona, Colorado, Nevada, and Utah in November 2011. A total of 447 individuals, groups, or organizations submitted scoping comments. Results of the public scoping process are described in the Scoping Summary Report (Reclamation and NPS 2012). There have also been formal and informal consultations with Tribes, which are described in Chapter 5.

The affected geographic region and resources of interest and the primary issues of concern to the public identified in scoping are summarized in the following sections. These inputs were used by the lead agencies to formulate a suite of alternative actions that could meet the purpose and need of the proposed action and to guide the comparative analysis of impacts of the alternatives in this EIS. The alternatives are described in Chapter 2.

The annual amount of water released under the LTEMP will be determined by the LROC, which is currently implemented through the 2007 Interim Guidelines until 2026; the guidelines for determining annual releases after that date will be determined under a separate process pursuant to the terms of the 2007 Guidelines. The LTEMP EIS assumes the annual volumes would be determined in accordance with the LROC and evaluates the effects on resources from the management of monthly, hourly, and daily releases from Glen Canyon Dam under various alternatives.

1.5.1 Affected Region and Resources

In general, the region examined in this EIS includes the area potentially affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead. More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. Portions of GCNRA, GCNP, and LMNRA outside the Colorado River Ecosystem were also included in the affected region for certain resources due to the potential effects of LTEMP operations. In addition, for resources such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP. The

potentially affected regions for these resources are specifically identified in Chapters 3 and 4. Figure 1-1 portrays the project area in context with the geographic regions of northern Arizona, southwestern Utah, and southern Nevada.

1.5.2 Impact Topics Selected for Detailed Analysis

Topics for analysis in the EIS were selected on the basis of public scoping comments, joint-lead agency guidance, meetings with Tribes and stakeholders, and relevant laws and regulations. A complete list of issues raised and discussed during scoping is available in the Scoping Summary Report (Reclamation and NPS 2012). Direct, indirect, and cumulative impacts of the effects of the proposed action, in combination with the effects of past, present, and reasonably foreseeable future projects, were analyzed in the LTEMP EIS for the following impact topics:

- Water resources, including annual, monthly, and hourly patterns of releases, water temperature, and water quality;
- Sediment resources, including sand and sandbars within the active river channel, and sand that accumulates in the Colorado River delta of Lake Mead;
- Natural processes that support ecological systems within the Colorado River Ecosystem;
- Aquatic ecology, including aquatic food base for fishes, nonnative fishes (warmwater, coolwater, and trout), native fishes (including the endangered humpback chub and razorback sucker), and aquatic parasites;
- Vegetation, including Old High Water Zone vegetation, New High Water Zone vegetation, wetlands, and special status plant species;
- Wildlife, including terrestrial invertebrates, amphibians and reptiles, birds, mammals, and special status wildlife species;
- Cultural resources, including archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, and ethnographic resources important to American Indian Tribes;
- Tribal resources, including vegetation, wildlife, fish, and wetlands, water rights, traditional cultural places, traditional knowledge, and continued access to important resources within Glen and Grand Canyons;
- Visual resources in GCNRA, GCNP, and LMNRA;
- Recreation, visitor use, and experience as related to fishing, boating, and camping activities in the Colorado River and on Lakes Powell and Mead;

- Wilderness and visitor wilderness experience;

- Hydropower, including the amount and value of hydropower generation at Glen Canyon Dam, marketable electrical capacity, capital and operating costs, and rate impacts;

- Socioeconomics, including recreational use values, nonuse economic value, employment and income, and environmental justice;

- Air quality effects related to changes in Glen Canyon Dam operations, including air emissions; and

- Climate change, including the effects of Glen Canyon operations on greenhouse gas emissions and the effects of climate change on future impacts of Glen Canyon Dam operations.

1.5.3 Impact Topics Dismissed from Detailed Analysis

The following topics suggested during scoping were dismissed from analysis in the LTEMP EIS for the reasons stated below:

- *Extirpated Species*. The reintroduction of extirpated species is beyond the scope of the LTEMP EIS, but was addressed for fish within the NPS Comprehensive Fisheries Management Plan (NPS 2013e).

- *Prime and Unique Agricultural Lands*. The Farmland Protection Act of 1981, as amended, requires federal agencies to consider adverse effects on prime and unique farmlands resulting in conversion of these lands to nonagricultural uses. There are no agricultural lands in GCNP or GCNRA, and proposed alternatives would not have direct or indirect effects on downstream agricultural lands. Therefore, this topic is dismissed from further analysis.

- *Land Use in GCNP and GCNRA*. Land use and development of visitor and park facilities in GCNP and GCNRA are managed under the NPS Organic Act, NPS 2006 Management Policies (NPS 2006a) and associated Directors' Orders, GCNP and GCNRA enabling legislation, the Wilderness Act, and other such policies and regulations. None of the proposed alternatives would fundamentally affect land use in the project area. Therefore, this topic is dismissed from further consideration.

- *Soundscapes*. For the LTEMP EIS, soundscapes are not addressed as an individual resource; however, effects of man-made noise are discussed under the following impact topics: Wildlife (Section 4.7); Recreation, Visitor Use, and Experience (Section 4.11); and Wilderness (Section 4.12). Impacts on soundscape are expected to be negligible on the small number of days when

noise-producing fish management and vegetation restoration activities take place.

1.6 ROLE OF ADAPTIVE MANAGEMENT

Since the 1996 ROD was signed by the Secretary, adaptive management has played a significant role in the operations of the Glen Canyon Dam and management of the resources downstream. The DOI is committed to continuing the Adaptive Management Program and Adaptive Management Work Group. The DOI promotes the use of adaptive management as a tool for resource management (DOI 2008) and has adopted the following definition put forth by the National Research Council's Panel on Adaptive Management for Resource Stewardship (NRC 2004):

> Adaptive Management is a decision process that promotes flexible decision making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become better understood. Careful monitoring of these outcomes both advances scientific understanding and helps adjust policies or operations as part of an iterative learning process. Adaptive management also recognizes the importance of natural variability in contributing to ecological resilience and productivity. It is not a 'trial and error' process, but rather emphasizes learning while doing. Adaptive management does not represent an end in itself, but rather a means to more effective decisions and enhanced benefits. Its true measure is in how well it helps meet environmental, social, and economic goals; increases scientific knowledge; and reduces tensions among stakeholders.

In addition, the DOI (Williams et al. 2009) published a technical guide describing how and in what situations one can implement adaptive management.

1.6.1 History of the Existing Adaptive Management Program

The 1996 ROD specified several environmental commitments, the first of which was adaptive management. The GCDAMP was established to comply with the monitoring and consultation requirements of the GCPA. The components of the GCDAMP were first proposed in the 1995 Glen Canyon Dam EIS, and it was established in 1997 under the direction of the Secretary of the Interior.

The GCDAMP creates a process for monitoring and assessing the effects of current operations of Glen Canyon Dam on downstream resources and using the results to develop recommendations for modifying operating criteria and other resource management actions. The GCDAMP includes the AMWG, a federal advisory committee that is appointed by the Secretary. The AMWG consists of stakeholders, including federal and state resource management agencies; representatives of the seven basin states; American Indian Tribes; contractors for the purchase of federal hydroelectric power; environmental and conservation organizations; recreational; and

other interest groups. The AMWG recommends suitable monitoring and research programs and may make other recommendations to the Secretary as well. The Technical Working Group (TWG) was also proposed in the 1995 EIS and was established to serve as a technical subcommittee to the AMWG. The GCMRC serves as the research branch of the GCDAMP, under the authority of the USGS. Monitoring and research conducted by GCMRC and others since 1996 have improved the understanding of riverine geomorphology and how dam operations can assist in the conservation of natural and cultural resources below the dam. The GCDAMP also includes an external and independent scientific review panel, the science advisors, who serve to peer review research and monitoring programs of the GCDAMP.

1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations

The 1995 EIS (Reclamation 1995) described adaptive management as the process "whereby the effects of dam operations on downstream resources would be assessed and the results of those resource assessments would form the basis for future modifications of dam operations." In describing the commitment to adaptive management in the 1996 ROD (Reclamation 1996), the Secretary specified that "any operational changes will be carried out in compliance with NEPA." In the 2011 NOI (DOI 2011b) that announced the LTEMP process, the DOI specified that a NEPA process would be used to document and evaluate impacts of the alternatives. By articulating and planning for critical uncertainties (Sections 1.7 and 2.1, and Appendix C) upfront, the LTEMP EIS puts forth an adaptive management plan for the next 20 years that is flexible and allows the experimental, operational, and management changes specified and analyzed in the LTEMP to proceed without additional NEPA analysis.

The LTEMP uses an adaptive management and experimental framework to refine existing information regarding the effects of dam operations and management actions on affected resources. Information gathered through the adaptive management and experimental process may be used to adjust operations within the range of the actions analyzed for impacts in this EIS.

1.7 ROLE OF DECISION ANALYSIS IN THE EIS PROCESS

The joint lead agencies used a structured decision analysis process to support the evaluation of alternatives in response to requests from some of the Glen Canyon Dam AMWG stakeholders to have additional substantive input into the EIS. The joint leads view structured decision analysis as a structured, scientific method to help evaluate complex alternatives; integrate information and critical uncertainties regarding the effects of independent environmental processes and resource response on outcomes; and bring additional transparency to the EIS process.

While structured decision analysis informed the analysis of the joint leads, it was not the only method by which a preferred alternative was identified. The identification of a preferred alternative was based on the full EIS analysis and considerations relating to qualitative and quantitative evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were also considered in this identification.

The joint-lead agencies partnered with the USGS Patuxent Wildlife Research Center to incorporate formal decision-analysis tools in the LTEMP EIS. Decision-analysis tools are used to help formally parse out complex problems into manageable pieces, while keeping track of multiple objectives (Gregory and Keeney 2002). Appendix C further describes the decision-analysis tools and methodology as related to the LTEMP EIS.

The joint-lead agencies, other DOI agencies, including the BIA, FWS, and USGS, and Argonne technical staff developed performance metrics to evaluate achievement of the resource goals, identified critical uncertainties, and evaluated a preliminary and final set of alternatives in a process that incorporated decision-analysis tools. Performance metrics provide a quantitative, transparent, and objective method to assess the performance of the alternatives against each of the resource goals. Input from some Cooperating Agencies, Tribes, and other stakeholders was used to prepare a final set of performance metrics used in the LTEMP EIS analysis. Six of the seven Basin States and some of the Tribes and other stakeholders elected not to participate in this process for various reasons. The resulting performance metrics are presented in Appendix B.

Participating stakeholders ranked and weighted the importance of each performance metric according to their preferences for the value of the metric to swing from its lowest to its highest value, representing the range of effects on resources measured by the metric. This process is referred to as "swing-weighting." The results of swing weighting under structured decision analysis are included in the analysis of alternatives in Chapter 4 and are discussed in further detail in Appendix C.

While the decision analysis process helped inform the analysis of the joint-lead agencies, it was not used as the method by which a preferred alternative was identified or the only method by which the environmental impacts were fully analyzed. The determination of the preferred alternative was based on the analyses presented in this EIS. Furthermore, public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were considered in the preparation of this EIS.

1.8 HISTORY, LOCATION, AND SETTING

1.8.1 History and Purpose of Glen Canyon Dam

Glen Canyon Dam, pictured in Figure 1-2, was authorized by CRSPA and completed by Reclamation in 1963 (DOI 2011b). Glen Canyon Dam is the second highest concrete-arch dam in the United States (exceeded only by the Hoover Dam) and rises 710 ft above bedrock within the steep sandstone walls of Glen Canyon. It was constructed to harness the potential of the Colorado River to provide for the water and power needs of millions of people (Reclamation 2008a).

The CRSPA was enacted for "the comprehensive development of the water resources of the Upper Colorado River Basin, for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of

the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes." The Glen Canyon Dam is specifically managed to regulate the release of water in a way that allows the Upper Colorado River Basin states of Utah, Colorado, Wyoming, and New Mexico to use their share of the Colorado River water. It also helps provide water to the Lower Colorado River Basin states of California, Nevada, and Arizona, consistent with the Colorado River Compact of 1922 and subsequent water delivery commitments (DOI 2011b). There is more than 26 million acre-feet (maf) of water storage capacity in Lake Powell, created by Glen Canyon Dam. This stored water has made it possible to successfully sustain the needs of cities, industries, and agriculture throughout the West during extended dry periods (Reclamation 2008a).

As identified under the CRSPA, another authorized purpose of Glen Canyon Dam is to generate hydroelectric power, which is a clean, renewable, and reliable energy source (DOI 2011b). The hydroelectric power is marketed and delivered by WAPA to municipalities, rural electric cooperatives, American Indian Tribes, and governmental agencies in Wyoming, Utah, Colorado, New Mexico, Arizona, and Nevada. The dam's hydroelectric generators, which have a total capacity of 1,320 megawatts (MW), produce about 5 billion kilowatt-hours (kWh) of hydroelectric power annually to help meet the electrical needs of about 5.8 million customers (Reclamation 2008a). In addition, Glen Canyon Dam serves as a backup facility for power and transmission outages across the Southwest. Revenues from production of hydropower fund the Basin Fund, including the operations and maintenance of CRSP facilities, repay costs for participating projects, and help fund the Salinity Control Forum and many important environmental programs associated with Glen and Grand Canyons (Reclamation 2008a).

1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area

The location of Glen Canyon Dam is shown in the upper right-hand corner of Figure 1-3, which shows the LTEMP affected area from Glen Canyon Dam to Lake Mead. Below Glen Canyon Dam, the Colorado River flows for 15 mi through the GCNRA, which is managed by NPS and encompasses more than 1.2 million acres of land in northern Arizona and southern Utah (DOI 2011b; NPS 2013c).

At about 15 mi downstream from the dam, Lee Ferry, Arizona, marks the end of Glen Canyon and the official division between the upper and lower Colorado River (Reclamation 2008b, 2011b). The confluence of the Paria River represents the beginning of Marble Canyon and the northern boundary of GCNP. For the next 277 mi, the Colorado River flows through the GCNP to Pearce Ferry, which marks the upper reaches of Lake Mead. Lake Mead extends from Pearce Ferry to Hoover Dam.

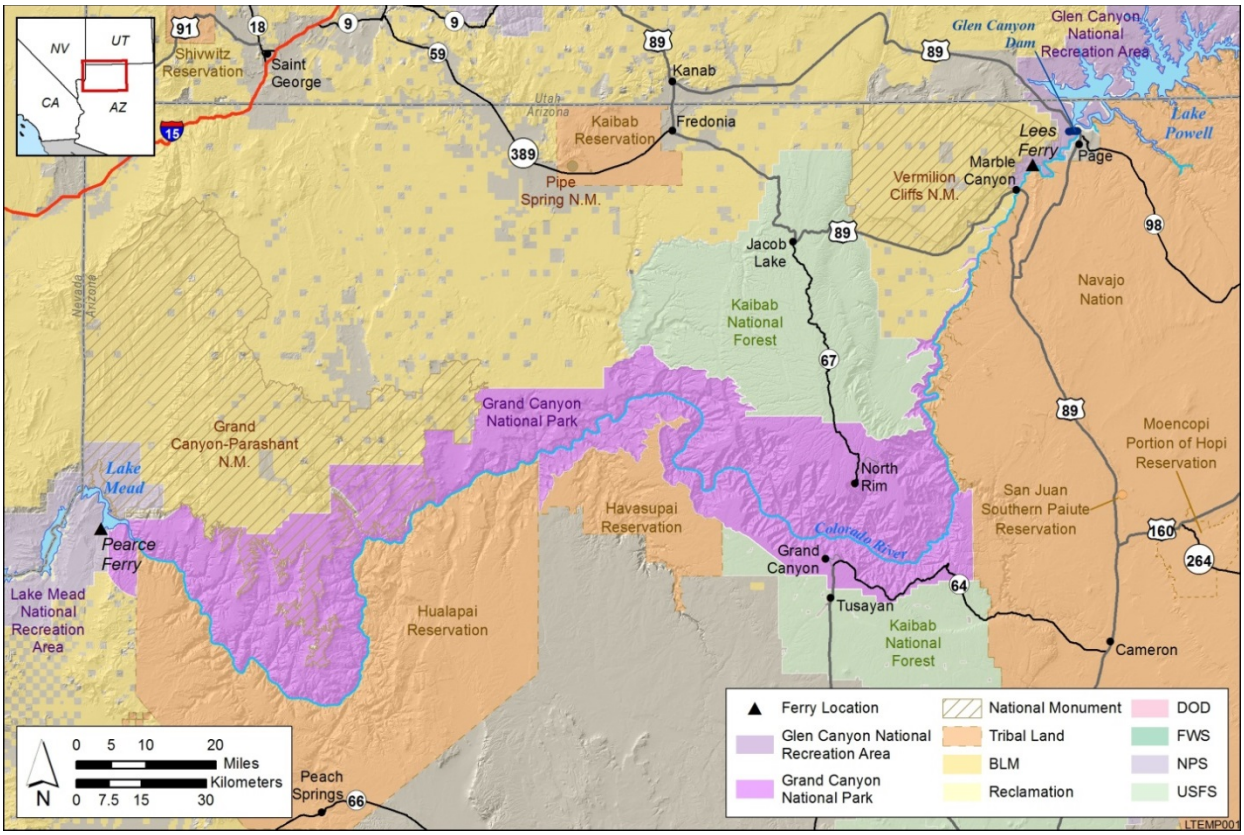

FIGURE 1-3 Map of the Colorado River between Lake Powell and Lake Mead (This map is for illustrative purposes only, not for jurisdictional determinations; potential area of effects varies by resource and is addressed in Chapters 3 and 4.)

The western boundary of the Navajo Indian Reservation lies near the Colorado River from Lake Powell through Glen and Marble Canyons. However, various orders and statutes reserved and withdrew land within one-quarter mile of the Colorado River to the United States for power purposes. The Kaibab Paiute Indian Reservation is on the plateau north of GCNP. The Havasupai Indian Reservation surrounds upper Havasu Creek, immediately south of GCNP. The Hualapai Indian Reservation comprises the southern portion of western Grand Canyon, adjacent to GCNP.

1.8.3 Operation of the Glen Canyon Dam

Glen Canyon Dam currently operates under the Modified Low Fluctuating Flow (MLFF) regime in conjunction with an adaptive management program outlined in the 1996 ROD for the 1995 EIS (Reclamation 1996). Dam releases are made according to the MLFF constraints and are presented in Table 1-1.

TABLE 1-1 Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows (after Reclamation 1995)

Parameter	Value	Conditions
Flow		
Maximum[a]	25,000 cfs	
Minimum	5,000 cfs	7:00 p.m. to 7:00 a.m.
	8,000 cfs	7:00 a.m. to 7:00 p.m.
Ramp Rates		
Ascending	4,000 cfs/hour	
Descending	1,500 cfs/hour	
Daily Flow Range[b]	5,000 to 8,000 cfs	

[a] May be exceeded for emergencies and during extreme hydrological conditions.

[b] Daily flow range limit is 5,000 cfs for months with release volumes less than 0.6 maf; 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf; and 8,000 cfs for monthly volumes over 0.8 maf.

The 1995 EIS analyzed an array of reasonable alternatives "to allow the Secretary to balance competing interests and to meet statutory responsibilities for protecting downstream resources and producing hydropower, and to protect affected Native American interests." The goal of selecting a preferred alternative in the 1996 ROD was "not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability." MLFF was selected as the preferred alternative in that ROD (Reclamation 1996). The 1996 ROD reduced daily flow fluctuations below those of historic release patterns and provided occasional high steady releases of short duration (referred to as Habitat Maintenance Flows or Beach Habitat Building Flows) to protect or enhance downstream resources while allowing limited flexibility for power operations.

Dam operations are affected by a number of physical factors, such as reservoir elevation, annual runoff, and discharge capacity. Operations are also constrained by legal and institutional factors specified in federal laws, interstate compacts, international treaties, and Supreme Court decisions. Criteria and guidelines for annual operations are contained in the LROC and 2007 Interim Guidelines as determined by the Secretary, with participation by the Basin States.

Water can be released from Glen Canyon Dam in three ways—via powerplant, river outlet works, and spillway releases. Powerplant releases are the largest and preferred means of release, as they result in the generation of hydroelectric power. The powerplant houses eight electric generator turbines, which have the capacity to produce a maximum of 1,320 MW of electric power.

The powerplant can release a maximum of about 33,200 cfs of water. Maximum discharges are less when the reservoir is less than full, while MLFF limits maximum flows to 25,000 cfs under normal circumstances.

River outlet works bypass the powerplant, with releases of up to 15,000 cfs, and are almost always combined with powerplant releases, with a maximum operational release capacity of about 48,200 cfs.

Spillway releases are only used to avoid overtopping of the dam or to lower the level of Lake Powell based on emergency and safety constraints. Such releases bypass both the powerplant and the river outlet works. The reservoir elevation at which the spillways could be accessed is 3,700 ft. The combined capacity of the right and left spillways is 208,000 cfs. Spillway releases are avoided whenever possible; the combined release capacity of all three means of release is about 256,000 cfs.

1.8.4 History, Purpose, and Significance of the National Park System Units

The overarching purpose of the National Park System, as set forth in the NPS's Organic Act, "is to conserve the scenery, natural and historic objects, and wild life in the System units and to provide for the enjoyment of the scenery, natural and historic objects, and wild life in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (54 USC § 100101(a)). Each unit of the National Park System is authorized or established by an act of Congress or Presidential proclamation (or sometimes both) to conserve the unit's unique and significant resources. A park's purposes, as described in its enabling legislation or proclamation, are the foundation on which later management decisions are based to conserve resources while providing for the enjoyment of future generations. This mission is further discussed and clarified in *Management Policies 2006* (NPS 2006d). Described below are the park system units relevant to this project: GCNP, GCNRA, and LMNRA.

1.8.4.1 Grand Canyon National Park

GCNP was established as a National Monument in 1908, given National Park status in 1919, and recognized as a World Heritage Site in 1979 (NPS 1995). The park attracts nearly 5 million visitors annually from the United States and around the world. The purpose of the park "is to be managed to preserve and protect its natural and cultural resources and ecological processes, as well as its scenic, aesthetic and scientific values; and provide opportunities for visitors to experience and understand the environmental interrelationships, resources, and values of the Grand Canyon without impairing the resources" (NPS 1995). Specifically, "the purpose of Grand Canyon National Park is to preserve and protect Grand Canyon's unique geologic, paleontologic, and other natural and cultural features for the benefit and enjoyment of the visiting public; provide the public opportunity to experience Grand Canyon's outstanding natural and cultural features, including natural quiet and exceptional scenic vistas; and protect and interpret Grand Canyon's extraordinary scientific and natural values" (NPS 2010a).

The significance of GCNP can be found in the richness of its resources (NPS 2010a):

> Grand Canyon is one of the planet's most iconic geologic landscapes. During the last 6 million yr, the Colorado River carved Grand Canyon; these same erosional and tectonic processes continually shape the canyon today. Grand Canyon's exposed layers span more than one-third of Earth's history, and record tectonic and depositional environments ranging from mountain building to quiet seas. Taken as a whole, Grand Canyon, with its immense size, dramatic and colorful geologic record exposures, and complex geologic history, is one of our most scenic and scientifically valued landscapes.
>
> The force and flow of the Colorado River along with its numerous and remarkably unaltered tributaries, springs, and seeps provide plants and animals an opportunity to flourish in this otherwise arid environment. These vital resources represent transmission of local aquatic recharge from high-elevation rims to the arid inner canyon. There are hundreds of known seeps and springs throughout the park, and probably more to be discovered.
>
> Wilderness landscapes are an important current resource. Park boundaries extend beyond canyon walls to include 1,904 sq. miles (1,218,376 acres) of which 94 percent is managed as wilderness. When combined with additional contiguous public and Tribal lands, this area comprises one of the largest U.S. undeveloped areas. Grand Canyon offers outstanding opportunities for visitor experiences including extended solitude, natural quiet, clean air, dark skies, and a sense of freedom from the mechanized world's rigors.

GCNP is considered one of the finest examples in the world of arid-land erosion (NPS 1995). The park contains several major ecosystems, from the mixed Mohave Desert scrub of the lower canyon to the coniferous forests of the North Rim, and serves as an ecological refuge for relatively undisturbed remnants of dwindling ecosystems (such as boreal forest and desert riparian communities) and numerous rare, endemic, or specially protected (threatened/endangered) plant and animal species, including the California condor (NPS 1995, 2013c). The Grand Canyon protects an important cultural history. More than 12,000 years of human occupation have resulted in an extensive archeological record. The park preserves thousands of archeological sites, many of which remain unknown.

Eleven American Indian Tribes have known ties to the Grand Canyon, and some consider the canyon their original homeland and place of origin. The 11 federally recognized associated Tribes are Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Las Vegas Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian Tribe of Utah, San Juan Southern Paiute Tribe, Yavapai-Apache Nation, and Zuni Tribe.

The scenic vistas, qualities, and values of GCNP are internationally recognized and include a variety of landscapes and water features. The Grand Canyon is also known for its natural quiet and opportunities for solitude. The natural, cultural, and scenic qualities of the

Grand Canyon give rise to inspirational and spiritual values and a sense of timelessness (NPS 1995).

1.8.4.2 Glen Canyon National Recreation Area

The GCNRA was established by Congress in 1972 and occupies approximately 1,255,000 ac of northern Arizona and southeastern Utah adjacent to Lake Powell (NPS 1979). Congress directed NPS to manage the GCNRA so as to provide for public outdoor recreation use and enjoyment of Lake Powell and lands adjacent thereto in the States of Arizona and Utah and to preserve scenic, scientific, and historic features contributing to public enjoyment of the area (Public Law [P.L.] 92-593). In 2012, GCNRA attracted approximately 2 million visitors (NPS 2014f), of which approximately 10,000 utilized the Lees Ferry trout fishery.

The GCNRA ecosystem typifies the Colorado Plateau, supporting habitat for a diverse range of plants and animals. The region is arid to semi-arid, and the ecosystem is complex and often fragile (NPS 1979). Several rare and federally listed plant and animal species within the Colorado River Ecosystem are found in the GCNRA (NPS 2013b) and are addressed in Sections 3.6.3 and 3.7.5.

Glen Canyon has been occupied periodically by humans from about 11,500 years ago through the present (NPS 1979, 2013a). Several different prehistoric cultures and current Native American groups are represented in the cultural history of Glen Canyon, and the recreation area occupies a cultural interface zone, where different groups historically came into contact with one another (NPS 2013a). In the late 1800s, the crossing at Lees Ferry and the Hole-in-the-Rock trail became important points on the migration route of Mormon settlers moving westward (NPS 1979).

1.8.4.3 Lake Mead National Recreation Area

The LMNRA was established on October 8, 1964. Its purpose is to provide diverse public recreation, benefit, and use on Lakes Mead and Mohave and surrounding lands in a manner that preserves the ecological, geological, cultural, historical, scenic, scientific, and wilderness resources of the park. LMNRA includes two reservoirs, Lakes Mead and Mohave, along 140 mi of the former Colorado River from the southern tip of Nevada to the northwest corner of Arizona. It occupies approximately 1,495,800 ac in southeastern Nevada and northwestern Arizona, and is the fourth largest unit of the national park system outside the state of Alaska. Approximately 60% of the park is located in Arizona and 40% is located in Nevada (NPS 2002c).

LMNRA offers dramatic scenery and a diverse array of land- and water-based recreational opportunities in close proximity to several large urban centers of the southwestern United States. With more than 6 million visitors each year, the park supports some of the nation's highest levels of water-based recreational and backcountry use and is an integral component of the region's economy (NPS 2002c).

Situated in the northeastern Mojave Desert near the interface with the Great Basin Desert to the north and the Sonoran Desert to the south, LMNRA preserves a great diversity of biological resources, intact habitat, and ecological connectivity in the region, including many threatened and endangered species and rare natural communities. It showcases a remarkable collection of geological and paleontological features spanning more than 1.7 billion years of earth history (USGS 2014a). The diversity of cultural resources found at LMNRA—both on land and submerged—remains as evidence of a 10,000-year continuum of human history in the region (NPS 2013f). LMNRA also includes vast backcountry and wilderness lands, including nine separate designated wilderness areas that serve to preserve ecological resources and processes and provide exemplary opportunities for primitive recreation and desert solitude (NPS 2002c).

1.8.5 Tribal Lands

Numerous laws and treaties have established Indian reservations within or adjacent to the project area (see Figure 1-4). Traditional territory and traditional use lands extend well beyond

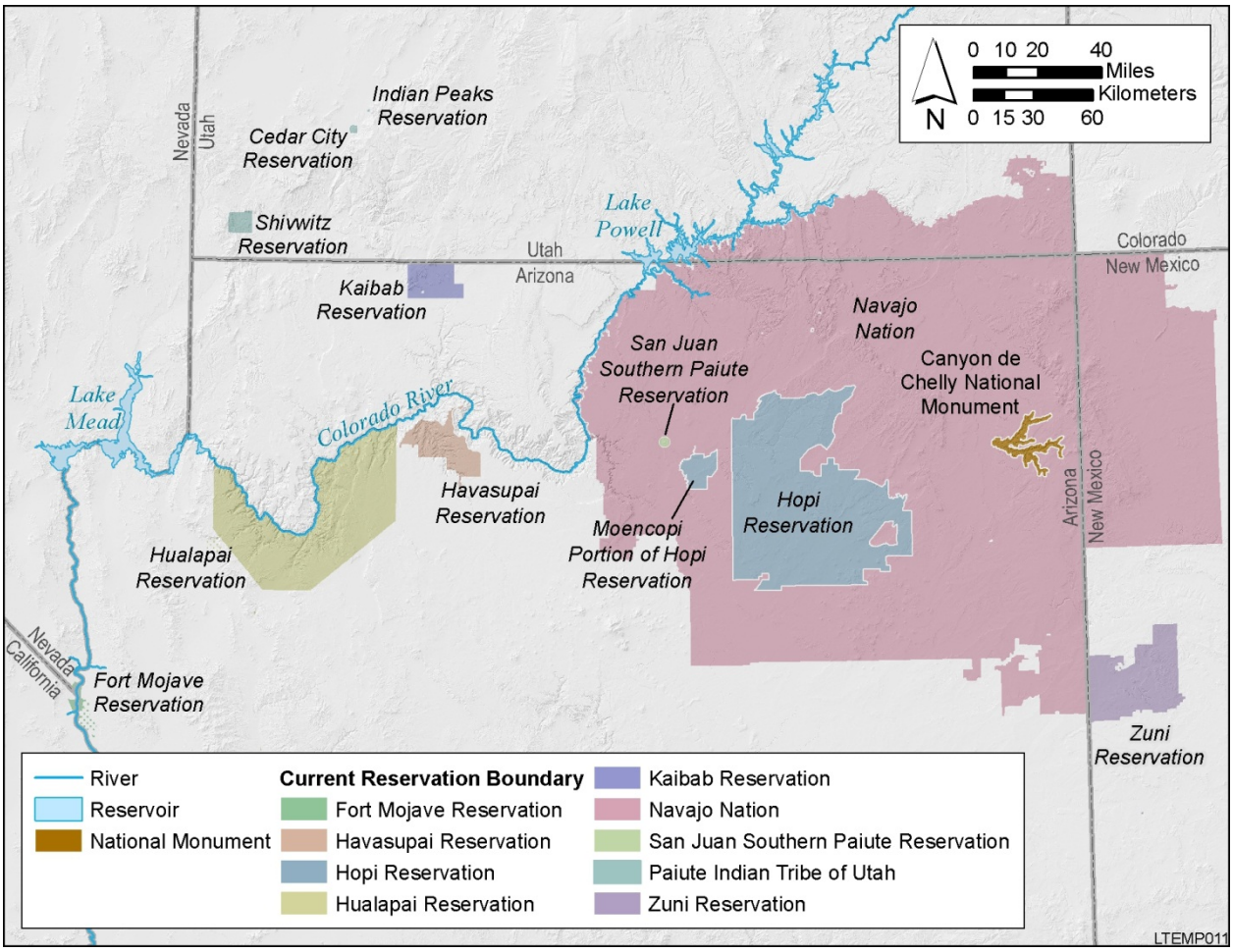

FIGURE 1-4 Indian Reservations within or Adjacent to the LTEMP EIS Project Area

these boundaries. The following sections summarize laws, treaties, and traditional use areas of Tribes with ancestral, spiritual, religious, or economic ties to the project area. These Tribes served as Cooperating Agencies (Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Kaibab Band of Paiute Indians, and Pueblo of Zuni) or a consulting Tribe (Fort Mojave). Tribal connections to resources in and around the Colorado River and the canyons are described in Chapter 3.

1.8.5.1 Fort Mojave Tribe

The Fort Mojave Indian Reservation was established through the Executive Orders of December 1, 1910, and February 2, 1911. The reservation is located along the Colorado River, near Needles, California, and encompasses 42,000 ac covering Mohave County, Arizona; Clark County, Nevada; and San Bernardino County, California (Fort Mojave Indian Tribe 2012).

Traditional Mojave territory encompasses most of the Mojave Desert in the State of California, from the Whipple Mountains, the Turtle Mountains, the Granite Mountains, the Eagle Mountains, the Little San Bernardino Mountains, and the San Bernardino Mountains in the south, west to the San Gabriel and Tehachapi Mountains, north to Granite and Soda Lakes and the Providence Mountains and Paiute Valley in the State of Nevada, to the Black, Buck, and Mojave Mountains to the east in the State of Arizona (CSRI 2002 [U.S. Court of Claims 1950-1960: Docket 283]).

1.8.5.2 Havasupai Tribe

The Havasupai Indian Reservation was established by the Executive Orders of June 8 and November 23, 1880, and March 31, 1882, and expanded by the Act of March 4, 1944 (58 Stat. 110), and the Grand Canyon Enlargement Act (88 Stat. 2089, 1975). In 1975, the Grand Canyon National Park Enlargement Act restored 185,000 ac to the Havasupai Reservation and identified 95,300 ac of traditional use lands within GCNP that were made available for traditional Havasupai practices.

The Havasupai Reservation consists of 188,077 ac of canyon and plateau along the western portion of the Grand Canyon's south rim. Additional traditional use lands are located within GCNP north of the reservation from the plateau to the Colorado River and extend from approximately river mile (RM) 116 to RM 165 (Havasupai 2012).

The Indian Claims Commission determined in 1968 that as of 1880, the Havasupai Tribe exclusively occupied, as their original territory, the land on the Coconino Plateau bounded by the mid-stream of the Colorado River on the north, the Hualapai Reservation on the west, south to the Trinity Mountain, Mount Floyd and easterly to Sitgreaves Mountain, north to Mount Kendricks and along the Little Colorado River on the east to the Colorado River.

The Grand Canyon Enlargement Act of 1975 replaced a portion of the Tribal lands, permitted the traditional uses of park lands, and placed restrictions on the use of portions of the

Havasupai Reservation within GCNP in order to preserve the scenic and natural values of the park (16 USC 228i(b)(7)).

1.8.5.3 Hopi Tribe

The original Hopi Reservation was established by the Executive Order of December 16, 1882, as a 1 × 1 degree latitude/longitude rectangular region. Subsequent partitioning of this original reservation area between the Hopi Tribe and Navajo Nation has resulted in a smaller reservation area, encompassing about 1.5 million ac in parts of Coconino and Navajo Counties, Arizona. There are 11 main Hopi villages within the central portion of the Hopi Reservation and two additional villages located to the west at Moencopi, on a non-contiguous portion of the Hopi Reservation (Figure 1-4).

The Hopi people view their traditional homeland as much larger than the current reservation. It encompasses an area running from near the confluence of the San Juan and Colorado Rivers in the north, southwest to the area of the Havasupai Reservation, southward past Williams and out to the Mogollon Rim in the south, and eastward to the Lupton area on the Arizona–New Mexico border. Even this area is but a small portion of the lands occupied by the ancestors of the Hopi people, which include portions of Colorado, Utah, Arizona, and New Mexico.

1.8.5.4 Hualapai Tribe

The Hualapai Reservation was established by Executive Orders of January 4, 1883; June 2, 1911; May 29, 1912; and July 18, 1913. The reservation encompasses 992,463 ac just south of the Colorado River. The reservation borders the river corridor for approximately 108 mi from approximately RM 164.5 to RM 273.5 (NPS 2006b).

Hualapai traditional territory is bounded by the Colorado River from the Big Bend near Hoover Dam-Lake Mead to the Little Colorado River on the north, the San Francisco Peaks on the east, the Bill Williams and Santa Maria Rivers on the south, and the Colorado River from its confluence with the Bill Williams River to Lake Mead on the west (Reclamation 1995).

1.8.5.5 Navajo Nation

The Navajo Indian Reservation was established by the Treaty of June 1, 1868 (15 Stat. 667). Between 1868 and 1918, various Executive Orders added lands to, or removed lands from, the reservation. The Act of May 25, 1918 (40 Stat. 561, 570), prohibited the creation of, or any additions to, Indian reservations in New Mexico and Arizona "except by Act of Congress." Congress added land to the Navajo Indian Reservation by the Act of May 23, 1930 (46 Stat. 378), amended by the Act of February 21, 1931 (46 Stat. 378), and the Act of March 1, 1933 (47 Stat. 1418). The Act of June 14, 1934 (48 Stat. 960), describes the exterior boundaries

of the 17.6-million-ac reservation in Arizona, subject to various exclusions and conditions set out in the act.

The traditional Navajo homeland, or *Dinetah*, is bounded by four sacred mountains: *Sissnaajinii* (Blanca Peak, near Alamosa, Colorado) on the east; *Tsoo Dzil* (Mount Taylor near Grants, New Mexico) on the south; *Dook' o' oosliid* (San Francisco Peaks near Flagstaff, Arizona) on the west; and *Dibe Ntsaa* (La Plata Mountains near Durango, Colorado) on the north. Traditional use areas extend well beyond this boundary encompassing areas associated with the Little Colorado River, the Colorado River and its tributaries, and alongside the rim. According to Navajo oral tradition, in aboriginal times, Tribal members ranged as far as the Gulf of California. Documented histories were shared during the initial EIS in 1995 from the Navajo Nation Historic Preservation Department (NNHPD), taken from the cultural resources inventory report (Roberts et al. 1995).

1.8.5.6 Pueblo of Zuni

The Zuni Indian Reservation was established by the Executive Orders of March 16, 1877, May 1, 1883, and March 3, 1885, and was expanded by the Proclamation of November 30, 1917 (40 Stat. 1723); the Congressional Act of June 20, 1935 (49 Stat. 393); the Executive Order of August 13, 1949; and the Congressional Act of March 16, 1962 (76 Stat. 33). The Pueblo of Zuni is located approximately 150 mi west of Albuquerque, New Mexico, and encompasses approximately 450,000 ac (Pueblo of Zuni 2013). In addition to the lands established by Executive Orders and Presidential proclamation, two additional non-contiguous areas are included in the Zuni Reservation: the Zuni Salt Lake (1 mi^2) added in 1978 and Kolhu'wala:wa (Zuni Heaven) in Arizona consisting of 14 mi^2 added on August 28, 1984.

The traditional territory of the Zuni Tribe is bounded by the San Francisco Peaks on the northwest corner and by portions of the Little Colorado River and Pueblo Colorado Wash on the far northern boundary. The view of Pueblo of Zuni is that traditional use extends considerably beyond the traditional territorial boundaries and includes GCNP and GCNRA (Reclamation 1995; Dongoske 2012). It also should be noted that the Zunis are considered an Indian Tribe of Arizona.

1.8.5.7 Southern Paiute Tribes

The Southern Paiute Tribes that have ties to the region and who are most directly tied to the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah, which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band, Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute Consortium. The Kaibab Band represents the consortium in matters pertaining to Glen Canyon Dam and Colorado River management, and served as a Cooperating Agency on the LTEMP EIS.

The Kaibab Band of Paiute Indians Reservation was established by the Executive Orders of June 11, 1913, and July 17, 1917. The reservation is located approximately 50 mi north of the Grand Canyon. The reservation encompasses approximately 121,000 ac and includes five Tribal villages and two non-Indian communities (Kaibab Paiute 2013).

The Paiute Indian Tribe of Utah Reservation was established on April 3, 1980, by an Act of Congress (94 Stat. 317, 1980) and consists of 10 separate land parcels located in 4 southwestern Utah counties, covering 33,709 ac (PITU 2013).

The San Juan Southern Paiute were given 5,400 ac of land within the Navajo Reservation boundary when their leaders signed a treaty with the Navajo Nation on May 20, 2000. Approximately 5,100 ac of this land is located near Tuba City, Arizona, with the remaining 300 ac located just south of Lake Powell (NPS 2013d).

The traditional lands of the Southern Paiute people are bounded by more than 600 mi of the Colorado River, extending from the Kaiparowits Plateau in southern Utah to Blythe, California (Bulletts et al. 2012). These lands extend from the Colorado River northward, inclusive of the Grand and Glen Canyons, into Beaver County, Utah, and from the Escalante River drainage on the east within GCNRA to Death Valley on the west, including the Virgin River drainage, the Muddy River drainage, and the area around present-day Las Vegas, Nevada (ICC 1965).

1.9 LAWS AND REGULATIONS RELATED TO OPERATIONS OF GLEN CANYON DAM AND PARK MANAGEMENT

The following lists of laws, regulations, and treaties are presented here to provide context for the management of the Colorado River because they must be complied with for operation of Glen Canyon Dam and for park management, and may or may not specifically apply to this action. Nothing in this EIS is intended to interpret the authorities listed below.

1.9.1 Environmental Laws and Executive Orders

- Bald and Golden Eagle Protection Act of 1940, as amended 1962 (16 USC 668c)
- Clean Air Act of 1970 (33 USC 1251 et seq.)
- Clean Water Act of 1972 (33 USC 1251 et seq.)
- Endangered Species Act of 1973 (16 USC 1531–1544, 87 Stat. 884)
- E.O. 11514, "Protection and Enhancement of Environmental Quality," as amended by E.O. 11991, "Relating to Protection and Enhancement of Environmental Quality" (U.S. President 1970)

- E.O. 11988, "Floodplain Management" (U.S. President 1977a)
- E.O. 11990, "Protection of Wetlands" (U.S. President 1977b)
- E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (U.S. President 1994b)
- E.O. 13112, "Invasive Species" (U.S. President 1999)
- E.O. 13186, "Responsibilities of Federal Agencies to Protect Migratory Birds" (U.S. President 2001)
- Fish and Wildlife Coordination Act of 1934 (16 USC 661 et seq.)
- The Grand Canyon Protection Act of 1992 (P.L. 102-575)
- Migratory Bird Treaty Act of 1918, as amended 2008 (16 USC 703)
- National Environmental Policy Act of 1969, as amended (42 USC 4321 et seq.)
- National Park Service Organic Act of 1916 (16 USC 1–4, 22, and 43, as amended)
- Redwoods National Park Expansion Act of 1978 (Redwoods Amendment) (16 USC 1a-1)
- Wild and Scenic Rivers Act of 1968 (16 USC 1271 et seq.)
- Wilderness Act of 1964 (16 USC 1131–1136)

1.9.2 Cultural/Historical Laws and Executive Orders

- Antiquities Act of 1906 (16 USC 431–433)
- Archaeological and Historic Preservation Act of 1974 (16 USC 469 et seq.)
- Archaeological Resources Protection Act of 1979 (16 USC 470 et seq., P.L. 96-95)
- E.O. 11593, "Protection and Enhancement of the Cultural Environment" (U.S. President 1971)
- Historic Sites, Buildings, and Antiquities Act of 1935 (16 USC 461 et seq., as amended by P.L. 89-249)

- National Historic Preservation Act of 1966 (54 USC 300101 et seq., P.L. 89-665)

1.9.3 American Indian and Tribal Consultation Laws and Executive Orders

- American Indian Religious Freedom Act of 1978 (P.L. 95-431, 92 Stat. 469, 42 USC 1996)
- E.O. 13007, "Indian Sacred Sites" (U.S. President 1996)
- E.O. 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000)
- Native American Graves Protection and Repatriation Act of 1990 (P.L. 101-601, 104 Stat. 3048, 25 USC 3001 et seq.)

1.9.4 Laws Establishing Criteria Related to Power Marketing

- Colorado River Storage Project Act of 1956 (P.L. 84-485, 70 Stat. 105)
- Department of Energy Organization Act of 1977 (P.L. 95-91, 91 Stat. 565, 42 USC 7101)
- Flood Control Act of 1944 (P.L. 78-534, 58 Stat. 887)
- Reclamation Project Act of 1939 (P.L. 76-260, 53 Stat. 1187, 43 USC 485)

1.9.5 Law of the River

The treaties, compacts, decrees, statutes, regulations, contracts, and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often referred to as the Law of the River. There is no single, universally agreed upon definition of the Law of the River, but it is useful as a shorthand reference to describe this longstanding and complex body of legal agreements governing the Colorado River. Documents generally considered to be part of the Law of the River include those listed in Table 1-2.

1.10 RELATED ACTIONS

Numerous ongoing and completed plans, policies, actions, and initiatives are related to the operation of the Glen Canyon Dam and Colorado River with respect to the proposed federal action analyzed in this EIS. Reclamation and NPS have identified documents that would assist

TABLE 1-2 Selected Documents Included in the Law of the River[a]

1899	The Rivers and Harbors Act (Mar. 3)	1948	The Upper Colorado River Basin Compact (Oct. 11)
1902	The Reclamation Act (Jun. 17)	1954	Consolidated Parker Dam Power Project and Davis Dam Project Act (May 28)
1904	Reclamation of Indian Lands in Yuma, Colorado River and Pyramid Lake Indian Reservations Act (Apr. 21)	1954	Palo Verde Diversion Dam Act (Aug. 31)
1904	Yuma Project authorized by the Secretary (May 10), pursuant to Section 4 of the Reclamation Act of June 17, 1902	1956	Change Boundaries, Yuma Auxiliary Project Act (Feb. 15)
1910	Warren Act (Feb. 21)	1956	The Colorado River Storage Project Act (Apr. 11)
1910	Protection of Property Along the Colorado River Act (Jun. 25)	1958	Water Supply Act (Jul. 3)
1912	Patents Act and Water-Right Certificates Act (Aug. 9 and 26)	1958	Boulder City Act (Sept. 2)
1917	Yuma Auxiliary Project Act (Jan. 25)	1960	Report of the Special Master, Simon H. Rifkind, *Arizona v. California* (Dec. 5)
1918	Availability of Money for Yuma Auxiliary Project Act (Feb. 11)	1964	International Flood Control Measures, Lower Colorado River Act (Aug. 10)
1920	Sale of Water for Miscellaneous Purposes Act (Feb. 25)	1965	Southern Nevada (Robert B. Griffith) Water Project Act (Oct. 22)
1920	Federal Power Act (Jun. 10)	1968	The Colorado River Basin Project Act (Sept. 30)
1922	The Colorado River Compact (Nov. 24)	1970 *(2005)*	Criteria for the Coordinated Long Range Operation of Colorado River Reservoirs (Jun. 8), amended Mar. 21, 2005
1925 *(1927–1946)*	The Colorado River Front Work Act (Mar. 3) and Levee System Acts (Jan. 21, 1927–Jun. 28, 1946)	1970	Supplemental Irrigation Facilities, Yuma Division Act (Sept. 25)
1928	The Boulder Canyon Project Act (Dec. 21)	1972	43 CFR Part 417 Lower Basin Water Conservation Measures (Sept. 7)
1929	The California Limitation Act (Mar. 4)	1974	The Colorado River Basin Salinity Control Act (Jun. 24)
1931	The California Seven Party Agreement (Aug. 18)	1984	Hoover Power Plant Act (Aug. 17)
1935	The Parker and Grand Coulee Dams Authorization (Aug. 30)	1991	Reclamation States Emergency Drought Relief Act
1939	The Parker Dam Power Project Appropriation Act (May 2)	1992	Grand Canyon Protection Act (Oct. 30)
1939	The Reclamation Project Act (Aug. 4)	1999	Offstream Storage of Colorado River Water and Development and Release of Intentionally Created Unused Apportionment in the Lower Division States (Nov. 1) (Reclamation 1999a)
1940	The Boulder Canyon Project Adjustment Act (Jul. 19)	2003	Colorado River Water Delivery Agreement (Oct. 10)
1944	The Flood Control Act (Dec. 22)	2006	The Consolidated Decree entered by the U.S. Supreme Court in *Arizona v. California* (1964)
1944	The Mexican Water Treaty (Feb. 3); subsequent minutes of the International Boundary and Water Commission	2007	Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead
1947	Gila Project Act (Jul. 30)		

[a] Years in italics indicate amendments or related actions.

Source: Reclamation (2007b).

the reader in understanding the issues analyzed in this process and underscore the importance of collaboration among agency and stakeholder participants.

1.10.1 Biological Opinions

- Final Biological Opinion for the Proposed Adoption of Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (FWS 2007a).

- Final Biological Opinion on the Operation of Glen Canyon Dam, including High-Flow Experiments and Nonnative Fish Control (FWS 2011c). This replaced former Biological Opinions from 1995 to 2009.

- Final Biological Opinion on the Comprehensive Fisheries Management Plan, Coconino and Mohave Counties, Arizona (FWS 2013a).

1.10.2 Environmental Impact Statements and Related Documents

Operation of Glen Canyon Dam: Environmental Impact Statement and Record of Decision (Reclamation 1996). Glen Canyon Dam currently operates under provisions of the 1996 ROD (Reclamation 1996) for the Glen Canyon Dam EIS (Reclamation 1995). The Secretary accepted the recommendation of the 1995 EIS and signed the 1996 ROD (Reclamation 1996) that selected MLFF as the operating system for the dam. The flow parameters of MLFF are presented in Section 1.8.3 of this EIS.

A component of the final Glen Canyon Dam EIS (Reclamation 1995) and the environmental commitments identified in the 1996 ROD (Reclamation 1996) was the implementation of a Programmatic Agreement regarding operations of the Glen Canyon Dam. This agreement, along with subsequent monitoring and remedial action plans and the 2007 Comprehensive Treatment Plan, set a strategy for long-term management of archaeological sites affected by the operations of Glen Canyon Dam. In addition, separate, action-specific Memoranda of Agreement were established among the signatories to the agreements, primarily Reclamation, NPS, Arizona State Historic Preservation Office, and affiliated Tribes for actions related to the High Flow Experimental Protocol EA (Reclamation 2011b) and the Nonnative Fish Control EA (Reclamation 2011a).

Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007b). In 2005, spurred by a multi-year drought, decreasing system storage, and growing demands for Colorado River water, the Secretary directed Reclamation to work with the Basin States to develop additional strategies for addressing the coordinated management of the reservoirs of the Colorado River system. In response, Reclamation began to develop and adopt interim operational guidelines that would address the operation of Lake Powell and Lake Mead during drought and low-reservoir conditions. Adopted in 2007, these Interim Guidelines would be used each year (through 2025

for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. This ROD did not modify the authority of the Secretary to determine monthly, daily, hourly, or instantaneous releases from Glen Canyon Dam.

The completed Interim Guidelines determine the availability of Colorado River water for use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to conserve reservoir storage and provide water users and managers with greater certainty regarding the reduction of water deliveries during drought and other low-reservoir conditions. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as Intentionally Created Surplus, intended to minimize the severity and likelihood of potential future shortages. Nothing in this LTEMP EIS is intended to affect, or will affect, future decisions that may be made regarding the implementation of the LROC after the Interim Guidelines expire in 2026.

Colorado River Management Plan: Final Environmental Impact Statement and Record of Decision (NPS 2006a). This Final EIS (NPS 2005a) presents a visitor use management plan for the Colorado River corridor in the Grand Canyon. The ROD (NPS 2006a) was approved in early 2006, and the CRMP were published later in the year (NPS 2006b). The CRMP's section on research, monitoring, and mitigation for the plan focuses on the impacts of visitor use and is a consideration for the LTEMP EIS analysis.

Lower Colorado River Multi-Species Conservation Program—Final Programmatic Environmental Impact Statement/Environmental Impact Report (DOI 2004). This Programmatic EIS evaluates the impacts of implementing the Lower Colorado River Multi-Species Conservation Program Conservation Plan. It is intended to avoid, minimize, and fully mitigate the incidental take of the covered species from the implementation of the covered activities to the maximum extent practicable. The Conservation Plan also is intended to contribute to the recovery of species listed as threatened or endangered under the ESA and reduce the likelihood for future listing of unlisted covered species along the lower Colorado River. The ROD (DOI 2005) was approved in 2005.

General Management Plan for Grand Canyon National Park (NPS 1995). This plan guides the management of resources, visitor use, and general development at the park over a 10- to 15-year period. The primary purpose of the plan is to provide a foundation from which to protect park resources while providing for meaningful visitor experiences. A secondary purpose is to encourage compatible activities on adjacent lands so as to minimize adverse effects on the park.

Backcountry Management Plan, Grand Canyon National Park, Arizona (NPS 1988). This plan defines the primary policies that manage visitor use and resource protection for the undeveloped areas of GCNP. GCNP has started work on a Backcountry Management Plan and EIS. The park's existing Backcountry Management Plan is being updated to comply with current

NPS laws and policies and the park's 1995 General Management Plan. Once completed, the revised Backcountry Management Plan will guide management decisions regarding the park's backcountry and wilderness resources into the future.

Lake Mead National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1986). This plan presents short-term and long-term strategies for meeting the management objectives of LMNRA. It addresses resource management, resource use, and park development challenges. The plan was intended to guide park management for 25 years or longer when it was issued. The purpose of the plan is to provide a cohesive framework for management decisions, management proposals, concession planning, and guidance for short-term decision-making.

Glen Canyon National Recreation Area General Management Plan—Final Environmental Impact Statement (NPS 1979). This plan and wilderness recommendation lays out proposals for meeting four levels of management objectives for GCNRA, ranging from general to specific. The first-level objective is to manage GCNRA to maximize its recreational enjoyment. Objective levels 2 through 4 address increasingly specific objectives, including those for cultural, Tribal, mineral, and grazing resources and management of the reservoir. The plan presents a management zoning proposal to divide GCNRA into four management zones: natural, recreation and resource utilization, cultural, and development.

1.10.3 Environmental Assessments and Related Documents

Nonnative Fish Control Environmental Assessment (Reclamation 2011a). In this assessment, Reclamation proposed to conduct research, monitoring, and specific actions to control nonnative fish in the Colorado River downstream from Glen Canyon Dam in an effort to help conserve native fish. The purpose of the action was to minimize the negative impacts of competition and predation on an endangered fish, the humpback chub. The action was needed because competition and predation by nonnative fishes, particularly rainbow trout and brown trout, may be contributing to a reduction in survival and recruitment of young humpback chub and threatening the potential recovery of the species. Rainbow trout and brown trout are not native to the Colorado River Basin and have been introduced into the region as sport fish. The Finding of No Significant Impact (FONSI) (Reclamation 2012b) was signed in May of 2012.

High-Flow Experiment Protocol Environmental Assessment (Reclamation 2011b). This experimental protocol was developed following analysis of a series of high-flow experimental releases. The protocol is intended to improve conservation of limited sediment resources in the Colorado River below Glen Canyon Dam. The FONSI (Reclamation 2012a) was signed in May of 2012.

Environmental Assessment, Comprehensive Fisheries Management Plan for Grand Canyon National Park and Glen Canyon National Recreation Area (NPS 2013e). The NPS is implementing a CFMP, in coordination with the Arizona Game and Fish Department (AZGFD), the FWS, Reclamation, and the USGS GCMRC, for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The intent of the CFMP is to maintain a thriving native

fish community within GCNP and a highly valued recreational rainbow trout fishery in the Glen Canyon reach of GCNRA. NPS released a FONSI on December 9, 2013, for the CFMP.

Environmental Assessment and Assessment of Effect, Exotic Plant Management Plan Grand Canyon National Park, Arizona (NPS 2009a). GCNP is using integrated pest management techniques to control and contain exotic plant species within park boundaries. Exotic plant species displace natural vegetation and consequently affect long-term health of native plant and animal communities.

1.10.4 Other Actions, Programs, Plans, and Projects

Additional actions, programs, plans, or projects involving the Colorado River may continue to operate or be contemplated during the life of the LTEMP. These items, which are not directly linked to LTEMP, include:

Colorado River Basin Salinity Control Program (Reclamation 2014c). The Colorado River and its tributaries provide municipal and industrial water to about 27 million people and irrigation water to nearly 4 million ac of land in the United States. The threat of salinity is a major concern in both the United States and Mexico. In June 1974, Congress enacted the Colorado River Basin Salinity Control Act (P.L. 93-320), which directed the Secretary to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico.

Lake Powell Pipeline Project (WCWCD 2012). Washington, Kane, and Iron Counties in Utah are pursuing the construction of a pipeline that would run from Lake Powell, near Glen Canyon Dam, through Kane County, to Sand Hollow Reservoir, which is located approximately 10 mi east of St. George. The pipeline would then run parallel to Interstate 15 into Iron County. The pipeline would be 158 mi long and bring 70,000 ac-ft of water to Washington County, 10,000 ac-ft to Kane County, and 20,000 ac-ft to Iron County.

Final Wilderness Recommendation, Grand Canyon National Park, 2010 Update. The 1980 Final Wilderness Recommendation submitted to the DOI includes 1,143,918 ac proposed for wilderness designation, and includes 26,461 ac as potential wilderness pending the resolution of boundary and motorized boat use issues. The Colorado River was identified as potential wilderness. In 2010, NPS conducted internal reviews and included refinements to the proposed wilderness acreage estimates. All refinements were consistent with the intent of the original document submitted to the DOI in 1980.

Grand Canyon National Park Foundation Statement for Planning and Management (NPS 2010a). The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Grand Canyon's natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNP and its mission, the Statement should remain relatively unchanged.

Glen Canyon National Recreation Area and Rainbow Bridge National Monument Foundation Document for Management and Planning (NPS 2014i). The Foundation Statement provides a base for future planning, as required by NPS, to help guide park management. The Foundation Statement summarizes fundamental resources and values critical to maintaining Glen Canyon and Rainbow Bridge's natural, cultural, and experiential value into the future. Because this Foundation Statement is based on laws and policies that define GCNRA and its mission, the Statement should remain relatively unchanged.

Management and Control of Tamarisk and Other Invasive Vegetation at Backcountry Seeps, Springs, and Tributaries in Grand Canyon National Park (NPS 2008). Grand Canyon National Park's backcountry seeps, springs, and tributaries of the Colorado River are among the most pristine watersheds and desert riparian habitats remaining in the coterminous United States. This report contains the details from the invasive plant control and monitoring efforts completed for one phase (Phase II-B) of the three-phase project. Reports for the previous two phases are also available on the NPS website.

Strategic Plan for Glen Canyon National Recreation Area and Rainbow Bridge National Monument FY2007–FY2011 (NPS 2006c). This 5-year Strategic Plan has been written for GCNRA and Rainbow Bridge National Monument (NM). Because Rainbow Bridge NM is administered by GCNRA, this strategic plan covers both units of the NPS.

Grand Canyon National Park Resource Management Plan (NPS 1997). The purpose of the Resource Management Plan was to provide long-term guidance and direction for the stewardship of the natural, cultural, and recreational resources of GCNP.

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2 DESCRIPTION OF ALTERNATIVES

Seven alternatives, including the No Action Alternative, were developed for consideration in the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Draft Environmental Impact Statement (DEIS). These alternatives were assigned letter designations of A through G, with Alternative A being the No Action Alternative.

Alternative A (the No Action Alternative) represents continued implementation of existing operations and actions as defined by existing agency decisions. The other six "action" alternatives represent various ways in which operations and actions could be modified under an LTEMP. Four of the action alternatives (Alternatives C, D [the preferred alternative], F, and G) were developed by the joint-lead agencies for the DEIS—Bureau of Reclamation (Reclamation) and National Park Service (NPS)—with various levels of participation by other U.S. Department of the Interior (DOI) agencies, including the Bureau of Indian Affairs (BIA), U.S. Fish and Wildlife Service (FWS), and U.S. Geological Survey's (USGS's) Grand Canyon Monitoring and Research Center (GCMRC), Argonne National Laboratory (Argonne), Western Area Power Administration (WAPA), and Arizona Game and Fish Department (AZGFD), and input and comments from Cooperating Agencies and Tribes. Two of the action alternatives were developed and submitted for consideration by two stakeholder organizations, the Colorado River Energy Distributors Association (CREDA; Alternative B) and the Colorado River Basin States Representatives from Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming, and the Upper Colorado River Commission (UCRC) (Basin States; Alternative E) in response to an offer made by the DOI in April 2012 to consider alternatives submitted by Cooperating Agencies and Adaptive Management Working Group (AMWG) members. Grand Canyon Trust and the Irrigation and Electrical Districts Association of Arizona submitted letters with comments on alternatives, but did not submit complete alternative proposals. In instances where the DOI made modifications to alternatives submitted by stakeholders, they are noted in the alternative descriptions below. The general process used to develop alternatives is described in Section 2.1, and characteristics of the alternatives are described in Section 2.2.

Several alternative concepts were identified by the public during scoping for the LTEMP DEIS (Argonne 2012):

- Decommission Glen Canyon Dam
- Fill Lake Mead first
- Grand Canyon first
- Maximum powerplant capacity operations
- Naturally patterned flows
- Run-of-the-river

- Species community and habitat-based alternative
- Stewardship alternative
- 12-year experiment of two steady-flow alternatives
- Year-round steady flows

These concepts were considered by Reclamation and NPS for detailed analysis during the alternative development process. In some cases, these were included as an LTEMP alternative, or elements were incorporated within one of the alternatives. In other cases, the concept was eliminated from consideration or further analysis because it did not meet the purpose, need, or objectives of the proposed action; clearly violated existing laws or regulations; or lacked enough specifics to be developed into a full and unique alternative (Section 2.3).

In addition to these submitted alternative concepts, the public identified a variety of specific elements that should be considered for inclusion in LTEMP DEIS alternatives. These elements were considered for inclusion by the joint-lead agencies as they developed LTEMP alternatives. Elements considered but not analyzed in detail are presented in Section 2.4.

2.1 DEVELOPMENT OF ALTERNATIVES

The alternative development process began with identification of the proposed action (i.e., development of an LTEMP), purpose and need of the LTEMP, and the objectives and resource goals of the LTEMP (Sections 1.1, 1.2, and 1.4, respectively). Once these items were defined, NPS and Reclamation worked to develop a set of alternatives that represented the full range of reasonable experimental and management actions; met the purpose, need, and objectives of the proposed action; and were considered within the constraints of existing laws, regulations, and existing decisions and agreements.

Alternative operations that either used different operational strategies (e.g., consistent monthly release pattern or condition-dependent release pattern) or had different primary objectives (e.g., native fish, sediment, or restoration of a more natural flow pattern) were developed and refined. In developing alternatives for detailed analysis, NPS and Reclamation considered and evaluated concepts identified by the public during scoping, alternatives that had been identified for the cancelled Long-Term Experimental Plan (LTEP) Environmental Impact Statement (EIS), and alternatives that had been identified in several efforts led by the Glen Canyon Dam Adaptive Management Program (GCDAMP) (USGS 2006, 2008).

An “alternative screening tool” was developed by the LTEMP EIS team to aid in the development of alternatives by providing preliminary analysis of alternative concepts; it subsequently helped to identify specific operational characteristics of alternatives (e.g., monthly volumes, daily ranges) that would meet the purpose, need, goals, and objectives of the proposed action. This spreadsheet tool used a set of simple models to produce a screening-level appraisal

of the impacts of alternatives on flow, sediment (sand) transport, water temperature, humpback chub (*Gila cypha*) growth, trout recruitment, and hydropower value (generation and capacity).

The screening tool was used primarily for rapid prototyping of alternative concepts and to supplement a full analysis of impacts. It was also used to evaluate potential modifications to Alternative D, after modeling was completed on the effects of alternatives on hourly changes in flow and other resources for the 20-year LTEMP period. The screening tool focused on the effects of monthly, daily, and hourly flow patterns in single years rather than the effects of multiple years. The screening tool produced:

- Daily, monthly, and annual estimates of sediment transport (metric tons/year) based on Figure 4a from Rubin et al. (2002);
- Mean monthly temperature at river mile (RM) 61 (confluence with the Little Colorado River) and RM 225 based on Wright, Anderson et al. (2008);
- Mean monthly and annual total growth rates for humpback chub at RM 61 and 225 based on a growth-temperature regression in Robinson and Childs (2001);
- Annual estimates of trout recruitment based on an empirical relationship developed by Korman et al. (2012);
- Daily, monthly, and annual estimate of hydropower value based on the value of hydropower ($/MWh) at different hours of the day and using a conversion factor for cfs to MWh using information from the GTMax model (Palmer et al. 2007); and
- Annual estimate of hydropower capacity based on the value of power generated by maximum daily flows during the peak power month of August.

Several iterations of preliminary draft alternative concepts developed by NPS and Reclamation were presented to the Cooperating Agencies and other stakeholders in workshops and webinars to explain the alternative development process, describe proposed alternative characteristics, and solicit feedback. Workshops included (1) a facilitated public workshop on April 4 and 5, 2012; (2) Cooperating Agency and Tribal meetings on August 10, 2012; (3) Tribal workshops on March 14, 2013; (4) a stakeholder workshop on August 5–7, 2013; (5) a stakeholder workshop on March 31–April 1, 2014; and (6) a stakeholder webinar on December 3, 2015. There were also monthly calls with Cooperating Agencies that included updates and information exchange related to the alternatives.

Alternative D was identified by the DOI as the preferred alternative in the DEIS, and WAPA, the Basin States, and the National Parks Conservation Association submitted letters of support for this alternative before the DEIS was published. DOI received both positive and negative feedback about this alternative from other stakeholders (see Appendix Q). Alternative D was developed by the DOI based on the results of the analysis of the impacts of the other original set of six alternatives. Alternative D adopted many of the best-performing characteristics of

Alternatives C and E. The effects of operations under these latter two alternatives were first modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance, reduce impacts, and better meet the purpose, need, and objectives of the LTEMP. The impacts of Alternative D were then evaluated using the same models employed for other alternatives (Section 4.1), and these results served as the basis for the assessments presented in Chapter 4. Subsequent to that modeling, relatively minor modifications were made to Alternative D based on discussions with Cooperating Agencies, and with the support of screening tool analyses.

To aid in the alternative development process, formal decision analysis tools were also used for the LTEMP DEIS. Such tools are useful because the LTEMP concerns the management of a very complex system with many—possibly competing—resources of interest, and it involves uncertainty about the relationships between management strategies and the responses of resources to those strategies. A structured decision analysis process for LTEMP alternative development and evaluation was facilitated by Dr. Michael Runge of the USGS to obtain multiple stakeholder viewpoints. This was accomplished through a series of workshops and webinars involving LTEMP project managers; EIS analysts; technical representatives from FWS, BIA, WAPA, Arizona Department of Water Resources, and AZGFD; and other AMWG stakeholders. See Section 1.7 for additional information on the role of decision analysis in the LTEMP EIS process, and Appendix C for a complete description of the structured decision analysis process as applied to the LTEMP EIS.

2.2 DESCRIPTIONS OF ALTERNATIVES CONSIDERED IN DETAIL

This section describes the seven alternatives considered for detailed analysis in the LTEMP EIS. Operations under all of these alternatives would use only existing dam infrastructure. There are a number of experimental and management actions that would be incorporated into all of the LTEMP alternatives, except where noted:

- High flow releases for sediment conservation. Implementation of high-flow experiments (HFEs) under all alternatives are patterned after the current HFE protocol (Reclamation 2011b), but some alternatives include specific modifications related to the frequency of spring and fall HFEs, the duration of fall HFEs, the triggers for HFEs, and the overall process for implementation of HFEs, including implementation considerations and conditions that would result in discontinuing specific experiments. For Alternative D, the specific components of the HFE protocol that will be followed are provided in Appendix P. Other alternatives would adopt the existing HFE protocol without modification.

- Nonnative fish control actions. Implementation of control actions for nonnative brown and rainbow trout are patterned after those identified in the Nonnative Fish Control Environmental Assessment (EA) (Reclamation 2011a) and Finding of No Significant Impact (FONSI) (Reclamation 2012b), but some alternatives include specific modifications

related to the area where control actions would occur, the specific actions to be implemented, and the overall process for implementation of control actions, including implementation considerations and conditions that would result in discontinuing specific experiments. Nonnative fish control actions are not included in Alternative F. For Alternative D, components of the Nonnative Fish Control EA and FONSI were modified and integrated with other actions in a tiered approach to humpback chub conservation. This tiered approach is described in Section 2.2.4.6 and Appendix O. Other alternatives would adopt the Nonnative Fish Control EA and FONSI actions without modification.

- Conservation measures established by FWS in previous Biological Opinions (BOs). Conservation measures identified in the 2011 BO on operations of Glen Canyon Dam (FWS 2011c) included the establishment of a humpback chub refuge, evaluation of the suitability of habitat in the lower Grand Canyon for the razorback sucker (*Xyrauchen texanus*), and establishment of an augmentation program for the razorback sucker, if appropriate. Other measures include humpback chub translocation; Bright Angel Creek brown trout control; Kanab ambersnail (*Oxyloma haydeni kanabensis*) monitoring; determination of the feasibility of flow options to control trout, including increasing daily down-ramp rates to strand or displace age-0 trout, and high flow followed by low flow to strand or displace age-0 trout; assessments of the effects of actions on humpback chub populations; sediment research to determine effects of equalization flows; and Asian tapeworm (*Bothriocephalus acheilognathi*) monitoring. Most of these conservation measures are ongoing and are elements of existing management practices (e.g., brown trout control, humpback chub translocation, and sediment research to determine the effects of equalization flows), while others are being considered for further action under the LTEMP (e.g., trout management flows [TMFs]). Additional conservation measures were developed for the preferred alternative during Endangered Species Act (ESA) Section 7 consultation with the FWS. These additional conservation measures are described in Appendix O. Other alternatives would adopt the existing conservation measures without modification.

- Non-flow experimental and management actions at specific sites such as nonnative plant removal, revegetation with native species, and mitigation at specific and appropriate cultural sites. Included are pilot experimental riparian vegetation treatment actions planned by NPS. These actions would also have involvement from Tribes to capture concerns regarding culturally significant native plants, and would provide an opportunity to integrate Traditional Ecological Knowledge in a more applied manner into the long-term program.

- Preservation of historic properties through a program of research, monitoring, and mitigation to address erosion and preservation of archeological and ethnographic sites and minimize loss of integrity at *National Register* historic properties.

- Continued adaptive management under the GCDAMP, including a research and monitoring component, as more fully discussed in Section 1.6.

With operational flows limited to 45,000 cfs and below, the overall extent of the riparian area in Grand Canyon is expected to continue to decrease, primarily as a result of continuing lack of water in the old high water zone and continued declines at the upper edges of the new high water zone; however, the vegetation density within the riparian area is expected to continue to increase. Nonnative vegetation and monoculture species such as arrowweed are expected to continue to increase, and key native species (e.g., Goodding's willow) are expected to continue to decrease.

Experimental riparian vegetation treatment activities would be implemented by NPS under all alternatives except for Alternative A and would modify the cover and distribution of riparian plant communities along the Colorado River. All activities would be consistent with NPS Management Policies (NPS 2006d) and would occur only within the Colorado River Ecosystem in areas that are influenced by dam operations. NPS will work with Tribal partners and GCMRC to experimentally implement and evaluate a number of vegetation control and native replanting activities on the riparian vegetation within the Colorado River Ecosystem in Grand Canyon National Park (GCNP) and Grand Canyon National Recreation Area (GCNRA). These activities would include ongoing monitoring and removal of selected nonnative plants, species in the corridor, systematic removal of nonnative vegetation at targeted sites, and native replanting at targeted sites and subreaches, which may include complete removal of tamarisk (both live and dead) and revegetation with native vegetation. Treatments would fall into two broad categories, including the control of nonnative plant species and revegetation with native plant species. Principal elements of this experimental riparian vegetation proposal include:

- Control nonnative plant species affected by dam operations, including tamarisk and other highly invasive species;

- Develop native plant materials for replanting through partnerships and the use of regional greenhouses;

- Replant native plant species to priority sites along the river corridor, including native species of interest to Tribes;

- Remove vegetation encroaching on campsites;

- Manage vegetation to assist with cultural site protection.

None of the alternatives include specific experimental tests or condition-dependent treatments for historic site preservation or Tribal cultural properties and resources other than operations and treatments intended to build and retain sandbars and targeted experimental vegetation actions in relation to cultural sites as described above. Continued evaluation of site stability and integrity would be undertaken as well as continued sediment evaluations, including those related to HFEs. Similarly, NPS's continued evaluation of Traditional Cultural Properties and resources of cultural concern would be evaluated in consultation with traditional

practitioners and knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as determined necessary in consultation with Tribes.

In addition to these common elements, there are recent plans and decisions of the joint-lead agencies and DOI-identified management actions that could be implemented under all alternatives (Section 1.10.2). The Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a), together with existing laws and regulations, were used to establish "sideboards" that constrain the breadth and nature of flow and non-flow actions that were considered in the LTEMP alternatives.

Under all alternatives, release patterns could be adjusted to provide ancillary services, including regulation and reserves for hydropower. Regulation is the minute-by-minute changes in generation needed to maintain a constant voltage within a power control area. Regulation affects instantaneous operations that deviate above and below the mean hourly flow without affecting mean hourly flow. Spinning reserves in the control area served by the Colorado River Storage Project are typically provided by power resources in the Aspinall Unit, a series of three hydropower dams on the Gunnison River. However, under rare hydrological and power resource conditions, Aspinall power resources cannot provide spinning reserves. When this occurs, the spinning reserve duty is typically placed on the Glen Canyon Dam powerplant. In the event that these reserves are placed on Glen Canyon and at the same time need to be deployed in response to a grid event, such as a system unit outage or downed power line, WAPA would invoke emergency exception criteria and within minutes or less increase the Glen Canyon Dam power generation level up to the spinning reserve requirement. Associated turbine water release rates would increase in tandem with higher power production.

Operations described under any alternative would be altered temporarily to respond to emergencies. The North American Electric Reliability Corporation (NERC) has established guidelines for the emergency operations of interconnected power systems. A number of these guidelines apply to Glen Canyon Dam operations. These changes in operations would be of short duration (usually less than 4 hr) and would be the result of emergencies within the interconnected electrical system. Examples of system emergencies include insufficient generating capacity; transmission system overload, voltage control, and frequency; system restoration; and humanitarian situations (search and rescue).

The original Notice of Intent to prepare the LTEMP EIS identified the need to determine whether to establish a recovery implementation program for endangered fish species below Glen Canyon Dam. The LTEMP team finds that identifying the need to determine whether to establish a recovery implementation program (RIP) for endangered fish species below Glen Canyon Dam does not meet the purpose and need for the action (Section 1.2). This decision does not preclude the implementation of a RIP for endangered fish species below Glen Canyon Dam in the future. Although the GCDAMP has undertaken a number of actions that have previously been identified as necessary for the recovery of humpback chub in FWS recovery planning documents, the emphasis of that program is on mitigation and conservation actions specified in the National Environmental Policy Act (NEPA) and ESA Section 7 BOs for federal actions—not on the endangered fish species' overall needs to reach recovery.

Specific details of each of the LTEMP alternatives are described in Sections 2.2.1 to 2.2.7. Operational characteristics of LTEMP alternatives are presented in Table 2-1, and condition-dependent and experimental elements are summarized in Table 2-2. In the descriptions below, typical monthly flow patterns, including the mean, minimum, and maximum daily flows, are presented for each alternative in years with an annual release volume of 8.23 million ac-ft (maf). It is known that a wide range of hydrologic conditions will occur over the LTEMP implementation time frame in response to intra-annual and inter-annual variability in basin-wide precipitation cycles. Within a year, monthly operations are typically adjusted (increased or decreased) based on numerous factors. For example, adjustments may be made because of changing annual runoff forecasts, and, since 2007, application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). To model each LTEMP alternative, reservoir operation rules that represent how Glen Canyon Dam would be operated under the alternative were developed for a range of hydrologic conditions and equalization requirements.

2.2.1 Alternative A (No Action Alternative)

The Council on Environmental Quality (CEQ) requires inclusion of an "alternative of no action" (Title 40, *Code of Federal Regulations*, Part 1502.14(d) [40 CFR 1502.14(d)]), which serves as a baseline against which the impacts of "action" alternatives can be compared. For the LTEMP EIS, the No Action Alternative (referred to here as Alternative A) represents a situation in which the DOI would not modify existing decisions related to operations. Alternative A represents continued operation of Glen Canyon Dam as guided by the 1996 Record of Decision (ROD) for operations of Glen Canyon Dam: Modified Low Fluctuating Flow (MLFF), as modified by recent DOI decisions, including those specified in the 2007 ROD on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (until 2026) (Reclamation 2007b), the HFE EA (Reclamation 2011b), and the Nonnative Fish Control EA (Reclamation 2011a) (both expiring in 2020). As is the case for all alternatives, Alternative A also includes implementation of existing and planned NPS management activities, with durations as specified in NPS management documents (see Section 1.10).

Under Alternative A, daily flow fluctuations would continue to be determined according to monthly volume brackets as follows: 5,000 cfs daily range for monthly volumes less than 600 kaf; 6,000 cfs daily range for monthly volumes between 600 kaf and 800 kaf; and 8,000 cfs for monthly volumes greater than 800 kaf. Other operating criteria specified in the 1996 ROD are identified in Table 2-1. Since 1996, operations under the 1996 ROD have typically resulted in higher monthly water volume allocations in the high electrical demand months of December, January, July, and August (Tables 2-1 and 2-3; Figure 2-1); operators have typically targeted releases of slightly above 800 kaf in these high demand months in order to achieve the maximum allowable daily fluctuation range (8,000 cfs). Figure 2-1 shows minimum, mean, and maximum daily flows in an 8.23 maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-2 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative A. Figure 2-3 shows details of hourly flows during a week in July.

TABLE 2-1 Operational Characteristics of LTEMP Alternatives

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Monthly pattern in release volume	Historic monthly release volumes. Higher volumes in high electric demand months of Dec., Jan., Jul., and Aug.; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Same as Alternative A	Highest volume in high electric demand months of Dec., Jan., and Jul.; Feb.–Jun. volumes proportional to contract rate of delivery; lower volumes Aug.–Nov.	Comparable to Alternative E, but Aug. and Sep. volume increased, with additional volume taken from Jan.–Jul.; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Monthly volumes proportional to the contract rate of delivery, but with a targeted reduction in Aug.–Oct. volumes; volume released in Oct.–Dec. = 2.0 maf in ≥ 8.23-maf years and 1.5 maf in years ≤ 7.48 maf	Relative to Alternative A, higher release volumes in Apr.–Jun.; lower volumes in remaining months	Equal monthly volumes, adjusted with changes in runoff forecast
Minimum flows (cfs)	8,000 between 7 a.m. and 7 p.m. 5,000 between 7 p.m. and 7 a.m.	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	5,000	5,000
Maximum non-experimental flows (cfs)[b]	25,000	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Daily range (cfs/24 hr)[c]	5,000 for monthly volumes <600 kaf 6,000 for monthly volumes 600–800 kaf 8,000 for monthly volumes >800 kaf	Dec. and Jan.: 12,000 Feb., Jul., and Aug.: 10,000 Oct., Nov., Mar., Jun., and Sep.: 8,000 Apr. and May: 6,000	Equal to 7 × monthly volume (in kaf) in all months	Equal to 10 × monthly volume (in kaf) in Jun.–Aug., and 9 × monthly volume (in kaf) in other months; daily range not to exceed 8,000 cfs	Equal to 12 × monthly volume (in kaf) in Jun.–Aug., and 10 × monthly volume (in kaf) in other months	0 cfs[d]	0 cfs[d]

TABLE 2-1 (Cont.)

Elements of Base Operations[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Ramp rates (cfs/hr)	4,000 up 1,500 down	4,000 up 4,000 down in Nov.–Mar. 3,000 down in other months	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 1,500 down	4,000 up 1,500 down

[a] Base operations are defined as operations in those years when no condition-dependent or experimental actions are triggered. Examples of experimental actions include HFEs, low summer flows, and TMFs (see Table 2-2).

[b] Maximum flows presented are for normal operations and may be exceeded as necessary for HFEs, emergency operations, and equalization purposes.

[c] Values presented are the normal daily range in mean hourly flow for each alternative. Some variation in instantaneous flows within hours is allowed in all alternatives to accommodate emergency conditions, regulation requirements, and reserve requirements. For several alternatives, reduced fluctuations would be implemented after significant sediment inputs or after HFEs as described in Table 2-2.

[d] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

TABLE 2-2 Condition-Dependent and Experimental Elements of LTEMP Alternatives

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs)								
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement when triggered through 2020 when protocol expires	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period, but no spring HFEs in first 2 years, and no spring HFE in the same water year as an extended-duration (>96 hr) fall HFE	Implement when triggered during entire LTEMP period, except no spring HFEs in first 10 years	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period
Proactive spring HFE in Apr., May, or Jun., with maximum possible 24-hr release up to 45,000 cfs	Trigger: High-volume equalization year (≥10 maf) Objective: To build beaches and protect sand supply otherwise exported by high equalization release	No	No	Yes, if no other spring HFE in same water year	Yes, if no other spring HFE or extended-duration fall HFE in same water year; no proactive spring HFE in first 2 years	No	No	Yes, if no other spring HFE in same water year

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
High-Flow Experiments (HFEs) (Cont.)								
Fall HFE (Oct. or Nov.)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement when triggered through 2020 when protocol expires	Implement when triggered during entire LTEMP period, but not to exceed one spring or fall HFE every other year	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period	Implement when triggered during entire LTEMP period
Fall HFEs longer than 96-hr duration	Trigger: Paria River sediment input in fall Objective: Rebuild sandbars	No	No	Yes, but HFE volume limited to that of a 45,000-cfs, 96-hr flow (357,000 ac-ft)	Yes, magnitude (up to 45,000 cfs) and duration (up to 250 hr[b]) dependent on sediment supply; limited to no more than four in a 20-year period	No	No	Yes, magnitude (up to 45,000 cfs) and duration (up to 336 hr) dependent on sediment supply
Adjustments to Base Operations								
Reduced fluctuations before HFEs ("load-following curtailment")[c]	Trigger: Significant sediment input from Paria River in Dec.–Mar. or Jul.–Oct. Objective: Conserve sediment input for spring or fall HFE	No	No	Yes, in Feb. and Mar. (spring HFE) or Aug.–Oct. (fall HFE)	No	Yes, in Aug.–Oct. (fall HFE)	No change in operations, which already feature steady flows throughout the year	No change in operations, which already feature steady flows throughout the year

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Reduced fluctuations after HFEs ("load-following curtailment")[c]	Trigger: HFE Objective: Reduce erosion of newly built sandbars	No	No	Yes, until Dec. 1 after fall HFEs, or May 1 after spring HFEs	No	No	No change in operations, which already feature steady flows throughout the year	No change in operations, which already feature steady flows throughout the year
Low summer flows (Jul., Aug., Sep.)	Trigger: Number of adult humpback chub, temperature at Little Colorado River confluence, and release temperature Objective: Improve recruitment of chub in mainstem	No	No	Test if number of adult chub <7,000, <12°C at Little Colorado River confluence, and release temperature is sufficiently warm to achieve 13°C only if low flows are provided; within-day range 2,000 cfs	Test in second 10 years if release temperature is sufficiently warm to achieve 14°C only if low flows are provided; within-day range 2,000 cfs. If initial test is successful, implement under same conditions when humpback chub population concerns warrant its use.	Test in second 10 years if releases have been cold, number of adult chub ≥7,000, and temperature of at least 16°C can be reached	No change in operations, which already feature low flows during summer	No
Macro-invertebrate production flows	Trigger: None Objective: Increase invertebrate production especially mayflies, stoneflies, and caddisflies	No	No	No	Test, but avoid confounding effects on TMFs. Minimum monthly flow would be held constant on Saturdays and Sundays in May through Aug.	No	No	No

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Adjustments to Base Operations (Cont.)								
Hydropower improvement flows (increased fluctuation levels)	Trigger: Annual volume ≤8.23 maf Objective: Test effect on sediment, humpback chub, and trout	No	Maximum daily flow (held for as long as possible): 25,000 cfs (Dec.–Feb., Jun.–Aug.) 20,000 cfs (Sep.–Nov.) 15,000 cfs (Mar.–May) Minimum daily flow all months: 5,000 cfs Ramp rate up and down: 5,000 cfs/hr Test in 4 years	No	No	No	No	No
Trout Management Actions								
Trout management flows	Trigger: Predicted high trout recruitment in Glen Canyon reach Objective: Improve fishery, reduce emigration to Little Colorado River reach, and subsequent competition and predation on humpback chub	Test	Test and implement if successful	Test and implement if successful; tests in first 5 years not dependent on high trout population	Test and implement if successful; test may be conducted early in the 20-year period even if not triggered by high trout recruitment[d]	2 × 2 factorial design testing with/without HFE and with/without TMFs under warm and cold conditions	No	Test and implement if successful

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Non-Flow Actions								
Tier 1: Expanded translocation of humpback chub within the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	No	No	No	Yes	No	No	No
Tier 1: Implement head-start program for larval humpback chub	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	No	No	No	Yes	No	No	No
Mechanical removal of nonnative fish in Little Colorado River reach[e]	Trigger: High trout numbers and low humpback chub numbers in Little Colorado River reach Objective: Increase number of adult and subadult humpback chub	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented until 2020	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	Trout numbers are above and humpback chub numbers are below Tier 2 triggers in Little Colorado River reach	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period	No	Trout numbers are above and humpback chub numbers are below Nonnative Fish Control EA and FONSI triggers in Little Colorado River reach; implemented for entire LTEMP period

TABLE 2-2 (Cont.)

Condition-Dependent Elements	Trigger[a] and Primary Objective	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Non-Flow Actions (Cont.)								
Riparian vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites	No	Yes	Yes	Yes	Yes	Yes	Yes

[a] Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

[b] The duration of extended-duration HFEs would be increased stepwise; the first test of an extended-duration HFE under Alternative D would be limited to 192 hr; depending on the results of that first test, subsequent durations could be up to 250 hr. Sediment concentration in the river would be monitored during the HFE at least during the first test.

[c] Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

[d] For Alternative D, the decision to conduct TMFs in a given year would consider the resource conditions, as specified in Section 2.2.4.3, and would also involve considerations regarding the efficacy of the test based on those resource conditions.

[e] Trout removal in the Paria River–Badger Rapids reach was assessed in the Nonnative Fish Protocol EA. However, it may not be practical based on the estimated level of effort needed to accomplish significant reductions in numbers of trout in the Little Colorado River reach when trout numbers are high in Marble Canyon (Appendix D in Reclamation 2011a).

TABLE 2-3 Flow Parameters under Alternative A in an 8.23-maf Year[a]

Month	Monthly Release Volume[b] (kaf)	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	600	0.0729	9,758	6,000
November	600	0.0729	10,083	6,000
December	800	0.0972	13,011	8,000
January	800	0.0972	13,011	8,000
February	600	0.0729	10,804	6,000
March	600	0.0729	9,758	6,000
April	600	0.0729	10,083	6,000
May	600	0.0729	9,758	6,000
June	650	0.0790	10,924	6,000
July	850	0.1033	13,824	8,000
August	900	0.1094	14,637	8,000
September	630	0.0765	10,588	6,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

Under the current HFE protocol (Reclamation 2011b), high-flow releases may be made in spring (March and April) or fall (October and November). HFE magnitude would range from 31,500 cfs to 45,000 cfs. The duration would range from less than 1 hr to 96 hr. Frequency of HFEs would be determined by tributary sediment inputs, resource conditions, and a decision process carried out by the DOI. The HFE protocol uses a "store and release" approach, in which sediment inputs are tracked over two accounting periods, one for each seasonal HFE: spring (December 1 through June 30) and fall (July 1 through November 30). Implementation of an HFE may require reallocating water from other months in order to maintain at least minimum flows (i.e., 5,000 to 8,000 cfs). The protocol would implement the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling.

One purpose of the HFE protocol is to assess whether multiple, potentially sequential, HFEs conducted under consistent criteria could better conserve sediment resources while not adversely affecting other resources (Reclamation 2011b). The 10-year (2011–2020) experimental period of the protocol provides opportunities for multiple HFEs to be conducted and analyzed. Because necessary sediment and hydrology conditions may not occur every year, the 10-year period increases the likelihood that multiple experiments can be conducted. The protocol incorporates annual resource reviews to provide information that will help to ensure that unacceptable impacts do not occur.

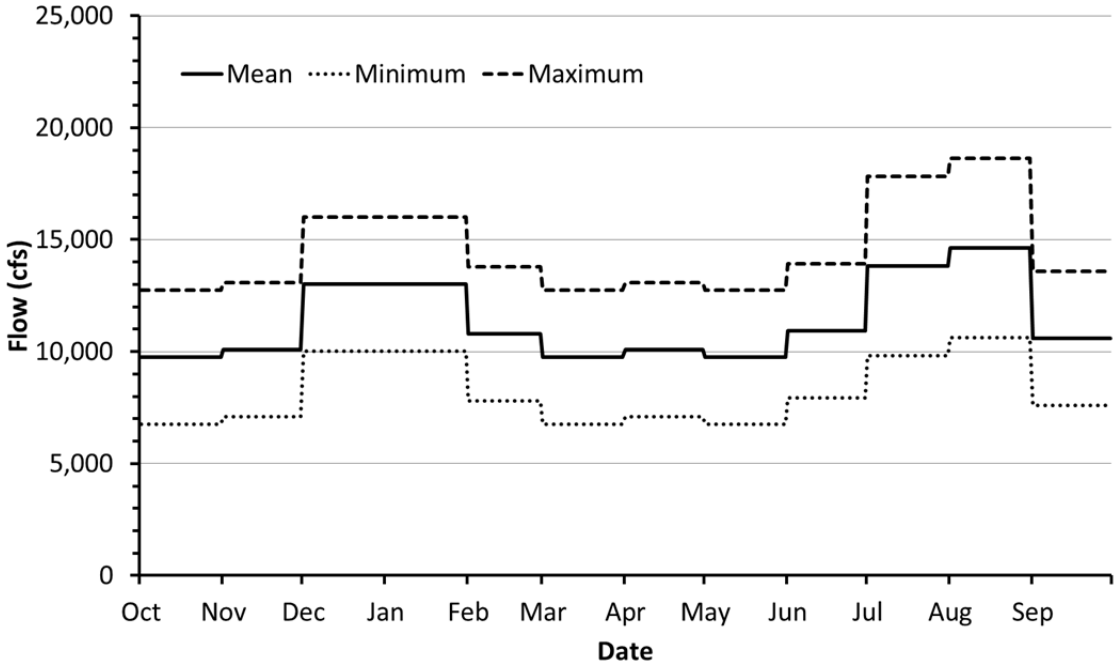

FIGURE 2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an 8.23-maf Year Based on Values Presented in Table 2-3

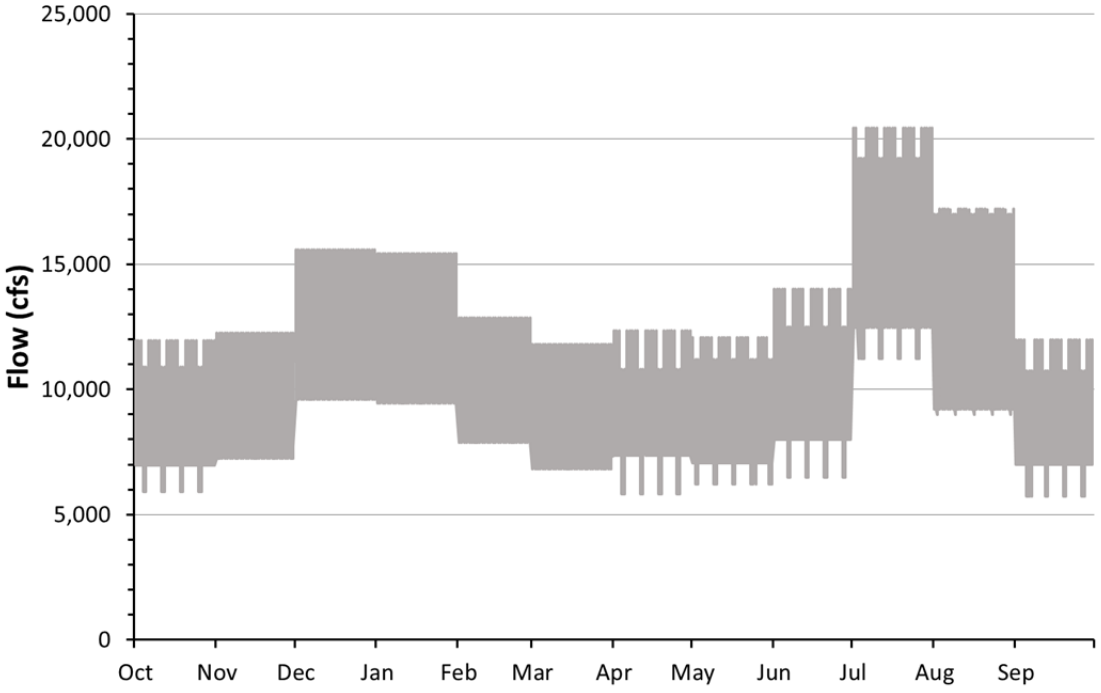

FIGURE 2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-1. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

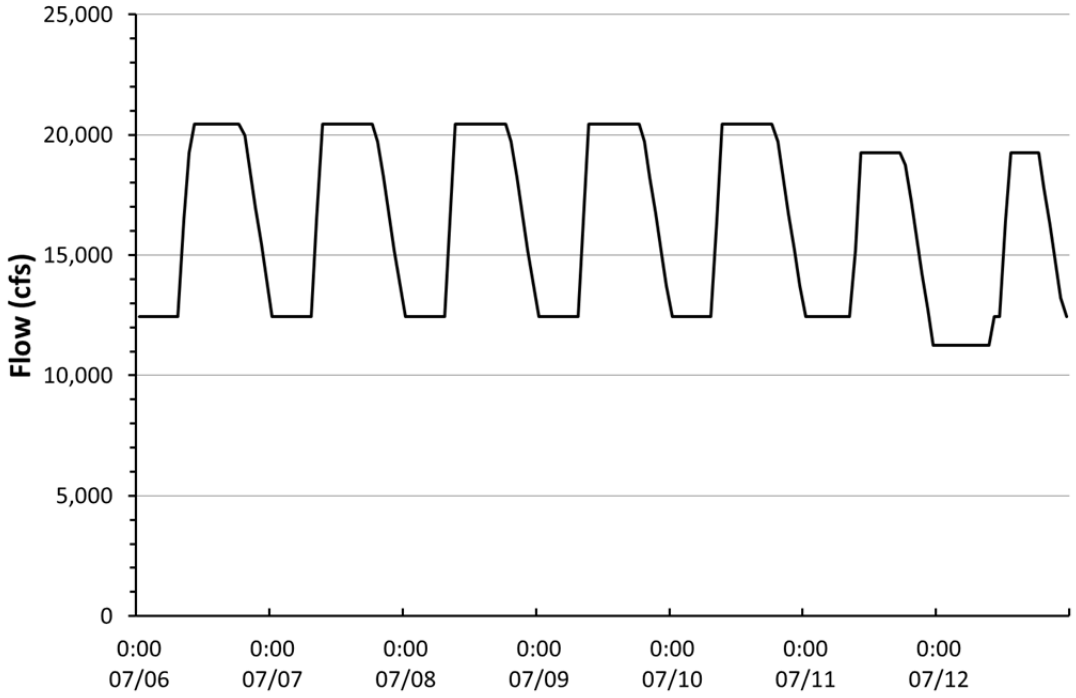

FIGURE 2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

To date, three HFEs have been implemented using the HFE protocol,[1] and they took place on November 18–19, 2012 (24 hr at 42,300 cfs), November 11–16, 2013 (96 hr at 34,100 cfs), and November 10–15, 2014 (96 hr at 37,500 cfs).

Reclamation also recently established a 10-year protocol (to expire in 2020) for trout removal and tests of TMFs (Reclamation 2011a). In part, this protocol was established to coincide with the HFE protocol because there is evidence that HFEs may result in an increase in trout production (Korman, Kaplinski et al. 2011; Melis et al. 2011), which may have negative effects, through competition and predation, on humpback chub. Under the protocol, trout removal may occur in two reaches—the Paria River–Badger Rapids reach (RM 1–RM 8)[2] and the Little Colorado River reach (RM 56–RM 66). The impacts of implementing the protocol were originally described in the Nonnative Fish Control EA (Reclamation 2011a) and are further

1 In November 2015, there was sufficient sediment input from the Paria River to support a 96-hr HFE; however, an HFE was not implemented due to concerns that arose after the discovery of the invasive nonnative green sunfish (*Lepomis cyanellus*) in the Glen Canyon reach.

2 An initial planned test of trout removal in the Paria River–Badger Rapids reach in 2012 was cancelled due to concerns about whirling disease. Removal in the Paria River–Badger Rapids reach may not be practical based on the estimated level of effort needed to accomplish significant reductions in numbers of trout in the Little Colorado River reach when trout numbers are high in Marble Canyon (Appendix D in Reclamation 2011a).

analyzed in this EIS. Mechanical removal would primarily consist of the use of boat-mounted electrofishing equipment to remove all nonnative fish captured. Motorized electrofishing boats would operate during the night over a period of up to 2 weeks, utilizing gas generators to power lights and electrofishing equipment. Captured nonnative fish would be removed alive and potentially stocked into areas that have an approved stocking plan, unless live removal fails, in which case fish would be euthanized and used for later beneficial use (Reclamation 2011a). Since 2011, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters.

Experimental components of Alternative A would be consistent with those that are part of the current program, including those detailed in the HFE and Nonnative Fish Control EAs and those identified as elements potentially common to all alternatives described above.

2.2.2 Alternative B

The objective of Alternative B is to increase hydropower generation while limiting impacts on other resources and relying on flow and non-flow actions to the extent possible to mitigate impacts of higher fluctuations. CREDA submitted this alternative for analysis and consideration in the LTEMP DEIS. The alternative is similar to the "Option A Variation," which was one of four options developed and evaluated by the GCDAMP and GCMRC in early planning efforts for the LTEP DEIS. Alternative B focuses on non-flow actions and experiments to address sediment resources, nonnative fish control, and native and nonnative fish communities. Alternative B originally included several elements that were determined to be either outside the scope of this EIS, were already part of a previous NEPA process, or were dismissed for other reasons. See Section 2.4 for elements that were considered but dismissed (i.e., sediment augmentation, bubblers in the Lake Powell forebay, bypass tube generators, and sediment check dams).

Under Alternative B, monthly volumes would be the same as under current operations, but daily flow fluctuations would be higher than under current operations in most months (Table 2-4; Figure 2-4). Increases would be greatest in February, which would have an approximately 66% increase in fluctuations over current operations (10,000 cfs versus the current 6,000 cfs range), while December and January would increase fluctuations approximately 50% (12,000 cfs versus the current 8,000 cfs range). Daily flow fluctuations would be increased by approximately 25% in March, June, September, October, and November (8,000 versus 6,000 cfs), and in July and August (10,000 versus 8,000 cfs). Fluctuations would remain unchanged relative to current operations (6,000 cfs) only in April and May (Tables 2-1, 2-2, and 2-4; Figure 2-4). Compared to current operations, the hourly up-ramp rate would remain unchanged at 4,000 cfs/hr, but the hourly down-ramp rate would be increased to 4,000 cfs/hr in November through March and 3,000 cfs/hr in other months. Figure 2-4 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-5 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative B. Figure 2-6 shows details of hourly flows during a week in July.

TABLE 2-4 Flow Parameters under Alternative B in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	600	0.0729	9,758	8,000
November	600	0.0729	10,083	8,000
December	800	0.0972	13,011	12,000
January	800	0.0972	13,011	12,000
February	600	0.0729	10,804	10,000
March	600	0.0729	9,758	8,000
April	600	0.0729	10,083	6,000
May	600	0.0729	9,758	6,000
June	650	0.0790	10,924	8,000
July	850	0.1081	13,824	10,000
August	900	0.1045	14,637	10,000
September	630	0.0765	10,588	8,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

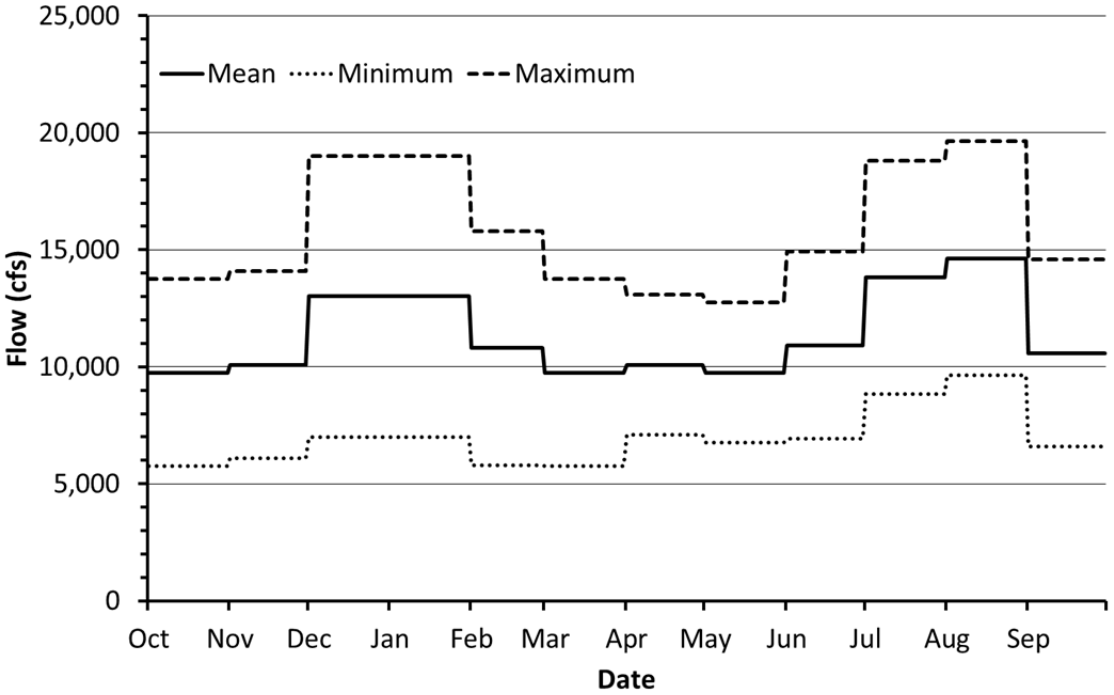

FIGURE 2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4

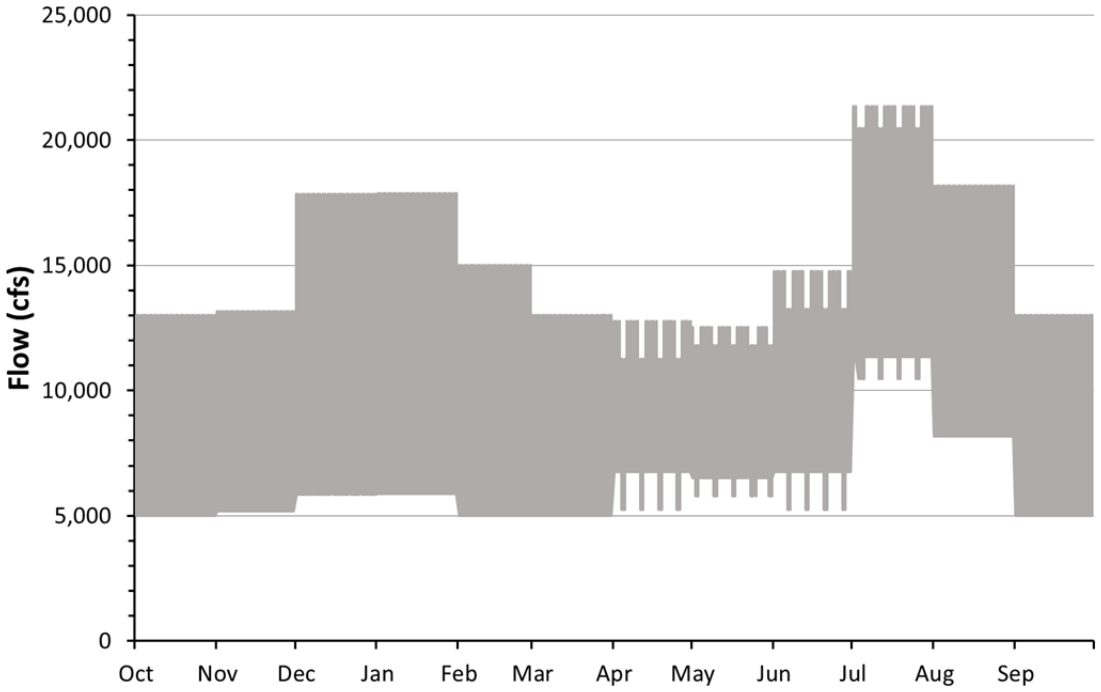

FIGURE 2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-4. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

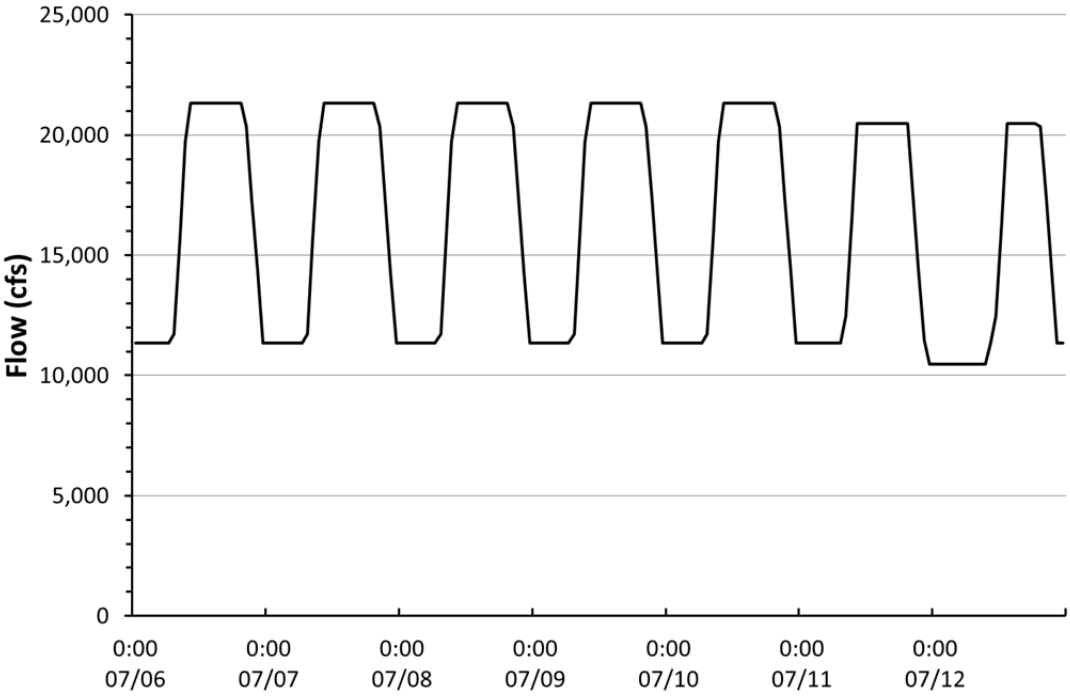

FIGURE 2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

Alternative B includes these elements:

- Implementation of the Nonnative Fish Control protocol (Reclamation 2011a);
- Implementation of the HFE protocol (Reclamation 2011b), but limiting HFEs to a maximum of one every other year;
- Experimental vegetation removal and replanting activities where appropriate.

Experimental components of Alternative B would include those detailed in the HFE and Nonnative Fish Control EAs (Reclamation 2011a,b). Alternative B also includes experiments to analyze specific hypotheses. The specifics of the flows that would be tested in these experiments would be subject to reservoir levels, hydrologic conditions, powerplant maintenance, and economic considerations, and would include the following:

- **TMFs:** TMFs would maintain elevated flows for 2 or 3 days, followed by a very sharp drop in flows to a minimum level for the purpose of reducing annual recruitment of trout. TMFs are described in greater detail in Section 2.2.3.
- **Hydropower improvement experiment:** Alternative B includes testing maximum powerplant capacity releases in up to four years during the LTEMP period, but only in years with annual volumes ≤8.23 maf. Under hydropower improvement flows, within-day releases during the high-demand months of December, January, February, June, July, and August would vary between 5,000 cfs at night and 25,000 cfs during the day; from September through November within-day releases would vary from 5,000 to 20,000 cfs; and from March through May within-day releases would vary from 5,000 to 15,000 cfs (Figures 2-7, 2-8, and 2-9). Up- and down-ramp rates would be 5,000 cfs/hr throughout the year. Years with annual flows ≤8.23 maf typically require firming purchases by WAPA to meet contractual demand; thus, the experiment could mitigate some of those more costly purchases in the high-power months. The experiment is intended to evaluate the effects of maximum powerplant operations on critical resources in the Colorado River Ecosystem.

Under Alternative B, experimental treatments would be implemented as soon as feasible during the LTEMP period. Using this approach, experimental treatments would be implemented at the initiation of the LTEMP period, and they would be eliminated or retained based on their success in providing resource benefits and avoiding adverse resource impacts.

2.2.3 Alternative C

The objective of Alternative C is to adaptively operate Glen Canyon Dam to achieve a balance of resource objectives with priorities placed on humpback chub, sediment, and minimizing impacts on hydropower. Alternative C features a number of condition-dependent

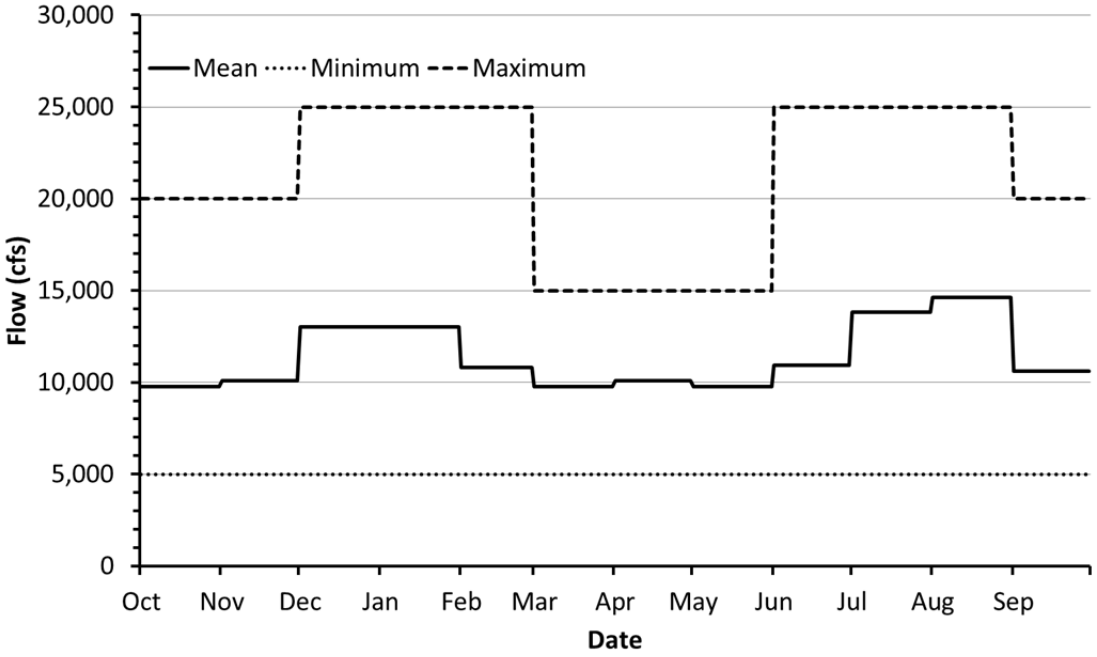

FIGURE 2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year

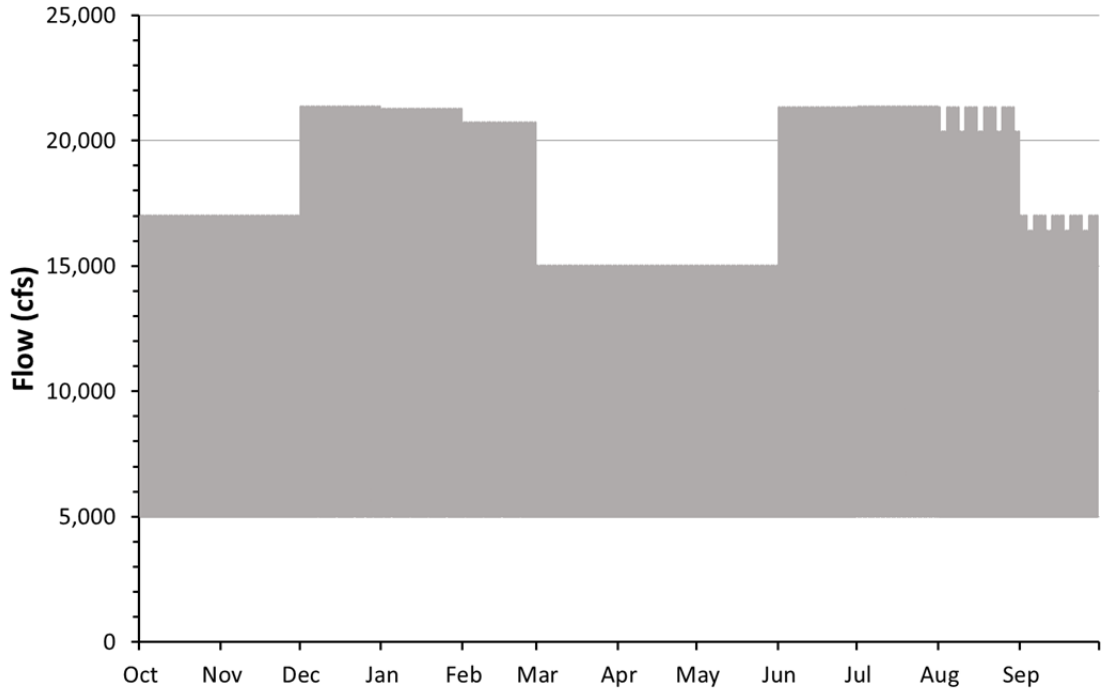

FIGURE 2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-7. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

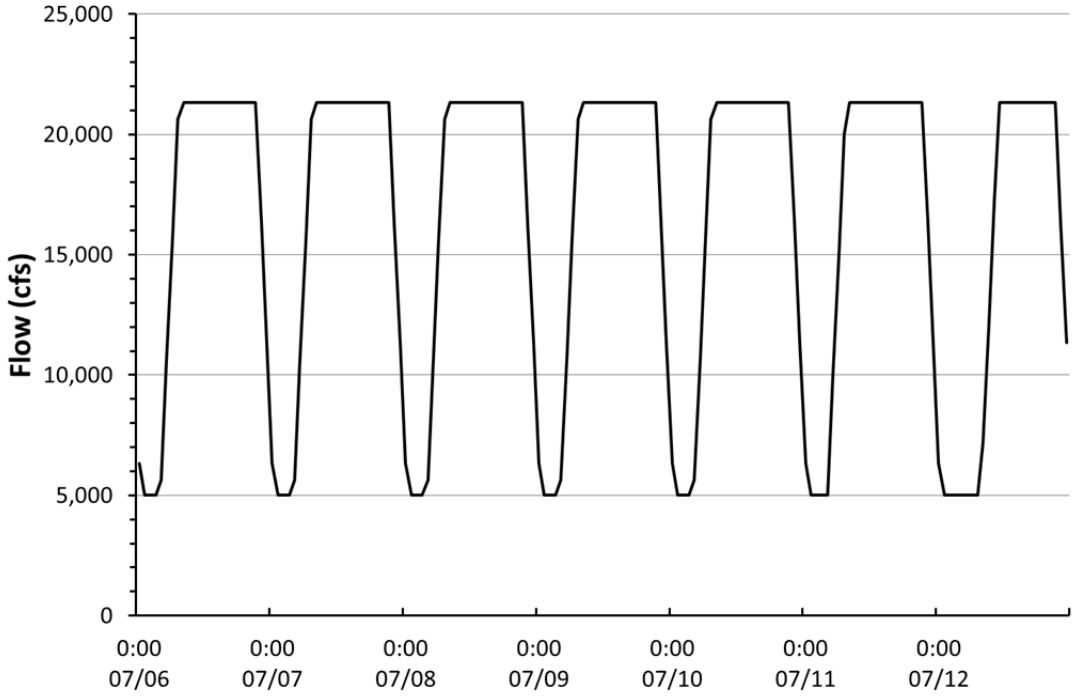

FIGURE 2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B for a Week in July in an 8.23-maf Year (The week starts on Monday and ends on Sunday.)

flow and non-flow actions that would be triggered by resource conditions (Table 2-2). The alternative uses decision trees to identify when a change in base operations or some other planned action is needed to protect resources. Operational changes or implementation of non-flow actions could be triggered by changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature.

2.2.3.1 Base Operations under Alternative C

Under base operations of Alternative C, monthly release volumes in August through November would be lower than those under most other alternatives to reduce sediment transport rates during the monsoon period. Release volumes in the high power demand months of December, January, and July would be increased to compensate for water not released in August through November, and volumes in February through June would be patterned to follow the monthly hydropower demand as defined by the contract rate of delivery (Tables 2-1 and 2-5; Figure 2-10).

TABLE 2-5 Flow Parameters under Alternative C in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	480	0.0583	7,806	3,360
November	480	0.0583	8,067	3,360
December	830	0.1009	13,499	5,810
January	830	0.1009	13,499	5,810
February	730	0.0887	13,148	5,111
March	771	0.0937	12,539	5,397
April	686	0.0833	11,524	4,800
May	710	0.0863	11,551	4,972
June	743	0.0903	12,485	5,200
July	830	0.1009	13,499	5,810
August	660	0.0802	10,734	4,620
September	480	0.0583	8,067	3,360

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

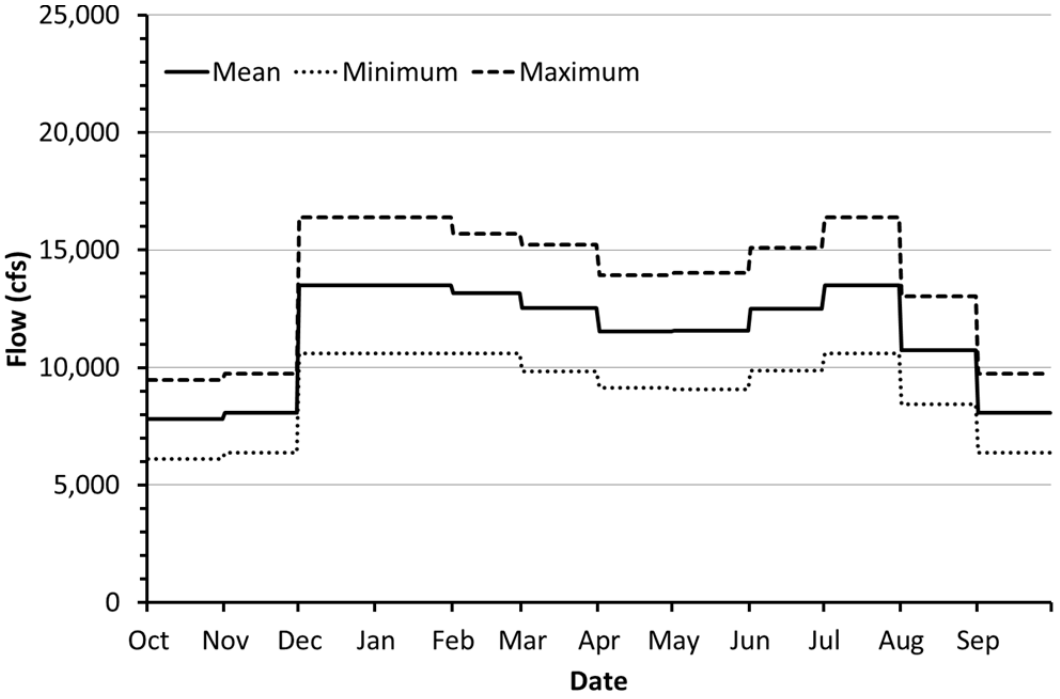

FIGURE 2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5

Reductions in August and September volumes also were intended to result in a slight increase in temperature relative to Alternative A at the confluence with the Little Colorado River. Warmer temperatures are expected to provide humpback chub and other native fish with some benefit during the critical time of year when many young-of-the-year (YOY) fish move from the Little Colorado River into the mainstem Colorado River.

Under base operations, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to monthly volume (7× monthly volume in kaf; e.g., daily range in a month with a volume of 800 kaf would be 5,600 cfs). The factor of 7 was chosen because it would provide improvement in sediment conservation relative to MLFF while limiting the effect on hydropower capacity and value. The down-ramp rate would be 2,500 cfs/hr (an increase from 1,500 cfs/hr under Alternative A); the up-ramp rate would be 4,000 cfs/hr as under Alternative A. Figure 2-10 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-11 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative C. Figure 2-12 shows details of hourly flows during a week in July.

2.2.3.2 Implementation Process for Experiments under Alternative C

Alternative C adopts a condition-dependent experimental approach. The underlying approach is to adopt a base operation that would serve as a long-term strategy to provide the conditions needed to support natural and cultural resources while reducing impacts on hydropower. Since there is uncertainty regarding future hydrologic conditions, sediment supply, and resource response to operational, experimental, and environmental conditions, Alternative C identifies condition-dependent flow and non-flow actions intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes.

Alternative C would use decision trees, tied to information collected under a long-term monitoring program, that would be implemented annually or, in some cases, as needed, to determine operations and flow and non-flow actions in a given year. Implementation would be closely integrated with existing operational and experimental decision processes involving Reclamation, NPS, USGS, and GCDAMP. Decision trees for sediment-related and humpback chub–related actions are shown in Figures 2-13 and 2-14.

Implementation criteria for experimental elements of Alternative C are provided in Table 2-6. Included are the triggers for tests, conditions that would prevent a test from being conducted (implementation considerations), conditions that would cause the test to be terminated prior to completion (off-ramps), and the number of replicates needed. In general, two to three replicates are considered necessary for all tests. Only two tests may be needed if consistent results are obtained for each replicate (e.g., both tests showed a benefit, or both showed an adverse effect). Three tests may be needed if the first two tests showed opposite results (i.e., one benefit, one adverse effect).

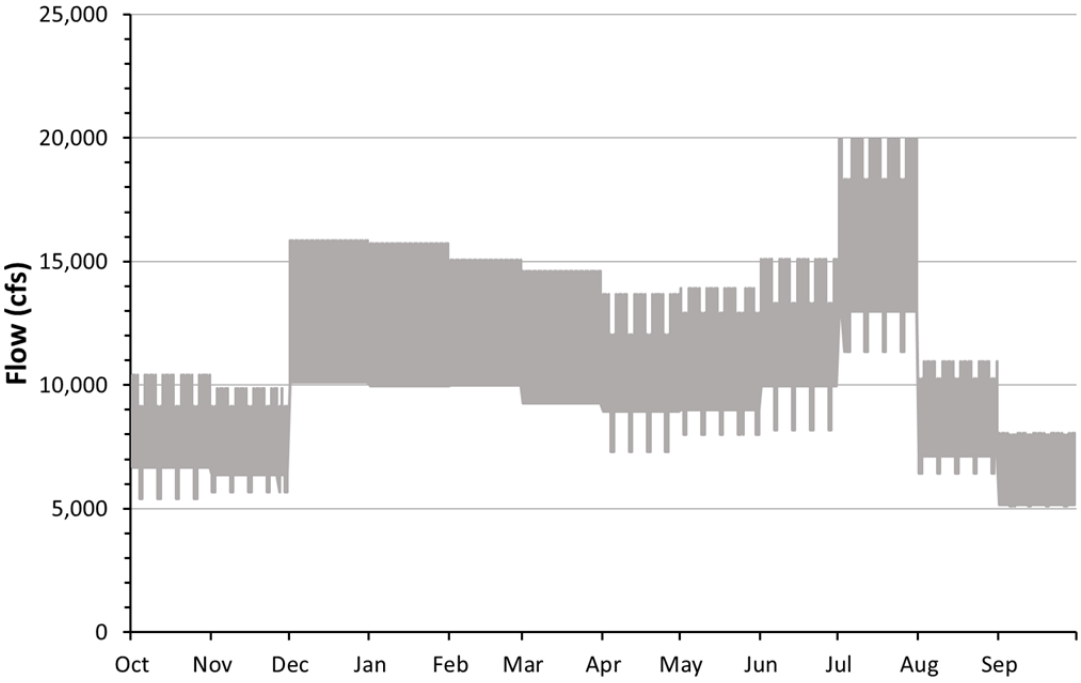

FIGURE 2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-10. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

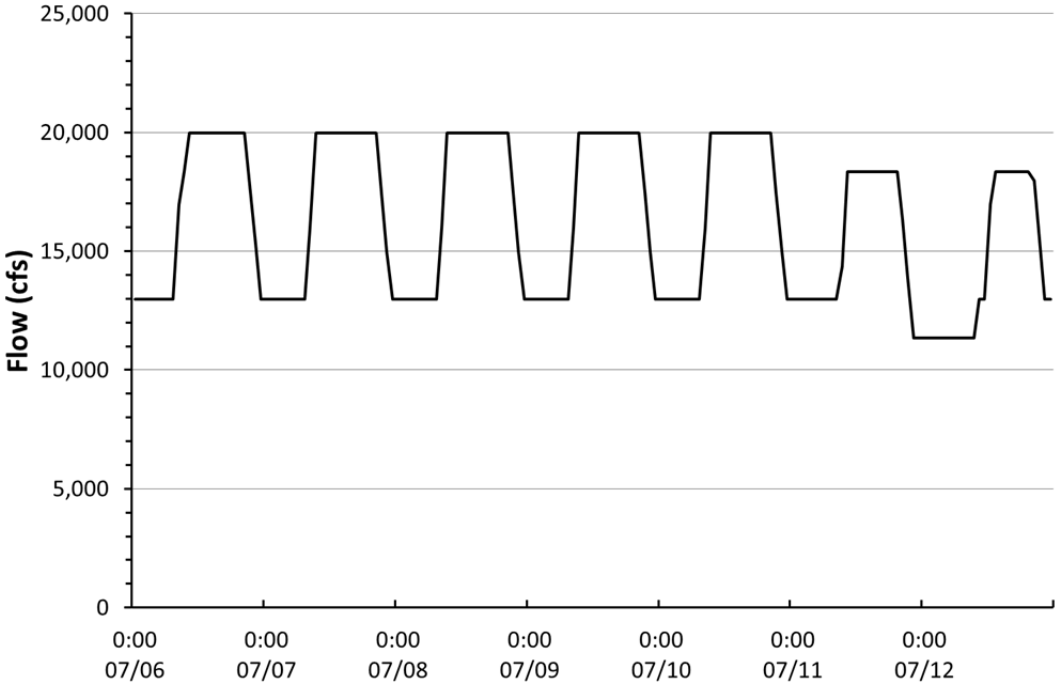

FIGURE 2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

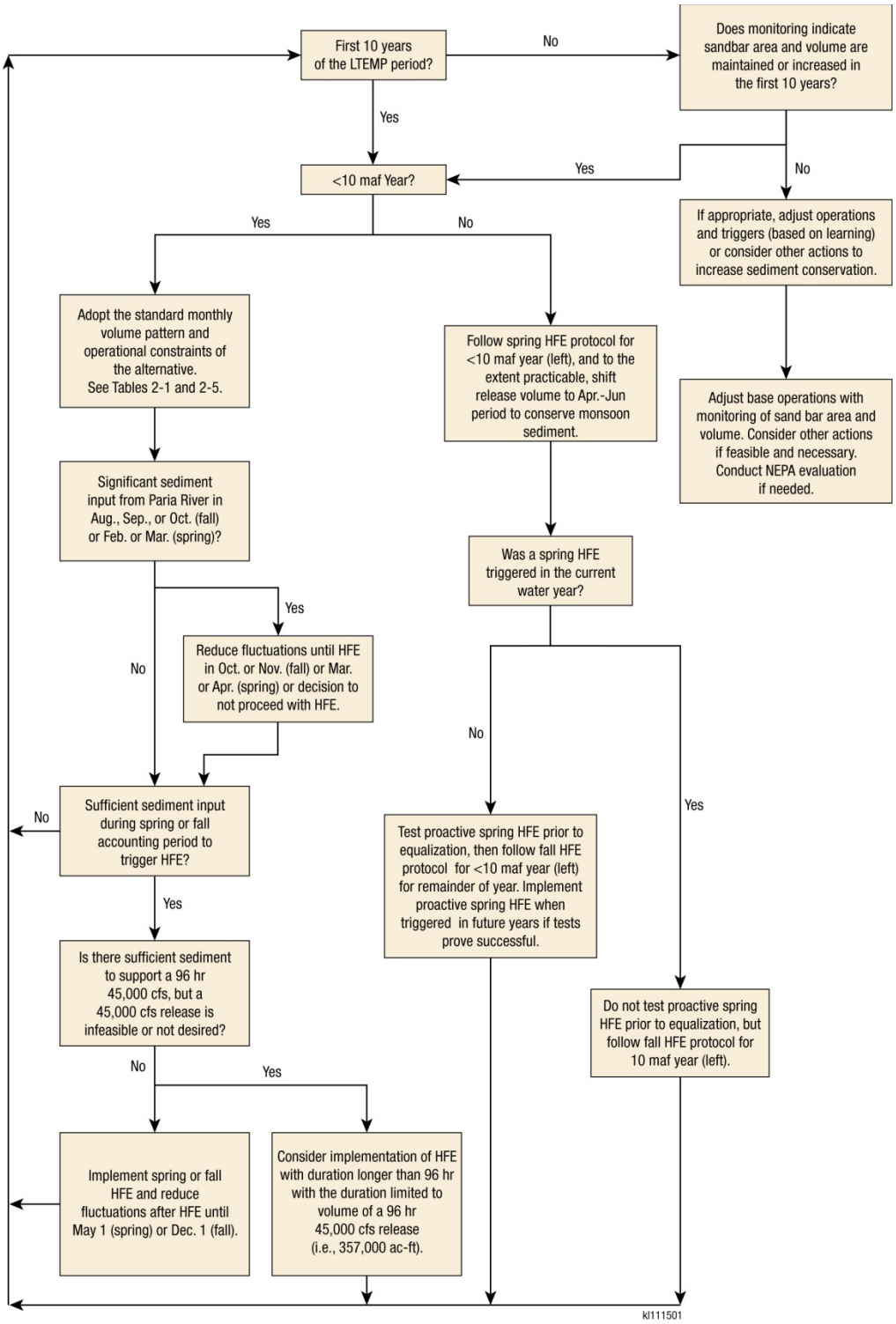

FIGURE 2-13 Decision Tree for Sediment-Related Actions under Alternative C (Implementation would be conditional on considerations presented in Table 2-6. If off-ramp conditions listed in Table 2-6 exist, related experimental treatments would be discontinued.)

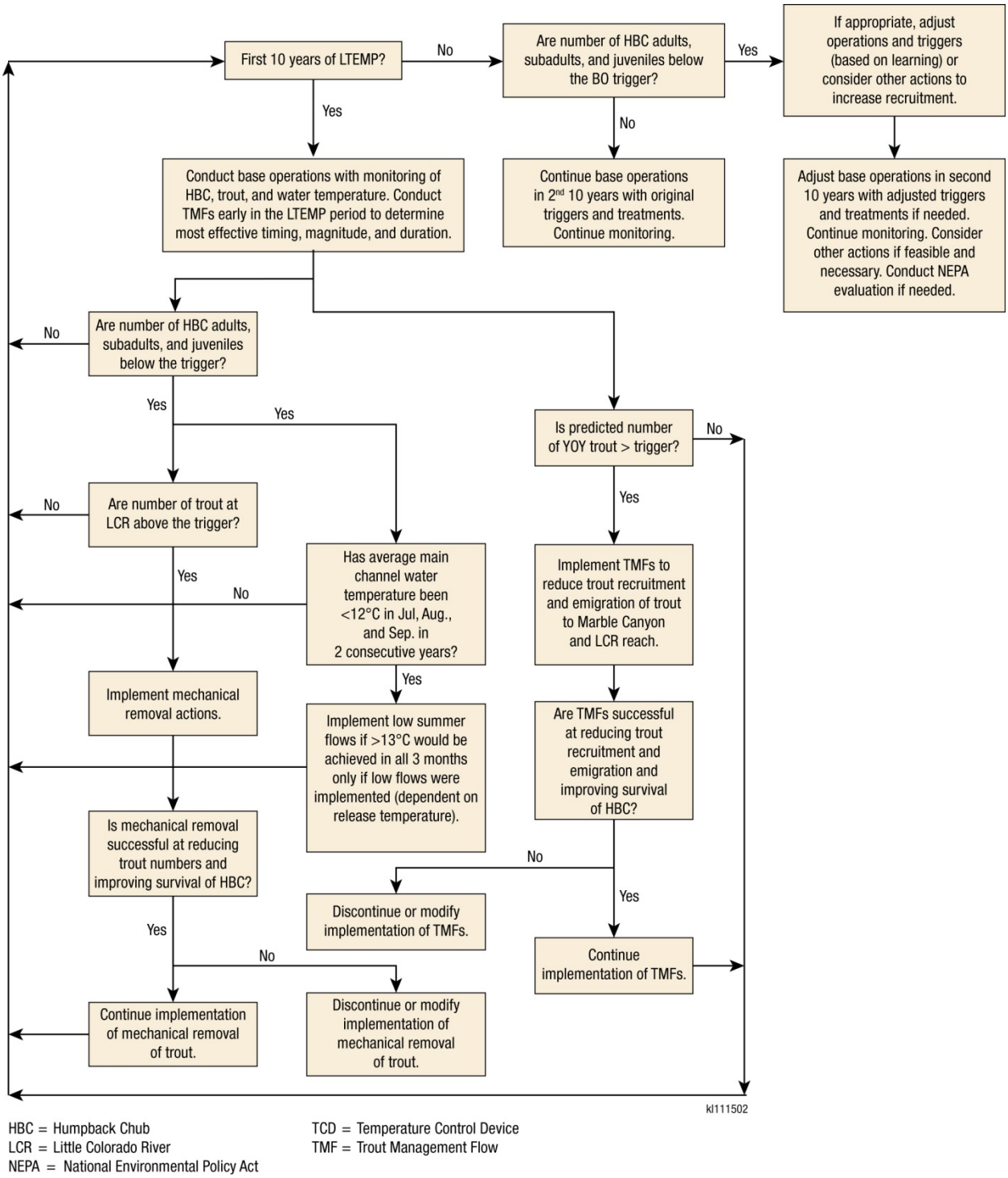

FIGURE 2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C (Implementation would be conditional on considerations presented in Table 2-6. If off-ramp conditions listed in Table 2-6 exist, related experimental treatments would be discontinued.)

TABLE 2-6 Implementation Criteria for Experimental Treatments of Alternative C

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments						
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs	HFEs were not effective in building sandbars; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from balancing and equalization releases	Implement in each year triggered, dependent on resource condition and response	24 hr	Same as spring HFEs	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments (Cont.)						
Fall HFE up to 45,000 cfs (Oct. or Nov.)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources; unacceptable cumulative effects of sequential HFEs	Same as spring HFEs	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs longer than 96-hr duration limited to the volume of a 96-hr 45,000-cfs release (357,000 ac-ft)	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of a 96-hr 45,000-cfs HFE, but a 45,000-cfs release is either not possible due to turbine outages or not desired Objective: Mobilize as much sediment as possible within the volume constraints of the HFE protocol	Implement in each year triggered	Limited by the volume of a 96-hr 45,000-cfs release (357,000 ac-ft) (a 137-hr 31,500-cfs release would comply with this volume constraint)	Same as fall HFEs	HFEs were not effective in building sandbars and resulting sandbars were no bigger than those created by shorter-duration HFEs; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Sediment Experiments (Cont.)						
Reduced fluctuations before and after HFEs ("load-following curtailment")[d]	Trigger: Spring or fall HFE Objective: Retain sediment before HFE and reduce erosion of newly built sandbars after HFE	Implement when triggered	Up to 4 months before (Jul.–Nov.) and 2 months after (Oct. –Nov.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Resulting sandbars were no bigger than those created without reduced fluctuation; or adverse impacts on trout fishery, humpback chub population, or other resources	Implement as adaptive treatment in association with HFEs when existing resource conditions allow
Aquatic Resource Experiments						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and competition and predation of chub	Implement as needed when triggered; test may be conducted early in the 20-year period even if not triggered by high trout recruitment; contingent on Tribal consultation	Implemented in as many as 4 months (May–Aug.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Little or no reduction in trout recruitment after at least three tests; or adverse impacts on trout fishery, humpback chub population, or other resources	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon taking into consideration Tribal concerns

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Experiments (Cont.)						
Mechanical removal of trout in Little Colorado River reach	Trigger: Number of trout in Little Colorado River reach and number of humpback chub Objective: Test efficacy of control on trout numbers and competition and predation of chub	Implement in each year triggered unless determined ineffective, contingent on Tribal consultation	Up to six monthly removal trips (Feb.–Jul.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	Little or no reduction in trout density at the Little Colorado River, or unacceptable adverse impacts on humpback chub population or other resources	Implement as adaptive treatment when triggered taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target ≥13°C at Little Colorado River confluence	Trigger: Chub numbers are below trigger, water temperature has been <12°C for two consecutive years and target temperature of ≥13°C can only be achieved if drop to low flow Objective: Test efficacy of low summer flows on warming and humpback chub growth	If needed, two to three tests would be conducted in second 10 years of 20-year period; would not be implemented in first 10 years	3 months (Jul.– Sep.)	Potential unacceptable impacts on water delivery or key resources such as humpback chub, sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, the rainbow trout fishery, recreation, and other resources	No increase in growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; or adverse impacts on the trout fishery, humpback chub population, or other resources	Implement as adaptive treatment when conditions allow

TABLE 2-6 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long-Term Off-Ramp Conditions[c]	Action if Successful
Riparian Vegetation Experiment						
Non-flow vegetation treatment activities	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential unacceptable site-specific impacts on sediment, riparian ecosystems, historic properties and traditional cultural properties, Tribal concerns, recreation, or other resources	Control and replanting techniques not effective or practical	Implement as adaptive treatment if invasive species can be reduced and native species increased

a Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

b Annual determination by the DOI. Any implementation would consider resource condition assessments and resource concerns using the annual process described in Section 2.2.3.3.

c Temporary or permanent suspension if the DOI determines effects cannot be mitigated.

d Hourly water release volumes would be nearly the same among all hours, while allowing for fluctuations in instantaneous flow rates to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

In general, the first 10 years of base operations and strategic tests would be used to test the effects of operations and experimental elements on resources, to determine the strategy for the second 10 years of implementation, and, ultimately, to help determine a long-term strategy for Glen Canyon Dam operations and management actions that benefit important downstream resources, while minimizing impacts on hydropower to the extent practicable.

If sandbar area and volume are maintained or increased in the first 10 years of the LTEMP, the combination of base operations and HFE implementation would continue as prescribed above. If sandbar area and volume declines during the first 10 years of LTEMP, the HFE protocol and/or base operations may be modified, as allowable, to increase sediment conservation based on information learned in the first 10 years. In addition, the DOI would consider applicable planning processes for sediment augmentation and would conduct a separate NEPA evaluation of augmentation if it is considered feasible and necessary to prevent continued loss of sediment resources.

The relative effects of temperature and trout predation and/or competition on humpback chub recovery are uncertainties that affect the selection of a future management strategy; Alternative C would attempt to resolve this uncertainty. If after 10 years humpback chub are declining, nonstructural options for creating warmwater (i.e., flow manipulations) were not successful in providing warmer temperatures, and evidence suggests that trout control alone is not sufficient to improve humpback chub numbers, the DOI would consider a separate NEPA evaluation and other appropriate planning processes for a structural change such as a temperature control device (TCD). Research and monitoring during the first 10 years also could indicate that other factors (e.g., parasites, pathogens, warmwater nonnatives, or food base) are limiting humpback chub numbers. Such information would be used to develop additional condition-dependent actions or adjustments to base operations other than those included in the alternative at the start of the LTEMP.

No experimental flow actions are planned specifically for riparian vegetation under Alternative C. However, as described in the introduction to Section 2.2, a pilot experimental vegetation treatment program would be implemented under this and other alternatives to control nonnative vegetation encroachment and restore native vegetation at selected sites. If successful, vegetation treatment actions would be considered for inclusion as a regular non-flow action implemented throughout the LTEMP period. There are no specific experimental tests or condition-dependent actions that specifically focus on historic site preservation or Tribal cultural properties and resources other than operations and actions intended to reduce sediment transport in the active river channel. During the first 10 years of the LTEMP, continued evaluation of site stability and integrity would be undertaken in coordination with sediment evaluations consistent with the existing HFE protocol. Similarly, continued evaluation of Traditional Cultural Properties and resources of cultural concern would be evaluated by traditional practitioners and knowledgeable Tribal scholars. Mitigation would be undertaken to address resource impacts as determined necessary in consultation with Tribes. If monitoring indicates that historical properties preservation and Tribal cultural properties and resources are adversely affected by operations in the first 10 years of LTEMP implementation, the DOI would consider modification of operations to address aspects that, based on the results of monitoring and Tribal consultation,

are causing degradation of these resources, and would consider an increase in non-flow actions, in consultation with the Tribes, to achieve these two resource goals.

Base operations under Alternative C would be experimentally modified in response to changes in resource conditions or the need for equalization as specified under the 2007 Interim Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation of HFEs in response to sediment inputs or equalization flows; (2) reductions in flow fluctuation in spring and fall in response to sediment inputs or the occurrence of HFEs; (3) flow actions in the spring and summer to control the Glen Canyon reach trout population; and (4) reductions in flows in certain years from July through September to provide warmer water for humpback chub near the confluence with the Little Colorado River. Non-flow actions are largely limited to those that are common to all alternatives as described at the beginning of Section 2.2.

2.2.3.3 Sediment-Related Experiments To Be Evaluated under Alternative C

Under Alternative C, the HFE protocol would be incorporated into the LTEMP process and extended to the end of the LTEMP period. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period using the same Paria River sediment input thresholds as used under the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods, the maximum possible magnitude (not to exceed 45,000 cfs) and duration of HFE (up to approximately 140 hr) that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented (see Section 2.2.1 for a brief description of the existing HFE protocol).

Daily fluctuations for load-following would be reduced (except for instantaneous increases or decreases in flow to provide ancillary services)[3] after significant sediment input (sufficient input to trigger an HFE) from the Paria River in February or March (in anticipation of a spring HFE); or August, September, or October (in anticipation of a fall HFE) to increase the amount of sediment available for transport and deposition by spring and fall HFEs. These reduced fluctuations would occur until an HFE was implemented or a decision to not implement an HFE was made. If an HFE was implemented, the restriction in daily fluctuations would continue after the HFE occurred until May 1 (spring HFE) or December 1 (fall HFE) to reduce the erosion of newly formed sandbars. Under Alternative C, within-day fluctuations in hourly flows would be reduced to a within-day range of 2,000 cfs (i.e., ±1,000 cfs of the mean daily flow).

Sandbar monitoring after the 2011 equalization releases indicated that high rates of sandbar erosion and sediment transport occurred during equalization. To offset these high

[3] Instantaneous changes in flows could occur within an hour to accommodate regulation services and calls on reserve generation to respond to system emergencies. Regulation affects instantaneous operations that deviate above and below the mean hourly flow with minimal impact on the mean hourly flow.

erosion and transport rates, Alternative C includes a proactive spring HFE in years when the April forecast indicates an annual release ≥10 maf. In these years, a 24-hr spring high flow (up to 45,000 cfs) would be tested prior to the occurrence of high equalization releases to determine the effectiveness of using high flows to conserve sediment downstream of the Paria River confluence above the elevation of equalization flows. The high flow would be timed to occur after the need for equalization has been determined, but before it was actually implemented. This would likely result in proactive spring HFEs occurring in May or June.

Under Alternative C, a proactive spring HFE would not be tested if there had been a spring HFE in the same water year. In high-volume years (≥10 maf) when there were no proactive spring HFEs, higher monthly volumes would be shifted to the April through June time period to the extent practicable to avoid sustained higher monthly flows and sediment transport rates at the end of the year.

The existing HFE protocol allows for HFEs up to 96 hr long, but there will be some years when a 45,000-cfs HFE is not feasible (e.g., one or more generating units are not available) and a longer duration release would be possible and desirable to achieve sediment goals. Under Alternative C, longer duration HFEs that did not exceed the total volume of a 96-hr, 45,000-cfs HFE (i.e., 357,000 ac-ft) would be allowed.

2.2.3.4 Aquatic Resource-Related Experiments To Be Evaluated under Alternative C

Under Alternative C, experimental flow and non-flow actions could be triggered by estimated numbers of rainbow trout, a combination of estimated numbers of rainbow trout and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the action under consideration. Humpback chub triggers and trout triggers would be developed with FWS, and there would be consultation with the AZGFD and other entities as appropriate. These triggers may be modified based on experimentation conducted early in the LTEMP period.

The humpback chub population in Grand Canyon has increased considerably under MLFF operations since the early 2000s. During this period, relatively warmer temperatures began to be reached at the Little Colorado River confluence as a consequence of lower reservoir elevations and concomitantly higher release temperatures; this warming may have contributed to the increase in humpback chub recruitment (Section 3.5.3). Base operations under Alternative C are intended to support continued and possibly improved humpback chub recruitment. Ongoing monitoring would be used to determine the need to adjust base operations to benefit humpback chub.

Under Alternative C, water temperature and trout numbers would be considered when determining the actions to take when chub numbers drop below the trigger levels identified above. Triggers for temperature and trout numbers would be used under Alternative C to trigger two potential actions: (1) low summer flows and (2) mechanical removal of trout. These are discussed individually below.

Two types of trout control actions are considered under Alternative C: (1) TMFs; and (2) mechanical removal. Both of these experimental actions could be implemented to reduce trout competition with and predation of humpback chub in the Little Colorado River reach or to manage the Glen Canyon rainbow trout fishery.

Mechanical Removal of Trout under Alternative C

Mechanical removal would occur at the Little Colorado River confluence (rainbow and brown trout) and would follow the protocol evaluated in the Nonnative Fish Control EA (Reclamation 2011a; see Section 2.2.1 of this EIS for a brief description of the protocol). Mechanical removal in the Little Colorado River reach (RM 56–RM 66) would be triggered by low humpback chub and high trout abundance estimates in the Little Colorado River reach. Mechanical removal, however, may be initiated in response to ongoing management of the trout fishery by the NPS (an element common to all alternatives) or in response to declining humpback chub numbers. The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly the Pueblo of Zuni, because it is a taking of life in the canyon. To the extent practicable, removal practices would include finding beneficial uses for removed fish, as has been practiced for trout removal actions at Bright Angel Creek.

Trout Management Flows under Alternative C

TMFs are a special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging YOY trout (Figure 2-15). TMFs have been proposed and developed on the basis of research described in Korman et al. (2005). The underlying premise of TMFs is based on observations that YOY trout tend to occupy near-shore shallow-water habitats to avoid predation by larger fish. TMFs feature repeated fluctuation cycles that consist of relatively high flows (e.g., 20,000 cfs) sustained for a period of time (potentially ranging from 2 days to 1 week) followed by a rapid drop to a very low flow (e.g., 5,000 cfs to 8,000 cfs).[4] This low flow would be maintained for a period of less than a day (e.g., 12 hr) to prevent adverse effects on the food base. Low flows would be timed to start in the morning, after sunrise, to expose stranded fish to direct sunlight and heat. Up-ramp rates to the TMF would be the same as the limit for this alternative overall (i.e., 4,000 cfs/hr). The down-ramp from peak to base would be over a single hour (e.g., 15,000 cfs/hr for a drop from 20,000 cfs to 5,000 cfs). In a TMF flow cycle, YOY trout are expected to occupy near-shore habitat when flows are highest, and would be stranded by the sudden drop to low flow. Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs. TMFs would be used to control trout recruitment in the Glen Canyon reach to manage the rainbow trout fishery, and to limit emigration of juvenile trout to downstream reaches, particularly to habitat occupied by humpback chub near the confluence

[4] TMFs have the potential to result in stranding of boats in the Glen Canyon reach, as well as a potential risk to public safety. Public notification and outreach in advance of implementing TMFs, as is currently done for planned HFEs, would be necessary to avoid safety concerns.

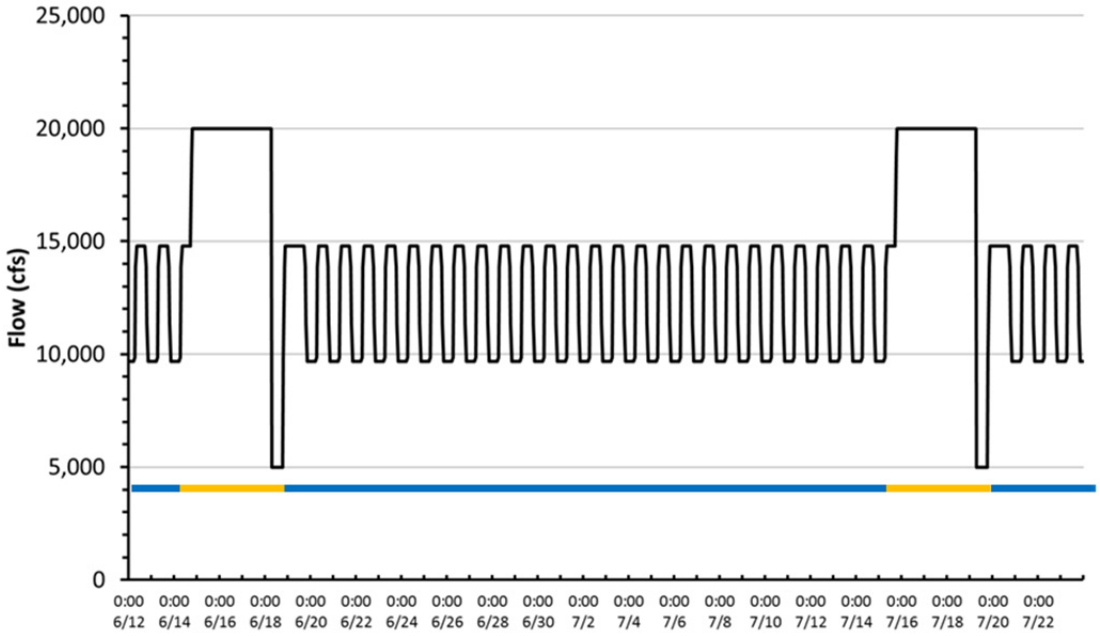

FIGURE 2-15 Example Implementation of a Two-Cycle TMF in June and July with Resumption of Normal Fluctuations between Cycles and Afterward (Monitoring for effectiveness would occur before and after each cycle. The horizontal line below the graph shows periods of normal fluctuation [blue] and TMFs [orange].)

with the Little Colorado River. Triggers for implementation of TMFs would be determined in consultation with the AZGFD.

It should be noted that several Tribes have expressed concerns about TMFs as a taking of life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-lead agencies will continue to work with the Tribes regarding options for trout management.

TMFs may be tested under this alternative early in the LTEMP period, even if not triggered by high trout recruitment. The intent of these early tests would be to determine the effectiveness of TMFs in reducing trout recruitment and the emigration of young trout to Marble Canyon and the Little Colorado River reach. The condition of the trout fishery, as determined in consultation with AZGFD, and potential impacts on other important resources would be considered prior to implementing TMFs. If TMFs are determined to be effective for these goals while minimizing impacts on other resources, they may be deployed on a regular or triggered basis. TMFs would be tested two to three times in the early part of the LTEMP period while attempting to minimize confounding effects with other experimental treatments. Tests would start with a conservative application of two cycles in June and July (Figure 2-15), but could be increased based on experimental testing to as many as three cycles per month for 3 months (May, June, and July).

Low Summer Flows under Alternative C

If water temperatures at the Little Colorado River confluence have been relatively cold (i.e., do not exceed 12°C, the minimum temperature for humpback chub growth) in two consecutive years,[5] low summer flows (no lower than a mean daily flow of 5,000 cfs) would be provided if the water released from the dam is sufficiently warm to result in at least 13°C at the confluence in the months of July, August, and September. A target temperature of 13°C was chosen because it represents an improvement over the minimum temperature needed for growth, 12°C. Note that reduction in summer flows would necessitate increasing flows in other months relative to base operations (Table 2-7; Figure 2-16).

The ability to achieve target temperatures at the Little Colorado River confluence by providing lower flows is dependent on release temperatures, which are in turn dependent on reservoir elevation. For example, using the temperature model of Wright, Anderson et al. (2008), in an 8.23-maf year, release temperatures of 9.6°C, 9.8°C, and 10.5°C would be needed in July, August, and September, respectively, to achieve a target temperature of 13°C at the Little Colorado River confluence at flows of 8,000 cfs.

Release temperatures fall into three categories for any temperature target: (1) too low to warm to target temperature even at low flow; (2) high enough to warm to target temperature only if low flows (5,000 cfs to 8,000 cfs) are provided; and (3) high enough to achieve target temperature regardless of the flow level. Low flows would only be triggered in years that fell into the second category. This is a fairly rare situation; modeling of 63 20-year periods determined that low summer flows would be triggered in at most four years per 20-year period.

A decision to conduct low summer flows in a year would be made by May 1. Such a decision would be based on reservoir and temperature modeling and other resource conditions, in addition to annual water delivery requirements. Because fluctuations have relatively little effect on mainstem water temperature and humpback chub, minor within-day flow fluctuations (i.e., ±1,000 cfs) would be allowed. If triggered, low summer flows would be provided in at least 2 years (not necessarily consecutive), and the response of chub would be determined.

2.2.4 Alternative D (Preferred Alternative)

The objective of Alternative D (the preferred alternative) is to adaptively operate Glen Canyon Dam to best meet the resource goals of the LTEMP (Section 1.4). Like Alternative C, Alternative D features condition-dependent flow and non-flow actions that would be triggered by resource conditions.

Alternative D was developed by the DOI after a full analysis of the other six LTEMP alternatives had been completed. This alternative was identified as the preferred alternative by

5 This temperature trigger is the same as that identified by FWS in the Nonnative Fish Control BO (FWS 2011c).

TABLE 2-7 Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	480	0.0583	7,806	3,360
November	480	0.0583	8,067	3,360
December	830	0.1009	13,499	5,810
January	830	0.1009	13,499	5,810
February	730	0.0887	13,148	5,111
March	771	0.0937	12,539	5,397
April	849	0.1032	14,273	5,945
May	880	0.1069	14,306	6,157
June	920	0.1118	15,462	6,440
July	492	0.0598	8,000	2,000
August	492	0.0598	8,000	2,000
September	476	0.0578	8,000	2,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts or other factors, and based on application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

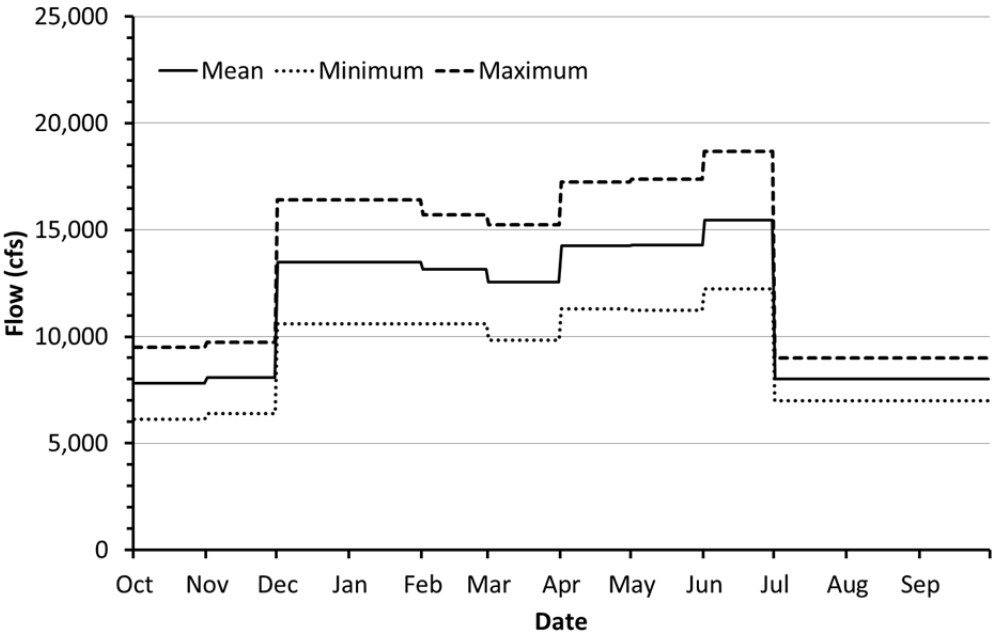

FIGURE 2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-6

the DOI, and its identification as the preferred alternative was supported by WAPA and the Basin States. Alternative D was also considered the environmentally preferred alternative, based on its relative impacts (compared to other alternatives) on the full range of environmental resources. Alternative D adopts operational and experimental characteristics from Alternative C and Alternative E. The effects of operations under Alternatives C and E were modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance and reduce impacts, while meeting the purpose, need, and objectives of the LTEMP EIS. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

On the basis of modeling results for Alternative C and E, discussions with subject matter experts and Cooperating Agencies, and specific impact analyses of various potential Alternative D characteristics conducted using the screening tool (see Section 2.1 for a discussion of the models integrated in the screening tool), the DOI developed the operational and experimental characteristics of Alternative D. This formulation of the alternative then was modeled with the same models used for the analysis of the original six alternatives.

Adjustments were made to Alternative D after the integrated multiple-resource modeling, illustrated in Figure 4-1, was completed in March 2015, prior to the release of the DEIS in January 2016. This modeling considered a full-range of hydrology and sediment conditions, as described in Section 4.1. Adjustments to Alternative D included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration (>96 hr) fall HFE. Adjustments made to Alternative D after the DEIS was published, and based on comments received from Cooperating Agencies and stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE.

The description of Alternative D provided in this section represents the final version of the alternative that resulted from these changes.

Once the adjustments to Alternative D were made, analyzing them using multiple-resource modeling would have taken many months and incurred significant additional cost. Therefore, instead of performing multiple-resource modeling on the effects of these adjustments, the joint-leads chose to perform streamlined modeling using the screening tool (see Section 2.1 for a description of this modeling tool) and analysis to assess the magnitude and direction of these effects of the adjustments. As described in Section 4.1, for most resources, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. However, the streamlined

analysis did show that the adjustments would result in some changes to the expected impacts on sediment and hydropower resources, but that for all resources other than hydropower these changes would not affect the relative performance of Alternative D compared to other alternatives (see discussion in Section 4.1). Because the adjustments to Alternative D would not change Alternative D's relative performance for most resources, and the changes to hydropower impacts would be reductions—not increases—in impact, the agencies chose not to perform additional multiple-resource modeling. In addition to presenting the original multiple-resource modeling results, the results of the streamlined modeling evaluating the effects of these adjustments on sediment and hydropower are presented in Sections 4.3.3.4 and 4.13.3.4, respectively. Because, for most resources, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D, the only quantitative analysis results presented in those sections of the EIS are those from the original multiple-resource modeling.

Operational characteristics of Alternative D are presented in Table 2-1, and condition-dependent experimental elements are summarized in Table 2-2. The alternative uses decision trees to identify when a change in the implementation of experimental actions may be considered; however, DOI will retain sufficient flexibility in the implementation of experiments to ensure the protection of resources (Section 2.2.4.3). Experimental flows and non-flow actions could be triggered by changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature after consideration of effects on all resources. Alternative D differs from Alternatives C and E in the specific trigger conditions and actions that would be taken.

2.2.4.1 Base Operations under Alternative D

Under Alternative D, the pattern of monthly releases would be relatively even compared to under Alternative A. The total monthly release volume of October, November, and December would be equal to that under Alternative A (i.e., 2 maf in years with ≥ 8.23 maf annual release volume) to avoid the possibility of the operational tier differing from that of Alternative A, as established in the Interim Guidelines (Reclamation 2007a). The August volume was set to a moderate volume level (800 kaf in an 8.23-maf release year) to consider both sediment conservation prior to a potential HFE and power-production and capacity concerns. January through July monthly volumes were set at levels that roughly track WAPA's contract rate of delivery (CROD). This produced a redistribution of monthly release volumes under Alternative D that would result in the most even distribution of flows of any alternative except for Alternative G.

Under base operations of Alternative D, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (10 × monthly volume in kaf in the high-demand months of June, July, and August and 9 × monthly volume in kaf in other months; Table 2-8; Figure 2-17). For example, the daily fluctuation range in July with a scheduled release volume of 800 kaf would be 8,000 cfs, and the daily fluctuation range in December with the same scheduled release volume would be 7,200 cfs.

TABLE 2-8 Flow Parameters under Alternative D in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	763	0.0927	12,409	6,867
February	675	0.0820	12,154	6,075
March	713	0.0866	11,596	6,417
April	635	0.0772	10,672	5,715
May	632	0.0768	10,278	5,688
June	663	0.0806	11,142	6,630
July	749	0.0910	12,181	7,490
August	800	0.0972	13,011	8,000
September	600	0.0729	10,083	5,400

[a] Within a year, monthly operations may be increased or decreased based on factors referenced in Section 2.2.4.2.

[b] Values have been rounded.

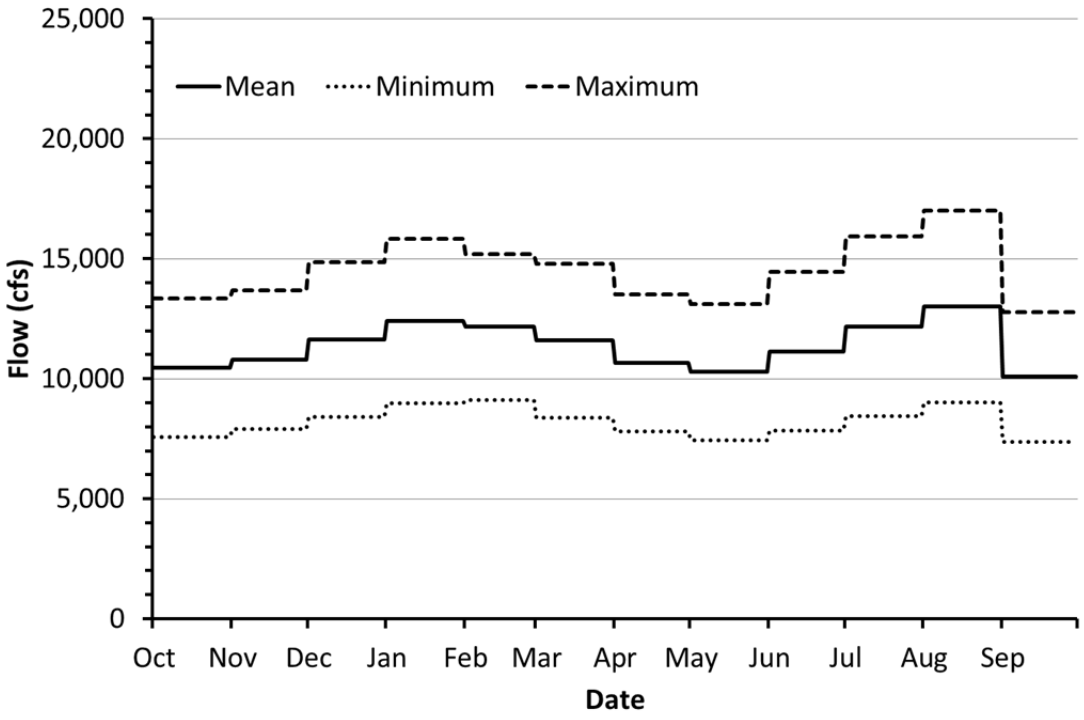

FIGURE 2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8

The maximum allowable daily fluctuation range in flows in any month would be 8,000 cfs, which is also the maximum daily fluctuation range under Alternative A.

An 8,000-cfs maximum daily fluctuation limit was established in the 1996 ROD (Reclamation 2006) to address safety, recreation, and sediment concerns (Reclamation 1995). The analysis conducted for the LTEMP EIS has not identified new evidence to suggest that these concerns are no longer relevant or that this fluctuation limit is no longer appropriate. The determination of 8,000 cfs as a maximum daily fluctuation level that is suitable for recreation was based on Bishop et al. (1995). Bishop et al. surveyed both the river guides and the general public regarding preferences, and the river guides reported a preference for a maximum of 8,000 cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. The current river guide community has continued to state the preference for retaining the 8,000-cfs maximum daily fluctuation that is currently in place.

The down-ramp rate under Alternative D would be limited to no greater than 2,500 cfs/hr, which is 1,000 cfs/hr greater than what is allowed under Alternative A. The up-ramp rate would be 4,000 cfs/hr, and this is the same as what is allowed under Alternative A.

Figure 2-17 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-18 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative D. Figure 2-19 shows details of hourly flows during a week in July.

Annually, Reclamation will develop a hydrograph based on the characteristics above. Reclamation will seek consensus on the annual hydrograph through monthly operational coordination calls with governmental entities, and regular meetings of the GCDAMP Technical Working Group (TWG) and AMWG. Reclamation will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, and BIA), WAPA, and representatives from the Basin States and UCRC. The purpose of these meetings or calls is for the participants to share and seek information on Glen Canyon Dam operations. One liaison from each Basin State and from the UCRC may participate in the monthly operational coordination meetings or calls.

2.2.4.2 Operational Flexibility under Alternative D

Reclamation retains the authority to utilize operational flexibility at Glen Canyon Dam because hydrologic conditions of the Colorado River Basin (or the operational conditions of Colorado River reservoirs) cannot be completely known in advance. Consistent with current operations, Reclamation, in consultation with WAPA, will make specific adjustments to daily and monthly release volumes during the water year. Monthly release volumes may be rounded for practical implementation or for maintenance needs. In addition, when releases are actually implemented, minor variations may occur regularly for a number of operational reasons that cannot be projected in advance.

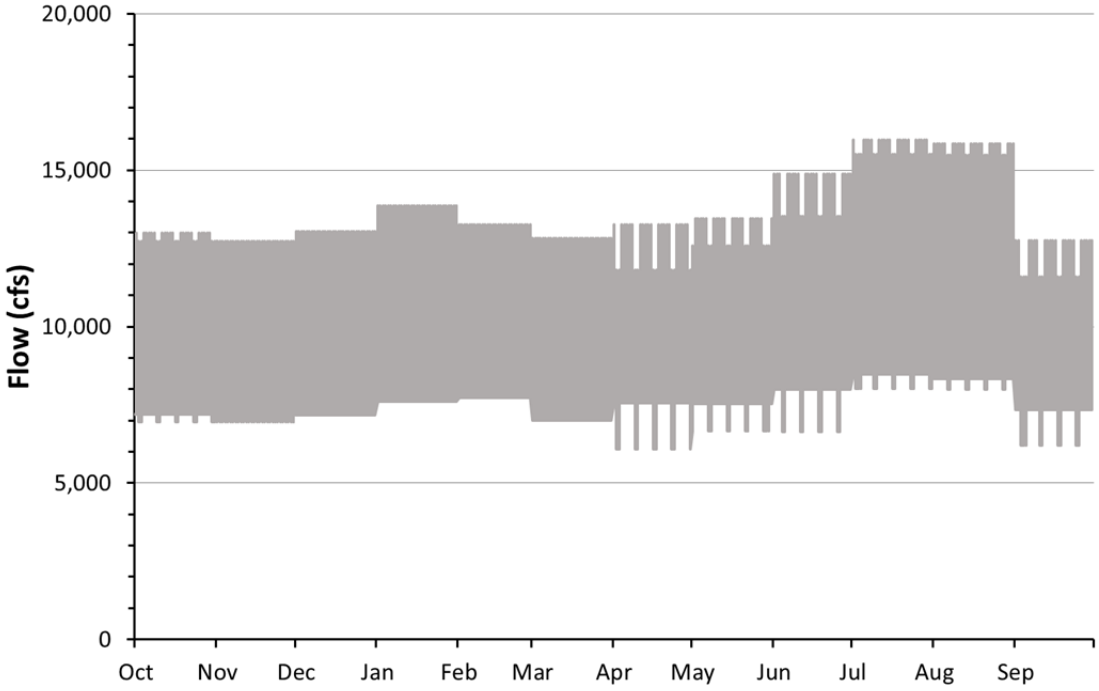

FIGURE 2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-17. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

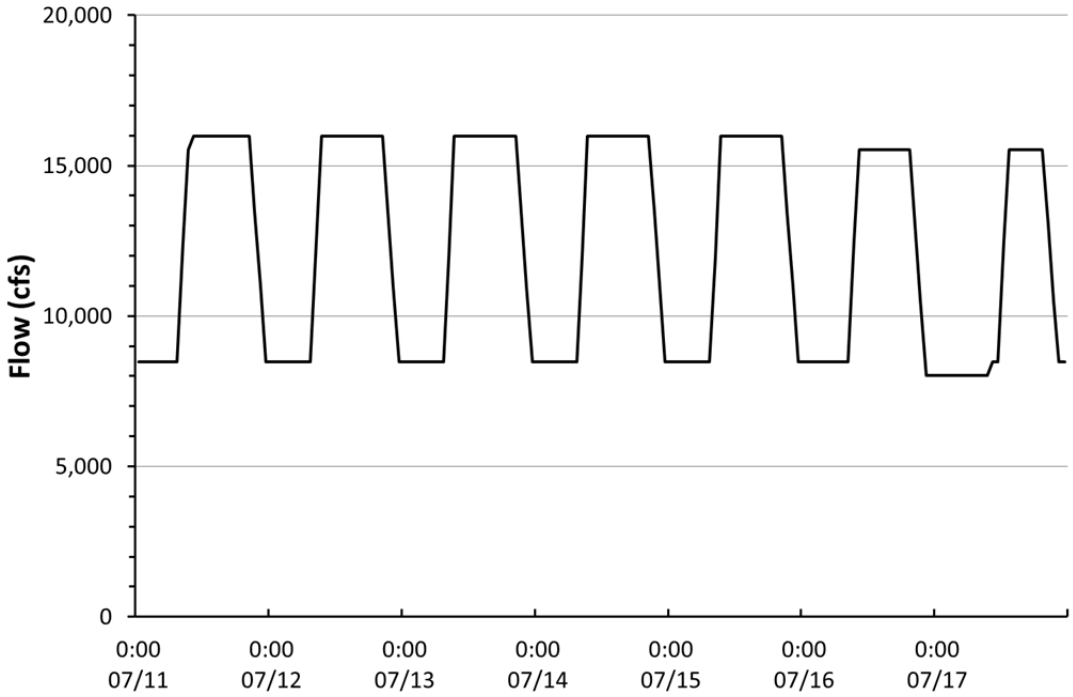

FIGURE 2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

Reclamation also will make specific adjustments to daily and monthly release volumes, in consultation with other entities as appropriate, for a number of reasons, including operational, resource-related, and hydropower-related issues. Examples of these adjustments may include, but are not limited to, the following:

- For water distribution purposes, volumes may be adjusted to allocate water between the Upper and Lower Basins consistent with the Law of the River as a result of changing hydrology;

- For resource-related issues that may occur uniquely in a given year, release adjustments may be made to accommodate nonnative species removal, to assist with aerial photography, or to accommodate other resource considerations separate from experimental treatments under the LTEMP;

- For hydropower-related issues, adjustments may occur to address issues such as electrical grid reliability, actual or forecasted prices for purchased power, transmission outages, and experimental releases from other Colorado River Storage Project dams.

In addition, Reclamation may make modifications under circumstances that may include operations that are prudent or necessary for the safety of dams, public health and safety, other emergency situations, or other unanticipated or unforeseen activities arising from actual operating experience (including, in coordination with the Basin States, actions to respond to low reservoir conditions as a result of drought in the Colorado River Basin). In addition, the Emergency Exception Criteria established for Glen Canyon Dam will continue under this alternative. (See, e.g., Section 3 of the Glen Canyon Operating Criteria at 62 FR 9448, March 3, 1997.)

Section 2.2.4.3 addresses adjustments to base operations for adaptive management-based experimental operations with flow components.

2.2.4.3 Implementation Process for Experiments under Alternative D

Alternative D identifies condition-dependent flow and non-flow treatments intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes to those resources. These condition-dependent treatments would be implemented experimentally during the LTEMP period unless they prove ineffective or result in unacceptable adverse impacts on other resources.

Prior to implementation of any experiment, the relative effects of the experiment on the following resource areas will be evaluated and considered: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and WAPA's assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources. Although these key resources are listed for consideration on a regular basis, DOI

intends to retain sufficient flexibility in implementation of experiments to allow for response to unforeseen circumstances or events that involve any other resources not listed here. The recent discovery of nonnative green sunfish in the Glen Canyon reach illustrates the need to be responsive to unforeseen conditions. DOI will engage in the communication and consultation process described in Section 2.2.4.4, when making decisions regarding implementation of experiments.

The proposed approach differs fundamentally from a more formal experimental design (e.g., before-after control-impact design, factorial design) that attempts to resolve uncertainties by controlling for or treating potentially influential or confounding factors. There are several reasons to avoid such a formal design and instead focus on the condition-dependent approach described here. Among these are (1) the difficulties in controlling for specific conditions in a system as complex as the Colorado River; (2) wide variability in temperature and flow conditions that are important drivers in ecological processes; (3) inherent risk of some experimentation to protected sensitive resources, in particular, endangered humpback chub; (4) conflicting multiple-use values and objectives; and (5) low expected value-of-information for the uncertainties that could be articulated, and around which a formal experimental design would be established. For these reasons, a condition-dependent adaptive approach is proposed.

The alternative utilizes the principle that a condition-dependent adaptive design is preferable to a formal experimental design because of the need for a flexible and adaptive program that is responsive to learning. A more formal experimental design, while potentially beneficial in resolving specific uncertainties, would involve multiple-year tests under different conditions, and with sufficient replicates of experimental conditions to statistically test the significance of treatment effects. Such an experimental design would necessarily span a period of years, during which environmental conditions would undoubtedly vary, and thus confound interpretation of results. The duration of the experiment could be lengthened and the potential for confounding effects increased if there was a desire to test system response under specific conditions that cannot be controlled (e.g., annual volume, water temperature, sediment load, and species population levels). These factors make a formal experimental design impractical in the Grand Canyon. Like Alternatives C and E, Alternative D would use condition-dependent triggers to inform operations and experimental flow and non-flow treatments in a given year.

Implementation criteria for condition-dependent experimental treatments of Alternative D are provided in Table 2-9, and decision trees for implementation of experimental treatments are presented in Figures 2-20 and 2-21. (Note: In both of these figures, triggering would also be conditional on annual implementation considerations and long-term off-ramps presented in Table 2-9. The nodes shown in rectangles are condition-dependent action nodes; the nodes shown in circles are information-dependent nodes that require the evaluation of accumulated evidence.) Included in Table 2-9 are the triggers for experimental changes in operations, implementation considerations for determining if an experimental treatment should proceed, conditions that would cause the treatment to be terminated prior to completion (i.e., off-ramps), and the number of replicates that are initially considered needed. In many cases, two to three replicates of an experimental treatment are considered necessary. The results of these tests would be used to determine if these condition-dependent treatments should be retained as part of the suite of long-term actions implemented under LTEMP. In other cases, following the process

TABLE 2-9 Implementation Criteria for Experimental Treatments of Alternative D

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Sediment Treatments[d]						
Spring HFE up to 45,000 cfs in Mar. or Apr.	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs; sediment-triggered spring HFEs will not occur in the same water year as an extended-duration (>96 hr) fall HFE	Sediment-triggered spring HFEs are not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from equalization releases	Not conducted during first 2 years of LTEMP, otherwise implement in each year triggered, dependent on resource condition and response	First test 24 hr; subsequent tests could be shorter, but not longer, depending on results of first tests	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs; would not be implemented in the same water year as a sediment-triggered spring HFE or extended-duration fall HFE	Proactive spring HFEs are not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Sediment Treatments (Cont.)						
Fall HFE ≤96 hr up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs	This type of fall HFE is not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs longer than 96-hr duration up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE longer than a 96-hr, up to 45,000-cfs flow Objective: Rebuild sandbars	Implement in each year triggered; limited to total of four tests in LTEMP period	Up to 250 hr depending on availability of sand duration of first test not to exceed 192 hr	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; unacceptable cumulative effects of sequential HFEs	Extended-duration fall HFEs are not effective in building sandbars; resulting sandbars are no bigger than those created by shorter-duration HFEs; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Treatments[e]						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and survival of humpback chub	Implement as needed when triggered after consultation with Tribes; test may be conducted early in the 20-year period even if not triggered by high trout recruitment[f]	Implemented in as many as 4 months (May–Aug.)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	TMFs have little or no effect on trout recruitment after at least three tests; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon, taking into consideration Tribal concerns
Tier 1: Expanded translocation of humpback chub in the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective	As needed	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Expanded translocation has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Tier 1: Implement head-start program for larval humpback chub	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective	As needed	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Head-start program has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Treatments (Cont.)						
Tier 2: Mechanical removal of nonnative fish in Little Colorado River reach	Trigger: Tier 1 actions ineffective; humpback chub numbers in Little Colorado River below Tier 2 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective after consultation with Tribes	Monthly removal trips (Feb.–Jul.) until "predator index" or adult humpback chub reach acceptable levels (see Appendix O)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Mechanical removal has little or no effect on reducing predator index in the Little Colorado River reach; no population-level benefit on humpback chub; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment when triggered, taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target ≥ 14°C at Little Colorado River confluence	Trigger: Initial experiment: in the second 10 years of the LTEMP period, when target temperature of ≥14°C can be achieved only with low summer flow Objective: Increase humpback chub growth	Subsequent experimental use if: (1) initial test was successful, (2) humpback chub population concerns warrant their use, (3) water temperature appears to be limiting recruitment, and (4) target temperature of ≥14°C could be achieved only with low summer flow	3 months (Jul.–Sep.)	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Low summer flows do not increase growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed; or sufficient warming does not occur as predicted	Implement as adaptive treatment when conditions allow

TABLE 2-9 (Cont.)

Experimental Treatment	Trigger[a] and Primary Objective	Replicates	Duration	Annual Implementation Considerations[b]	Long Term Off-Ramp Conditions[c]	Action if Successful
Aquatic Resource Treatments (Cont.)						
Macroinvertebrate production flows	Trigger: None Objective: Improve food base productivity and abundance or diversity of mayflies, stoneflies, and caddisflies	Target two to three replicates	Up to 4 months (May–Aug.)[g]	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3; coordinate planning with other experiments to avoid confounding conditions or results	Steady weekend flows have little or no benefit on food base, trout fishery, or native fish; increase in warmwater nonnative species or trout at the Little Colorado River; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment in target months when conditions allow
Riparian Vegetation Treatments						
Non-flow vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential short-term unacceptable impacts on resources listed in Section 2.2.4.3	Control and replanting techniques are not effective or practical; or long-term unacceptable adverse impacts on the resources listed in Section 2.2.4.3 are observed	Implement as adaptive treatment if invasive species can be reduced and native species increased

a Triggers will be modified as needed during the 20-year LTEMP period in an adaptive manner through processes including ESA consultation and based on the best available science utilizing the experimental framework for each alternative.

b Annual determination by the DOI. Any implementation would consider resource condition assessments and resource concerns using the annual processes described in Sections 2.2.4.3 and 2.2.4.4.

c Suspension of experiment if the DOI determines effects cannot be mitigated.

d Details of implementation of sediment experiments are presented in Section 2.2.4.5.

e Details of implementation of aquatic resource experiments are presented in Section 2.2.4.6.

f The decision to conduct TMFs in a given year would consider the resource conditions, as specified in Section 2.2.4.3, and would also involve considerations regarding the efficacy of the test based on those resource conditions.

g The duration and other characteristics of experimental macroinvertebrate production flows could be adjusted based on the results of initial experiments.

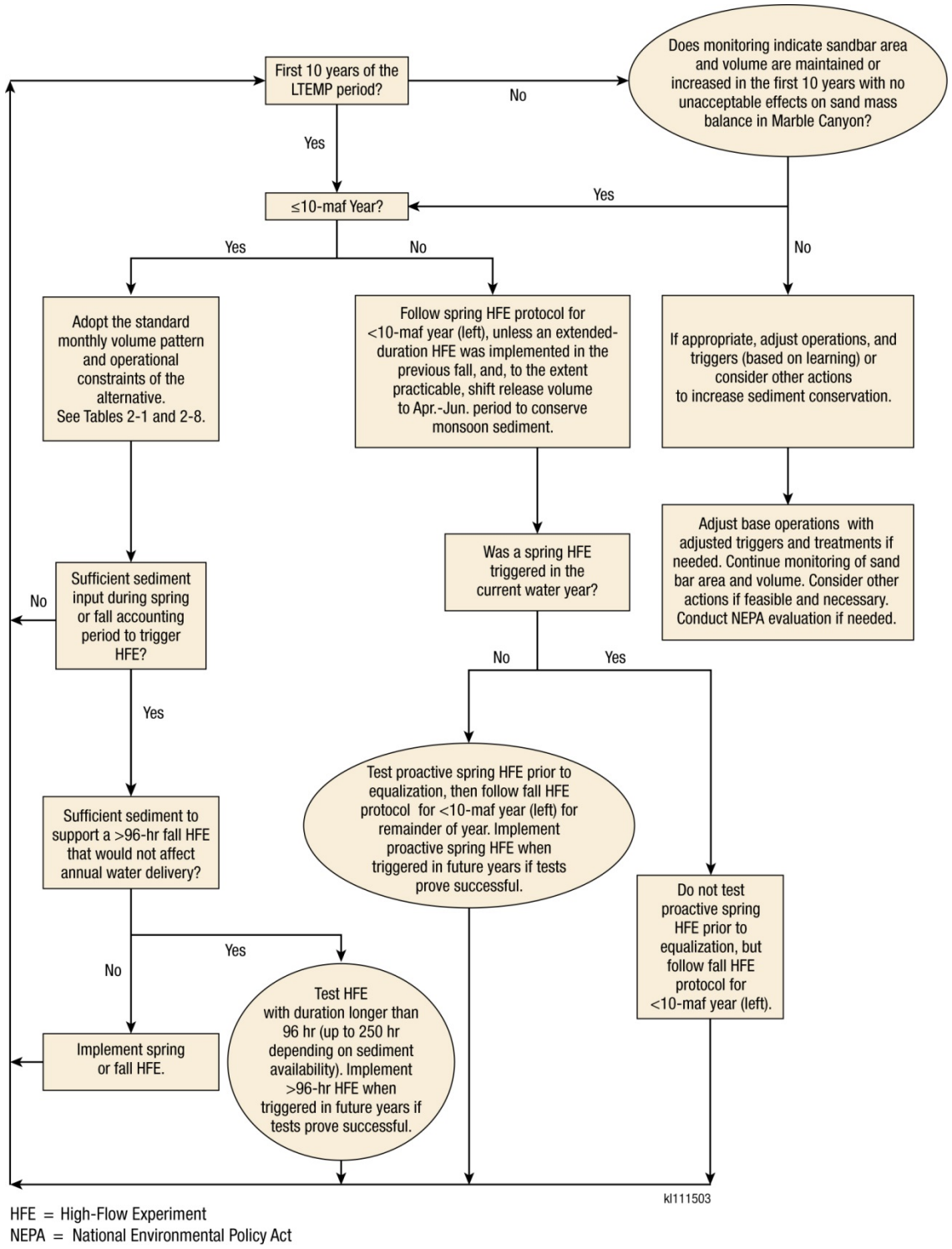

FIGURE 2-20 Decision Tree for Implementation of Sediment-Related Experimental Treatments under Alternative D (Implementation would be conditional on annual considerations presented in Section 2.2.4.3. If off-ramp conditions listed in Table 2-9 exist, related experimental treatments would be suspended.)

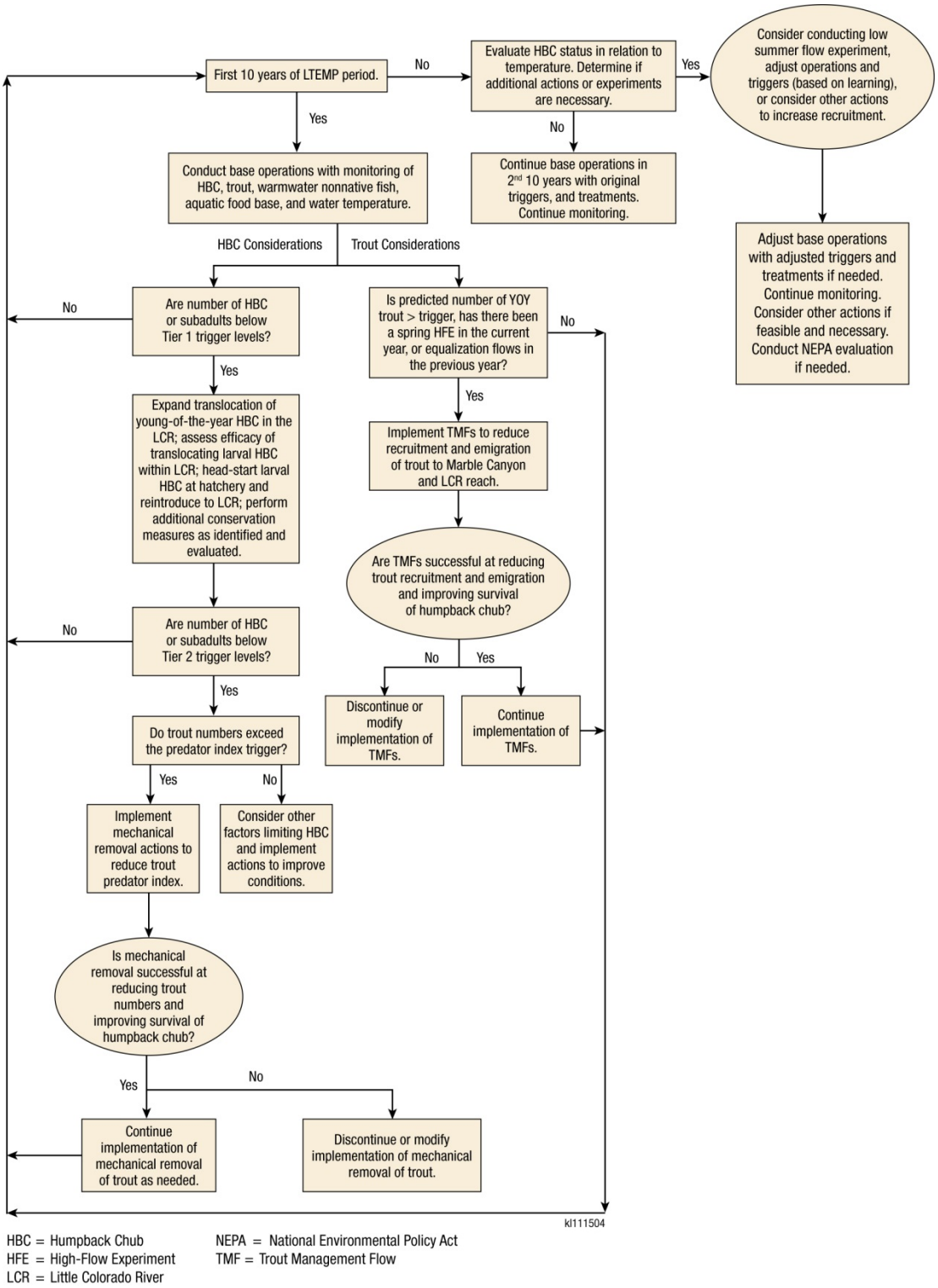

FIGURE 2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental Treatments under Alternative D (Implementation would be conditional on annual considerations presented in Section 2.2.4.3. If off-ramp conditions listed in Table 2-9 exist, related experimental treatments would be suspended.)

described elsewhere in this section, implementation of experimental treatments would continue throughout the LTEMP period if triggered (e.g., spring and fall HFEs), except in years when it was determined that the proposed experiment could result in unacceptable adverse impacts on resource conditions. For these experiments, effectiveness would be monitored and the experiments would be terminated or modified, only if sufficient evidence suggested the treatment was ineffective or had unacceptable adverse impacts on other resources. All experimental treatments would be closely monitored for adverse side effects on important resources. At a minimum, an unacceptable adverse impact would include significant negative impacts on resources as a result of experimental treatments that have not been analyzed for Alternative D in the LTEMP EIS.

Sections 2.2.4.5 and 2.2.4.6 describe specific processes for the development and implementation of experiments related to sediment, aquatic resources, and riparian vegetation. The overall approach attempts to strike a balance between identifying specific experiments and providing flexibility to implement those experiments when resource conditions are appropriate. As discussed above, rather than proposing a prescriptive approach to experimentation, an adaptive management-based approach that is responsive and flexible would be used to adapt to changing environmental and resource conditions and new information. The potential for confounding interactions among individual experimental treatments is discussed when relevant for each of the proposed treatments. Given the size of the project area and the variability inherent in the system, this pragmatic approach to experimentation is warranted. Although confounding treatments are possible given the complexity of the experimental plan, they are not expected to limit learning over the life of the LTEMP.

2.2.4.4 Communication and Consultation Process for Alternative D

In implementing the processes described in Section 2.2.4.3 and the associated decision process shown in Figures 2-20 and 2-21, the DOI will exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. As an initial platform to discuss potential future experimental actions, the DOI will hold GCDAMP annual reporting meetings for all interested stakeholders; these meetings will present the best available scientific information and learning from previously implemented experiments and ongoing monitoring of resources. As a follow-up to this process, the DOI will meet with the TWG to discuss the experimental actions being contemplated for the year.

The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and representatives from the Basin States and the UCRC. Each DOI bureau will provide updates on the status of resources and dam operations. In addition, WAPA will provide updates on the status of the Basin Fund, projected purchase power prices, and its financial and operational considerations. These meetings or calls are intended to provide an opportunity for participants to share and obtain the most up-to-date information on dam operational considerations and the status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One

liaison from each Basin State and from the UCRC will be allowed to participate in the monthly operational coordination meetings or calls.

To determine whether conditions are suitable for implementing or discontinuing experimental treatments or management actions, the DOI will schedule implementation/planning meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by the participants. The implementation/planning group will strive to develop a consensus recommendation to bring forth to the DOI regarding resource issues as detailed at the beginning of this section, as well as including WAPA's assessment of the status of the Basin Fund. The Secretary of the Interior will consider the consensus recommendations of the implementation/planning group, but retains sole discretion to decide how best to accomplish operations and experiments in any given year pursuant to the ROD and other binding obligations.

DOI will also continue separate consultation meetings with the Tribes, AZGFD, the Basin States, and UCRC upon request, or as required under existing RODs.

2.2.4.5 Sediment-Related Experiments To Be Evaluated under Alternative D

Under Alternative D, the existing HFE protocol was updated and incorporated into the LTEMP process as specified in Appendix P. Changes to the existing protocol were related to implementation of the new HFEs that are included under Alternative D and an extension of the protocol to the end of the LTEMP period. This new protocol would replace the existing protocol when the LTEMP ROD is issued. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period based on the estimated sand mass balance resulting from Paria River sediment inputs during the spring and fall accounting periods, and the dam release pattern during the accounting period. HFE releases would be 1 to 250 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods and the expected accumulation of sand, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

Sand mass balance modeling would be used to ensure that the duration and magnitude of an HFE are best matched with the mass of sand present in the system during a particular release window. The magnitude and duration of HFEs would not affect the total annual release from Glen Canyon Dam. Reclamation would consider the total water to be released in the water year when determining the magnitude and duration of an HFE.

Sediment-related experiments under Alternative D include (1) sediment-triggered spring and fall HFEs up to 96-hr duration; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of up to four extended-duration (>96-hr) HFEs, up to 250 hr long, depending on sediment conditions. The pattern of transferring water volumes from other months to make up the HFE volume would be

discussed in the monthly Glen Canyon Dam operational coordination meetings described in Section 2.2.4.4.

If sediment resources are stable or improving, the combination of base operations, HFEs, and other treatments would continue as prescribed for Alternative D. If sediment resource conditions decrease to unacceptable levels during the LTEMP period, operations may be modified to the extent allowable under the LTEMP ROD or would be evaluated and considered under a separate NEPA process, potentially including additional studies of sediment augmentation or other actions.

For all sediment experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were unacceptable adverse impacts on resources (Table 2-9). Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted.

Implementation of HFEs would consider resource condition assessments and resource concerns using the annual processes described in Sections 2.2.4.3 and 2.2.4.4. HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3. In addition, there is uncertainty associated with cumulative impacts from sequential HFEs. These cumulative impacts would be considered before implementing an HFE.

Sediment-Triggered Spring HFEs under Alternative D

Under Alternative D, sediment-triggered spring HFEs would be implemented after an initial 2-year delay in order to enable testing of the effectiveness of TMFs, if warranted, and address concerns raised by the apparent positive response of trout to the 2008 spring HFE (Korman, Kaplinski et al. 2011; Melis et al. 2011). Modeling trout response to spring HFEs for the EIS was based on relationships developed from the observed response to the 2008 spring HFE. That modeling also evaluated uncertainty related to the effectiveness of TMFs to control excess trout produced by HFEs. Modeling indicated that even at a relatively low level of effectiveness (10% reduction in trout recruitment), TMFs could effectively reduce the number of trout out-migrants from Glen Canyon to the Little Colorado River reach (RM 61) where humpback chub occur.

After the first 2 years of the LTEMP period, spring HFEs would be implemented when triggered by sediment conditions, except in water years when an extended-duration fall HFE was conducted. Modeling indicates that there may be sufficient sediment input for spring HFEs in about 26% of the years in the LTEMP period. Sediment-triggered spring HFEs would be implemented when triggered during the entire LTEMP period unless new information indicated they were not effective in building sandbars, or there were unacceptable adverse effects on resources (Section 2.2.4.3).

Implementation of a spring HFE would provide important replication of the 2008 spring HFE and aid in understanding the effect of spring HFEs on the trout population. It is possible

that the strong 2008 response was a result of the specific conditions present in 2008 (e.g., condition of the food base, trout population size). It is unclear whether implementation under current conditions would produce the same result, and there is a good deal of learning that could result from early implementation. Implementing a spring HFE early in the LTEMP period when chub numbers are relatively high may also be a relatively low-risk option. To provide a means of controlling trout recruitment following tests of spring HFEs, TMFs would be experimentally implemented and tested for efficacy as early in the LTEMP period as possible (see discussion of TMFs below).

Implementation of sediment-triggered spring HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Spring HFEs may not be tested when there appears to be the potential for unacceptable adverse impacts on the resources listed in Section 2.2.4.3. In addition, there is uncertainty associated with the cumulative impacts of sequential HFEs on sediment, aquatic, and potentially other resources. These cumulative impacts would be considered before implementing a spring HFE, particularly if a fall HFE had been implemented in the same water year.

Proactive Spring HFEs under Alternative D

GCMRC scientists identified proactive spring HFEs as a potential experimental treatment to transport and deposit in-channel sand at elevations above those of equalization flows. These HFEs would be tested only in years with high annual water volume (i.e., ≥10 maf), and modeling suggests this would be a relatively rare treatment. A first test would be a 24-hr 45,000-cfs release conducted in April, May, or June. Duration in subsequent tests could be shortened depending on the observed response during the first tests. It would be preferable to test proactive spring HFEs at least two to three times in the 20-year LTEMP period, but being able to do so will be dependent upon annual hydrology. Modeling indicates that proactive spring HFEs would be triggered in about 10% of the years in the LTEMP period.

Proactive spring HFEs would not be tested in the first 2 years of the LTEMP. In addition, proactive spring HFEs would not be tested in years when there had been a sediment-triggered spring HFE or an extended-duration fall HFE earlier in the same water year. Proactive spring HFEs could be performed in the same water year as a 96-hr or shorter sediment-triggered fall HFE, although prior to implementation, the potential effects of these HFEs would be carefully evaluated using the processes described in Sections 2.2.4.3 and 2.2.4.4. The first test would be carefully evaluated to determine whether additional tests were warranted based on the efficacy of building and maintaining sandbars. If initial tests show positive results without unacceptable adverse effects on the resources listed in Section 2.2.4.3, proactive spring HFEs would be implemented when triggered during the entire LTEMP period.

Implementation of proactive spring HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Proactive spring HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources identified in Section 2.2.4.3. The cumulative impacts of sequential HFEs would be considered before implementing a proactive spring HFE.

Sediment-Triggered Fall HFEs under Alternative D

The effects of sediment-triggered fall HFEs on trout recruitment are uncertain, but fall HFEs are expected to have less effect on trout production than spring HFEs. HFEs in November 2012, 2013, and 2014 resulted in little or no increase in the number of YOY trout (VanderKooi 2015; Winters et al. 2016), and this observation may be based on the observed resilience of the food base to disturbance in the fall (Kennedy et al. 2015). However, factors affecting trout response to fall HFEs are not well understood. Modeling for the EIS considered the effect of fall HFEs on trout and modeled fall HFEs in two ways: in one, the effect of fall HFEs was half as long as that of a spring HFE (i.e., it affected trout production only in the water year in which it occurred); in the other, fall HFEs had no effect on trout production. Modeling the effect of fall HFEs in these two ways had an effect on the overall predicted number of trout produced, the number of out-migrants, and ultimately their effect on humpback chub, but the relative performance among alternatives was unchanged.

Modeling indicates fall HFEs would be triggered in about 77% of the years in the LTEMP period. Testing fall HFEs is considered to be a relatively low-risk treatment due to the lack of observed or documented trout response from previous fall HFEs, and would be implemented when triggered during the entire LTEMP period unless new information indicated fall HFEs were not effective in building sandbars, or there were unacceptable adverse effects.

Implementation of sediment-triggered fall HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Fall HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3. The cumulative impacts of sequential HFEs would be considered before implementing a sediment-triggered fall HFE.

Extended-Duration Fall HFEs under Alternative D

Under Alternative D, sediment-triggered fall HFEs with durations longer than 96 hr (up to 250 hr) would be tested. The duration of these extended-duration fall HFEs would be based on the amount of sediment delivered from the Paria River during the fall accounting period and would be no more than the maximum magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling. Based on examination of the observed historical sediment input from the Paria River, it was determined that HFEs up to 10.4 days in length (250 hr) could be supported before exhausting seasonal sediment inputs and affecting water delivery requirements. GCMRC scientists have suggested that increasing the duration of HFEs when sediment supply can support a longer duration may lead to more sand being deposited at higher elevations, resulting in bigger sandbars. Modeling indicates the sediment trigger for this treatment may be reached in 25% of the years in the LTEMP period. There would be no more than four extended-duration fall HFEs over the 20-year LTEMP period.

The duration of the first implementation of an extended-duration HFE would be limited to no more than 192 hr (twice as long as the current limit of 96 hr). This duration is considered

long enough to produce a measurable result if the treatment represents an effective approach to building sandbars under enriched sediment conditions. The duration of all tests would be based on available sediment, current hydrology, reviews of available information, the expert opinion of GCMRC and other Grand Canyon scientists, and consideration of potential effects on the resources listed in Section 2.2.4.3. If feasible, monitoring would include real-time observations of sediment concentrations to determine if sediment deposition continues throughout the duration of the extended HFEs.

Implementation of extended-duration fall HFEs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Extended-duration fall HFEs may not be tested when there appears to be potential unacceptable impacts on the resources listed in Section 2.2.4.3. Because the effects of extended-duration HFEs on Lake Mead water quality are a concern, DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of extended-duration HFEs. The cumulative impacts of sequential HFEs would be considered before implementing an extended-duration fall HFE.

Another important concern that results from the large volume of water bypassed is water delivery. Water delivery issues would be considered before deciding to implement an extended-duration fall HFE. An extended-duration HFE would not be implemented if annual release volume would be affected. It is possible that in lower volume years, there would not be sufficient water available to support an extended-duration HFE. A 250-hr extended-duration HFE would result in a monthly total release of approximately 1.2 maf. In lower volume release years (e.g., 7.0 maf or 7.48 maf), the maximum duration may be less than 250 hr. In addition, a sediment-triggered spring HFE or proactive spring HFE would not be conducted in the same water year as an extended-duration fall HFE. If an extended-duration fall HFE was triggered but not implemented for any of the reasons described above, a fall HFE 96 hr or less in duration could be implemented instead. Implementation would necessitate reducing water volume in other months of the same water year.

In order to fully test the efficacy of these longer HFEs, several replicates would be desirable in the 20-year LTEMP period. Extended-duration HFEs would be considered successful and would be continued up to a total of four times in the 20-year LTEMP period as part of an adaptive experimental treatment if there was a widespread increase in bar size relative to ≤96-hr HFEs, and if sand mass balance was not significantly compromised relative to the ability to maintain a long-term equilibrium. Extended-duration HFEs would not continue to be tested if they were not effective in building sandbars, if resulting total sandbar volumes were no bigger than those created by shorter-duration HFEs, or if unacceptable adverse impacts on the resources listed in Section 2.2.4.3 were observed.

2.2.4.6 Aquatic Resource-Related Experiments To Be Evaluated under Alternative D

Under Alternative D, most experimental flow and non-flow actions would be triggered by either estimated numbers of nonnative fish, a combination of estimated numbers of nonnative

fish and humpback chub, or measured water release temperature at Glen Canyon Dam, depending on the action under consideration. Humpback chub triggers and nonnative fish triggers were developed during formal Section 7 ESA consultation with the FWS. These triggers may be modified based on experimentation conducted during the LTEMP period.

Aquatic resource experiments that may be tested under Alternative D include (1) TMFs, (2) Tier 1 conservation actions for humpback chub, (3) Tier 2 mechanical removal of nonnative fish, (4) low summer flows in the second 10 years of the LTEMP, and (5) macroinvertebrate production flows. Aquatic resource experiments would seek to refine our understanding of the impacts of water releases, HFEs, and TMFs on these resources. The primary uncertainty surrounding HFEs revolves around the extent to which the seasonality of HFEs or the number of adult rainbow trout determines the strength of rainbow trout recruitment.

Experimental nonnative fish control actions would be implemented if the humpback chub population declined, and proactive conservation actions had failed to reverse declining populations. Two different tiers of population metrics would be used to trigger responses, including actions to increase growth and survival of humpback chub (Tier 1) and mechanical removal of nonnative fish (Tier 2), which would only be implemented when Tier 1 actions fail to slow or reverse the decline in the humpback chub population. This tiered approach and the triggers that would be used to implement it are described below and in the LTEMP Biological Assessment and BO presented in Appendix O.

For all aquatic resource experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were potential unacceptable adverse impacts on the resources listed in Section 2.2.4.3. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted.

Implementation of aquatic resource experiments would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Aquatic resource experiments may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

Trout Management Flows under Alternative D

TMFs (described in Section 2.2.3.2) are a potential tool that could be used to control annual trout production in the Glen Canyon reach for purposes of managing the trout fishery and for limiting emigration from the Glen Canyon reach to Marble Canyon and the Little Colorado River reach. If resource conditions are appropriate, TMFs may be tested under Alternative D early in the experimental period, preferably in the first 5 years. These first tests could be triggered by modeled trout recruitment levels or otherwise implemented to test the effectiveness

of TMFs.[6] The intent of these early tests would be to determine the effectiveness of TMFs and a best approach to trout management. If TMFs are determined to be effective for controlling trout numbers while minimizing impacts on other resources, they may be deployed as an adaptive experimental treatment triggered by estimated trout recruitment.

It should be noted that several Tribes have expressed concerns about TMFs as a taking of life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-lead agencies will continue to work with the Tribes regarding options for trout management, and to determine the most appropriate means of mitigating impacts on Tribal values if TMFs are implemented.

As many as three TMF cycles/month (see Section 2.2.3.2) in a period of up to 4 months during May through August could be tested, depending on the results of early tests. Aspects of TMF design that would be investigated include:

- Duration of high flows needed to lure YOY rainbow trout into near-shore habitats,
- Magnitude of the high flow that would be more effective in luring YOY trout to near-shore habitats,
- Whether or not moving to high flows first is needed to reduce YOY trout numbers (as opposed to simply dropping rapidly from normal flows to minimum flows),
- Timing of TMF cycles during the May–August period of trout emergence, and
- Number of cycles necessary to effectively limit trout recruitment.

If TMFs prove to be effective in controlling trout production and emigration to the Little Colorado River reach, and they become an integral part of the LTEMP, regular implementation of TMFs may need to include variable timing to prevent adaptation of the population to specific timing (e.g., increase in recruitment by fall-spawning rainbow trout).

Certain aspects of TMF effectiveness can be addressed through observational studies (e.g., the number of YOY rainbow trout observed in the near-shore environment in daily increments after the high flow is initiated);[7] others may be addressed through consideration of the physical environment in Glen Canyon (i.e., what areas are inundated or exposed at different

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6 The decision to conduct TMFs in a given year would consider the resource conditions as specified in Section 2.2.4.3 and would also involve considerations regarding the efficacy of the test based on those resource conditions.

7 Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs.

flows). Ultimately, however, effectiveness would be judged based on comparison of fall trout recruitment estimates to expectations based on prior years. It may take several years to make this determination, depending on the strength of the response and the type of TMFs tested. Ultimately, however, effectiveness would be based on the ability of TMFs to reduce recruitment in and emigration from the Glen Canyon reach. The driving forces behind emigration are not fully understood, but are expected to be related to population size and food base in the Glen Canyon reach.

For the EIS modeling, a trigger of 200,000 YOY trout was used to determine when TMFs would be implemented. A regression equation based on annual volume, the variability in flows from May through August, and the occurrence of a spring HFE was used to predict the number of YOY. The actual trigger used could be higher or lower depending on the results of experiments that will be conducted on the effectiveness of TMFs. In addition, the predictive regression equation could be modified based on new information. The trigger and predictive equation used would be modified as needed in an adaptive management context utilizing the process described in Section 2.2.4.3. Triggers for implementation of TMFs would also be developed in consultation with the AZGFD and other entities as appropriate.

Monitoring of other resources, particularly food base and the physiologic condition of adult rainbow trout, would also be considered. In addition, the number of YOY trout at the end of the summer would be estimated to determine if it equals or exceeds the estimated number of recruits needed to sustain the desired number of adult trout. If the estimated number of recruits is less than the recruitment target, TMFs would be re-evaluated for modification before implementation in subsequent years. It is anticipated that the trout population could rebound from a 1-year drop below this target level.

As discussed in relation to sediment experiments above, there is concern among scientists and stakeholders with regard to the risk associated with implementation of spring HFEs as related to trout response and subsequent effects on the humpback chub population. For this reason, TMFs would be implemented and tested for effectiveness as early in the LTEMP period as possible, preferably before the first spring HFEs are triggered, even if not triggered by high trout recruitment. TMFs could be implemented in years that feature a spring HFE and in the water year that follows an equalization flow because of the expected positive effects of equalization on rainbow trout recruitment. Any implementation of TMFs would consider the status of the trout fishery prior to implementation. Modeling indicates TMFs would be triggered by trout recruitment numbers in 32% of the years in the LTEMP period.

There is potential for confounding effects when coupling TMFs with HFEs. If trout recruitment is still high after implementation of TMFs that follow HFEs, this would suggest TMFs were not effective as designed for that trial. If recruitment is lower than expected after TMF implementation, however, uncertainty will remain about whether an HFE failed to stimulate trout recruitment or whether TMFs were effective in suppressing otherwise strong recruitment. It may not be necessary to determine the underlying effect on trout numbers unless TMFs have undesirable side effects on other resources or the trout population.

If TMFs are found to be highly effective in controlling trout recruitment and emigration of trout, and emigration only occurs or primarily occurs immediately following high recruitment years, it may be possible to limit TMF implementation and achieve multiple resource goals, particularly if unintended impacts of TMFs on other resources such as native fish become evident. Timing of TMFs may also be adjusted based on the best scientific information available related to trout emigration behavior. If adverse impacts of TMFs become evident, this may also suggest revisiting whether or not TMFs are necessary in response to spring HFEs. Lastly, if, there is an observed increase in trout recruitment due to fall HFEs, then application of TMFs in the spring following a fall HFE would be considered.

Implementation of TMFs would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. TMFs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

Tier 1 Conservation Actions for Humpback Chub under Alternative D

Tier 1 conservation actions designed to improve rearing and recruitment of juvenile humpback chub would be implemented if the combined point estimate for adult (≥200 mm) humpback chub in the Colorado River mainstem Little Colorado River aggregation (RM 57–RM 65.9) and in the Little Colorado River falls below 9,000 (2,000 in the mainstem and 7,000 in the Little Colorado River), as estimated by the currently accepted humpback chub population model, or if recruitment of subadult (150 mm–199 mm) humpback chub does not meet or exceed estimated adult mortality (Appendix O). Tier 1 actions would include expanded translocations of YOY humpback chub within the Little Colorado River to areas within the river that have relatively few predators (i.e., above Chute Falls, Big Canyon), or larval fish would be taken to a rearing facility and released in the Little Colorado River inflow area once they reach 150 mm to 200 mm. In addition to these translocation activities, 300 to 750 larval or YOY humpback chub would be collected from the Little Colorado River and reared in a fish hatchery to less vulnerable sizes before releasing them. Once these fish reach 150 mm to 200 mm, they would be translocated to the Little Colorado River in the following year.

Tier 2 Mechanical Removal of Nonnative Fish under Alternative D

Mechanical removal of nonnative fish in the Little Colorado River reach (potentially from RM 50–RM 66) would be conducted if the Tier 1 conservation actions described in the previous section were not successful in halting a decline in the number of adult humpback chub. Mechanical removal, using the methods described in Section 2.2.1 and Appendix O, would be conducted if the point estimate of adult humpback chub falls below 7,000 (the trigger level used in Reclamation 2011b), as estimated by the currently accepted humpback chub population model. Up to six monthly removal trips (February through July) would be implemented in each year triggered.

Mechanical removal would stop if the "predator index" is depleted to less than 60 rainbow trout/km (see Appendix O) for at least 2 years in the reach between RM 63 and RM 64.5, and immigration rate is low, or the adult humpback chub population estimates exceed 7,500, and recruitment of subadult chub exceeds adult mortality for at least 2 years. The predator index calculates predator densities by incorporating additional species, in addition to rainbow trout, and makes assumptions about their relative predation rates compared to rainbow trout. For example, brown trout are estimated to be about 17 times more predacious on humpback chub than are rainbow trout (Ward and Morton-Starner 2015). Additional predators (e.g., smallmouth bass) could be included based on their piscivory level relative to that of rainbow trout.

If humpback chub adult numbers continue to decline and Tier 1 and Tier 2 actions are not working, FWS, in coordination with Reclamation, NPS, and the Tribes, will consider other actions to stop the decline. Triggers will be reviewed and modified as necessary, and actions and triggers will be modified if humpback chub are found to be affected by other factors.

Implementation of mechanical removal would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4.

The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly the Hopi Tribe and Pueblo of Zuni, because it is a taking of life in the canyon without a beneficial use. (See Sections 3.5.3.4 and 4.9.1.3 for more information regarding concerns of the Tribes.) Reclamation had committed in agreements with the Tribes in 2012 to consider live removal when feasible (Reclamation 2012b); however, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. Reclamation and NPS have worked with the Tribes to determine a beneficial use of the removed fish on other projects and understand that what is considered beneficial use may not be the same for all Tribes. Reclamation and NPS are committed to consult further with the Tribes to determine acceptable mitigation for nonnative fish control.

Low Summer Flows under Alternative D

Low summer flows could be considered a potential tool for improving the growth and recruitment of young humpback chub if temperature had been limiting these processes for a period of years. Low summer flows may lead to warmer water temperatures in the Little Colorado River reach and farther downstream, as well as contribute to enhanced growth rates of young humpback chub. There are also potential negative effects from low summer flows on several resources such as hydropower, sediment, water quality, vegetation, and recreation. Low summer flows may also negatively affect humpback chub due to an increase in warmwater nonnative fish or a decrease in the aquatic food base. There was one test of low steady summer flows below Glen Canyon Dam in 2000; however, the results relative to humpback chub were not conclusive (Ralston et al. 2012).

Because of the uncertainty related to the effects of low summer flows on humpback chub, other native fish, warmwater nonnative fish, water quality, and potentially other resources, DOI will ensure that the appropriate baseline data are collected throughout the implementation of the

LTEMP. In addition, DOI will convene a scientific panel that includes independent experts prior to the first potential use of low summer flows to synthesize the best available scientific information related to low summer flows. The panel may meet periodically to update the information, as needed. This information will be shared as part of the AMWG annual reporting process.

It is thought that the potential benefit of an increase in temperature could be greatest if a water temperature of at least 14°C could be achieved, because these warmer temperatures could favor higher humpback chub growth rates (nearly 60% higher). For comparison, the July through September growth increments of YOY humpback chub are estimated to be 4, 7, 11, 14, and 17 mm at temperatures of 12, 13, 14, 15, and 16°C, respectively, based on a growth-temperature regression in Robinson and Childs (2001). Note that reduction in summer flows would necessitate increasing flows in other months relative to base operations (Table 2-10; Figure 2-22).

If tested, low summer flows would occur for 3 months (July, August, and September), and only in the second 10 years of the LTEMP period. The duration of low summer flows could be shortened to less than 3 months in successive experiments if supported by the scientific panel described above or based on the scientific data and observed effects. The probability of triggering a low summer flow experiment is considered low (about 7% of years), because the water temperature conditions that would allow such a test occur infrequently (see Appendix D).

TABLE 2-10 Flow Parameters for a Year with Low Summer Flows under Alternative D in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	764	0.0928	12,423	6,874
February	675	0.0820	12,153	6,074
March	691	0.0840	11,245	6,223
April	859	0.1044	14,433	7,730
May	851	0.1034	13,841	7,659
June	930	0.1130	15,631	8,000
July	492	0.0598	8,000	2,000
August	492	0.0598	8,000	2,000
September	476	0.0578	8,000	2,000

[a] Within a year, monthly operations may be increased or decreased based on factors referenced in Section 2.2.4.2.

[b] Values have been rounded.

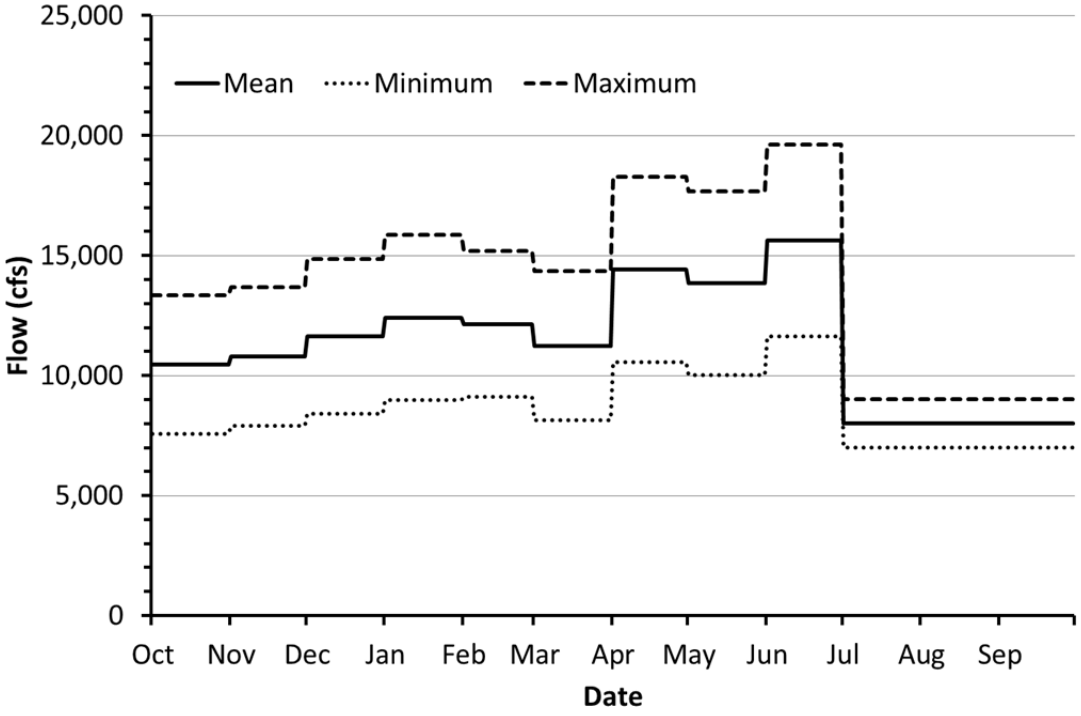

FIGURE 2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative D in an 8.23-maf Year Based on the Values Presented in Table 2-10

Low summer flows would only be implemented in years when the projected annual release was less than 10 maf, and if the temperature at the Little Colorado River confluence was below 14°C without low summer flows, and the release temperature was sufficiently high that 14°C could be achieved at the Little Colorado River with the use of low summer flows.

The ability to achieve target temperatures at the Little Colorado River confluence by providing lower flows is dependent on release temperatures, which are in turn dependent on reservoir elevation. For example, using the temperature model of Wright, Anderson et al. (2008) in an 8.23-maf year, release temperatures of 10.8°C, 11.0°C, and 11.7°C would be needed in July, August, and September, respectively, to achieve a target temperature of 14°C at the Little Colorado River confluence at flows of 8,000 cfs.

Release temperatures fall into three categories for any temperature target: (1) too low to achieve the target temperature at the Little Colorado River even at low flow; (2) high enough to achieve the target temperature at the Little Colorado River only if low flows (5,000 cfs to 8,000 cfs) are provided; and (3) high enough to achieve target temperature at the Little Colorado River regardless of the flow level. Low summer flows would only be triggered in years that fell into the second category.

Implementation of a low summer flow experiment is complicated by two factors: the earliest date at which it could be determined that a target temperature of at least 14°C could be

achieved in all 3 months, and the ability to release the remaining annual volume once that determination is made. The earliest time a determination could be made would be in early April of each year, and it would be based on the April 1 forecast of reservoir elevation. Because low summer flows could be implemented in the 3 months at the end of the water year, it is possible that by the time a determination was made to conduct a low summer flow experiment, it may not be possible to release enough water in the remainder of the spring to compensate for the low flow period. A low summer flow experiment would only be tested in years when performing the experiment would not result in a deviation from the annual Glen Canyon Dam release volumes made pursuant to the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

A first test of low summer flows would feature low flows of 8,000 cfs and relatively little fluctuation (±1,000 cfs per day). Depending on the results of the first test with regard to warming and humpback chub response, the magnitude of the low flow could be adjusted up or down (as low as 5,000 cfs), and the level of fluctuation also modified up to the range allowed under Alternative D (i.e., 10× monthly volume [in kaf] in July and August, and 9 × monthly volume [in kaf] in September).

The first test of low summer flows will be determined to be successful or unsuccessful for humpback chub based on input from an independent scientific panel review. If the first test was determined to be unsuccessful (and it was determined to have been implemented without major confounding factors), then additional tests would not be performed. Low summer flows would be considered successful if it can be determined that they produced sufficient growth of YOY humpback chub and that growth resulted in an increase in recruitment, but avoided unacceptable increases in warmwater nonnative fishes, trout, or aquatic parasites, or resulted in unacceptable adverse impacts on other aquatic resources. If it was determined to be successful, then additional low summer flows would occur only when humpback chub population concerns warranted them and water temperature has been colder for a period of years, and the desired warming could be achieved only with low summer flows. The temperature target could be adjusted 1°C higher based on the results of the first test or the limitations between predicted and measured temperatures.

Implementation of low summer flows would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. Low summer flows may not be conducted in years when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

The effects of low summer flows on Lake Mead water quality are an identified concern. DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of low summer flows. There are additional concerns related to the risk of warmwater nonnative fish expansion or invasion (e.g., the elevation of Lake Mead was high or the number of warmwater nonnative fish was high). These issues are potential off-ramps as described in Section 2.2.4.3 using the process described in Section 2.2.4.4.

Macroinvertebrate Production Flows under Alternative D

A more diverse and productive aquatic food base could benefit a variety of priority resources, including native fish (including the endangered humpback chub), the rainbow trout fishery, and other riparian species that occur in Glen, Marble, and Grand Canyons. Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), collectively referred to as EPT, are important components of a healthy aquatic food base, but they are notably absent from the Glen and Marble Canyon reaches and very low in abundance and diversity in the Grand Canyon. GCMRC has hypothesized that EPT taxa are recruitment limited, because daily flow fluctuations to meet hydropower demand cause high egg mortality, and the absence of EPT has an adverse effect on the carrying capacity and condition of the trout fishery and native fish communities. EPT are thought to be recruitment limited because Glen Canyon Dam fluctuations create a large varial (intermittently wetted) zone along shorelines. Because the Colorado River in Glen, Marble, and Grand Canyons is canyon-bound and the tributaries that join the river all have comparatively low flow, the size of the varial zone does not appreciably decrease with distance downstream. Thus, although water temperature regimes become more naturalized with distance downstream, the effect that daily flow fluctuations to meet hydropower demand have on the stability of shoreline habitat does not attenuate much with distance from the dam.

This hypothesis attributes the absence of EPT and the poor health of the invertebrate assemblage to the width of the varial zone, similar to earlier investigations (Blinn et al. 1995), but focuses on the effects unstable shorelines have on the eggs of these species. This hypothesis assumes that egg-laying by EPT occurs principally along shorelines. According to the hypothesis, EPT taxa downstream of Glen Canyon Dam are recruitment limited, because daily flow fluctuations to meet hydropower demand negatively affect habitat quality along the shorelines where egg laying is assumed to occur.

To test this hypothesis, macroinvertebrate production flows would be provided every weekend from May through August (34 days total).[5] The flow on weekends would be held steady at the minimum flow for that month, which would ensure that the insect eggs laid during weekends would remain submerged throughout larval development. If the hypothesis is true, there would be an increase in insect production due to the reproductive success of insects that laid eggs during weekends. No change in monthly volumes, ramping rates, or the maximum daily range in flow during weekdays would be required for this experiment. To offset the smaller water releases that would occur during weekends within a given month, larger releases would need to occur during the weekdays within a given month.

Implementation of macroinvertebrate production flows would consider resource condition assessments and resource concerns using the processes described in Sections 2.2.4.3 and 2.2.4.4. These flows may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 2.2.4.3.

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5 The duration and other characteristics of experimental macroinvertebrate production flows could be adjusted within the range of the analysis based on the results of initial experiments.

Effects of the tests would be evaluated using observation to determine the location where insect eggs are deposited and the emergence rates of species. Depending on the outcome of the tests, the experiment could be discontinued if there were unacceptable effects on other resources. There is also the possibility that implementation would result in confounding interactions with TMF experiments, and this will be discussed during the communication and consultation process as described in Section 2.2.4.4.

2.2.4.7 Conservation Measures under Alternative D

Applicable conservation measures identified in previous BOs related to Glen Canyon Dam operations would be carried forward in Alternative D and are described fully in Appendix O. Additional conservation measures to minimize or reduce the effects of actions under Alternative D, or that benefit or improve the status of listed species as part of the LTEMP, also are described in Appendix O.

2.2.5 Alternative E

The objective of Alternative E is to provide for recovery of the humpback chub while protecting other important resources including sediment, the Glen Canyon rainbow trout fishery, aquatic food base, and hydropower resources. Alternative E features a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions (Table 2-2). The alternative uses decision trees to identify when a change in base operations or some other action is needed to protect resources. Of particular focus under Alternative E are changes in sediment input, humpback chub numbers and population structure, trout numbers, and water temperature. The Basin States submitted this alternative for analysis and consideration in the LTEMP EIS.

Some aspects of Alternative E originally proposed by the Basin States were not included in the alternative evaluated in the EIS. These include new infrastructure in the form of a pump-back system that would be used to pump water from the mainstem Colorado into the Paria River to mobilize fine sediment that would then flow into the Colorado River and increase turbidity to reduce the predation efficiency of trout on young humpback chub. The Basin States also proposed implementation of rapid-response HFEs that would be implemented by timing high releases from Glen Canyon Dam to coincide with sediment inputs from the Paria River. See Section 2.4 for a discussion of elements considered but dismissed from analysis in the LTEMP EIS.

2.2.5.1 Base Operations under Alternative E

Under Alternative E, monthly volumes would closely follow the monthly hydropower demand as defined by the contract rate of delivery (Table 2-11). The total monthly release volume of October, November, and December, however, would be equal to that under Alternative A (i.e., 2 maf in years with ≥8.23 maf annual release volume) to minimize the

TABLE 2-11 Flow Parameters under Alternative E in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	6,426
November	642	0.0780	10,781	6,415
December	716	0.0870	11,643	7,159
January	781	0.0949	12,707	7,813
February	691	0.0840	12,449	6,914
March	730	0.0887	11,870	7,298
April	650	0.0790	10,922	6,499
May	672	0.0817	10,935	6,724
June	704	0.0855	11,829	8,446
July	767	0.0932	12,471	9,202
August	659	0.0801	10,721	7,911
September	575	0.0699	9,668	5,753

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts or other factors, and based on application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

possibility of the operational tier differing from that of Alternative A, as established in the Interim Guidelines (Reclamation 2007a). In addition, lower monthly volumes (relative to Alternative A) would be targeted in August and September (15% of the annual release volume for August and September combined) to reduce sediment transport during the monsoon period, when most sediment is delivered by the Paria River.

Under base operations, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month (12 × monthly volume in kaf in high power demand months of June, July, and August, and 10 × monthly volume in kaf in other months; Table 2-1; Figure 2-23). For example, the daily fluctuation range in July with a scheduled release volume of 800 kaf would be 9,600 cfs, and the daily fluctuation range in December with the same scheduled release volume would be 8,000 cfs. The down-ramp rate under this alternative would be limited to no greater than 2,500 cfs/hr, which is 1,000 cfs/hr greater than what is allowed under Alternative A. The up-ramp rate would be 4,000 cfs/hr, and this is the same as under Alternative A. Figure 2-23 shows minimum, mean, and maximum daily flows in an 8.23-maf year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 2-24 shows the hourly flows in a simulated 8.23-maf year within the constraints of Alternative E. Figure 2-25 shows details of hourly flows during a week in July.

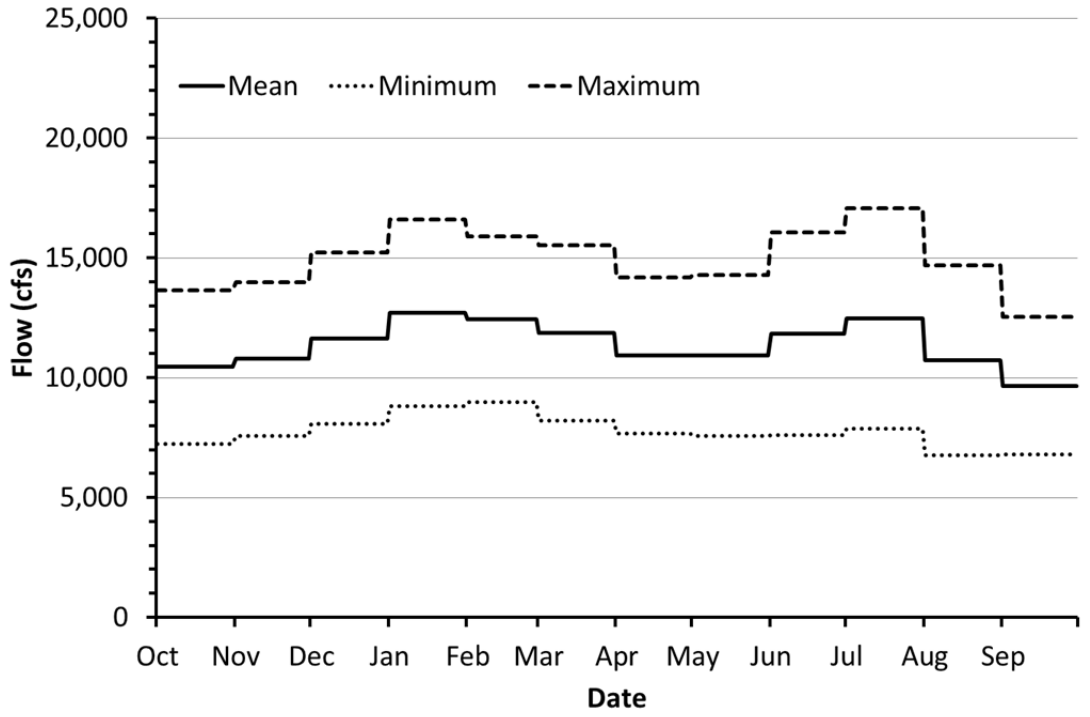


FIGURE 2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11

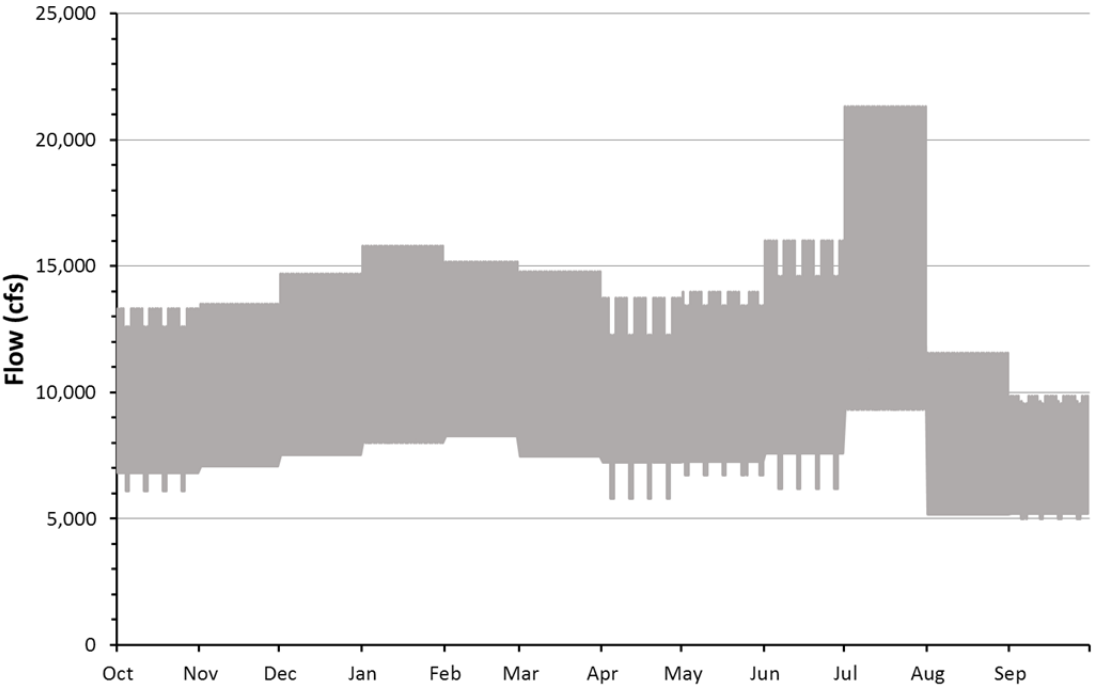


FIGURE 2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2-23. These differences reflect flexibility in operational patterns allowed within the constraints of the alternative.)

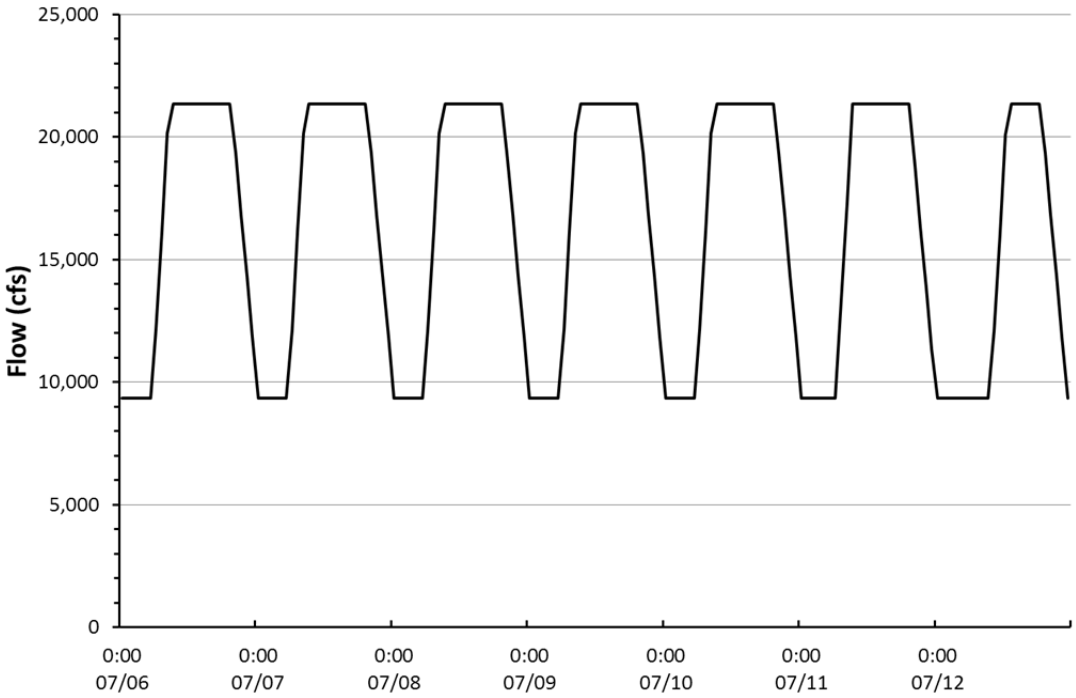
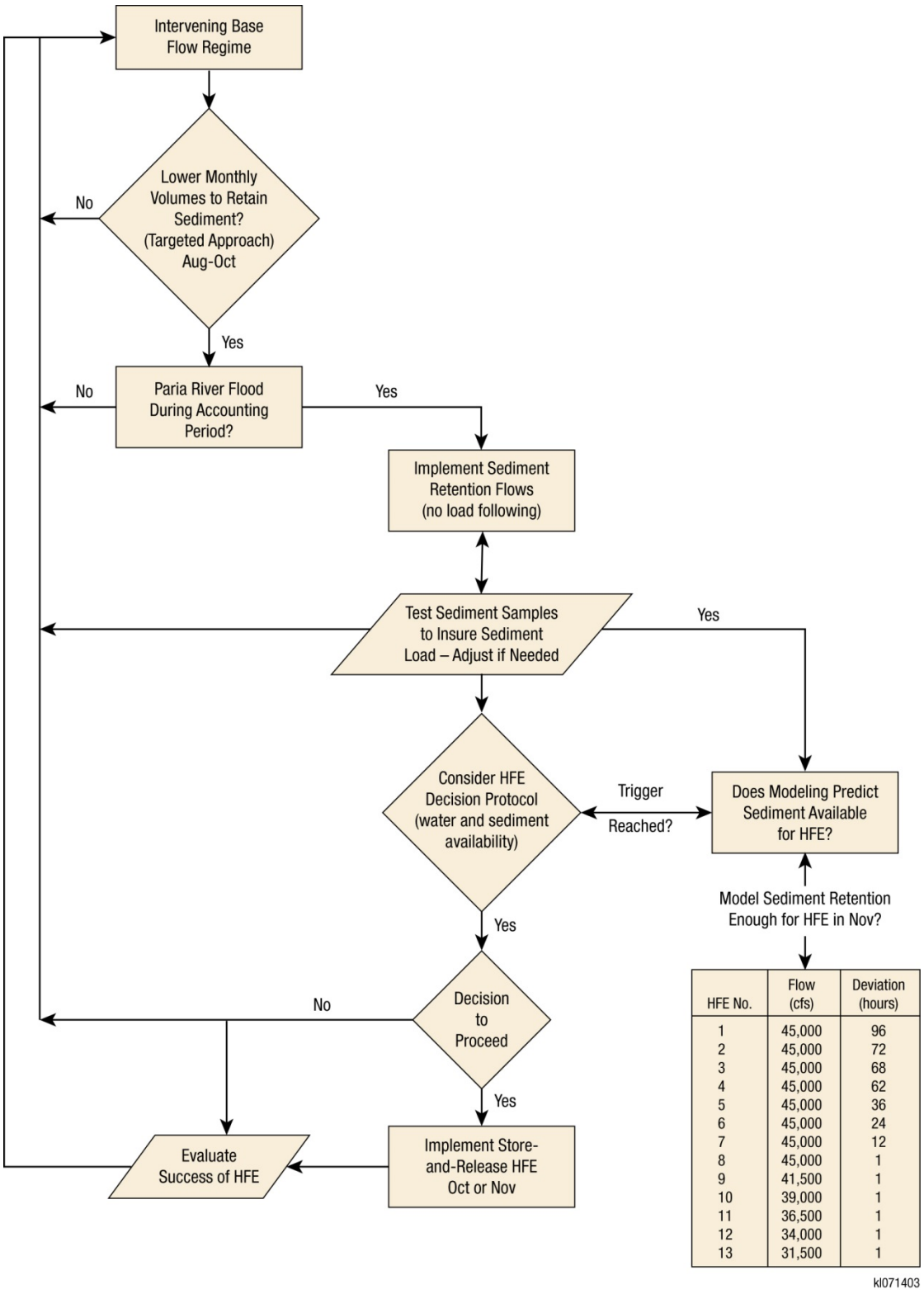


FIGURE 2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows (The week starts on Monday and ends on Sunday.)

2.2.5.2 Experimental Framework for Alternative E

Alternative E uses a condition-dependent approach to implement experimental elements. The alternative would use decision trees, tied to information collected under a long-term monitoring program that would be implemented annually to determine operations and flow and non-flow actions in a given year (Figures 2-26 and 2-27). In general, the experimental framework considered under Alternative E is more structured than that proposed under other alternatives, especially for the experimental evaluation of TMFs. Alternative E would incorporate a 2 × 2 factorial science design to test TMFs.

Base operations under Alternative E would be experimentally modified in response to changes in resource conditions or the need for equalization as specified under the 2007 Interim Guidelines (Reclamation 2007a). The most important experiments relate to (1) implementation of HFEs in response to sediment inputs; (2) reductions in fluctuation in certain parts of the year in response to sediment inputs; and (3) reductions in flows in certain years from July through September to provide warmer water for humpback chub near the confluence with the Little Colorado River. Non-flow actions are largely limited to those that are common to all alternatives as described at the beginning of Section 2.2.



HFE No.	Flow (cfs)	Deviation (hours)
1	45,000	96
2	45,000	72
3	45,000	68
4	45,000	62
5	45,000	36
6	45,000	24
7	45,000	12
8	45,000	1
9	41,500	1
10	39,000	1
11	36,500	1
12	34,000	1
13	31,500	1

FIGURE 2-26 Decision Tree for Sediment-Related Actions under Alternative E (modified from Figure 1 in original Basin States submittal)

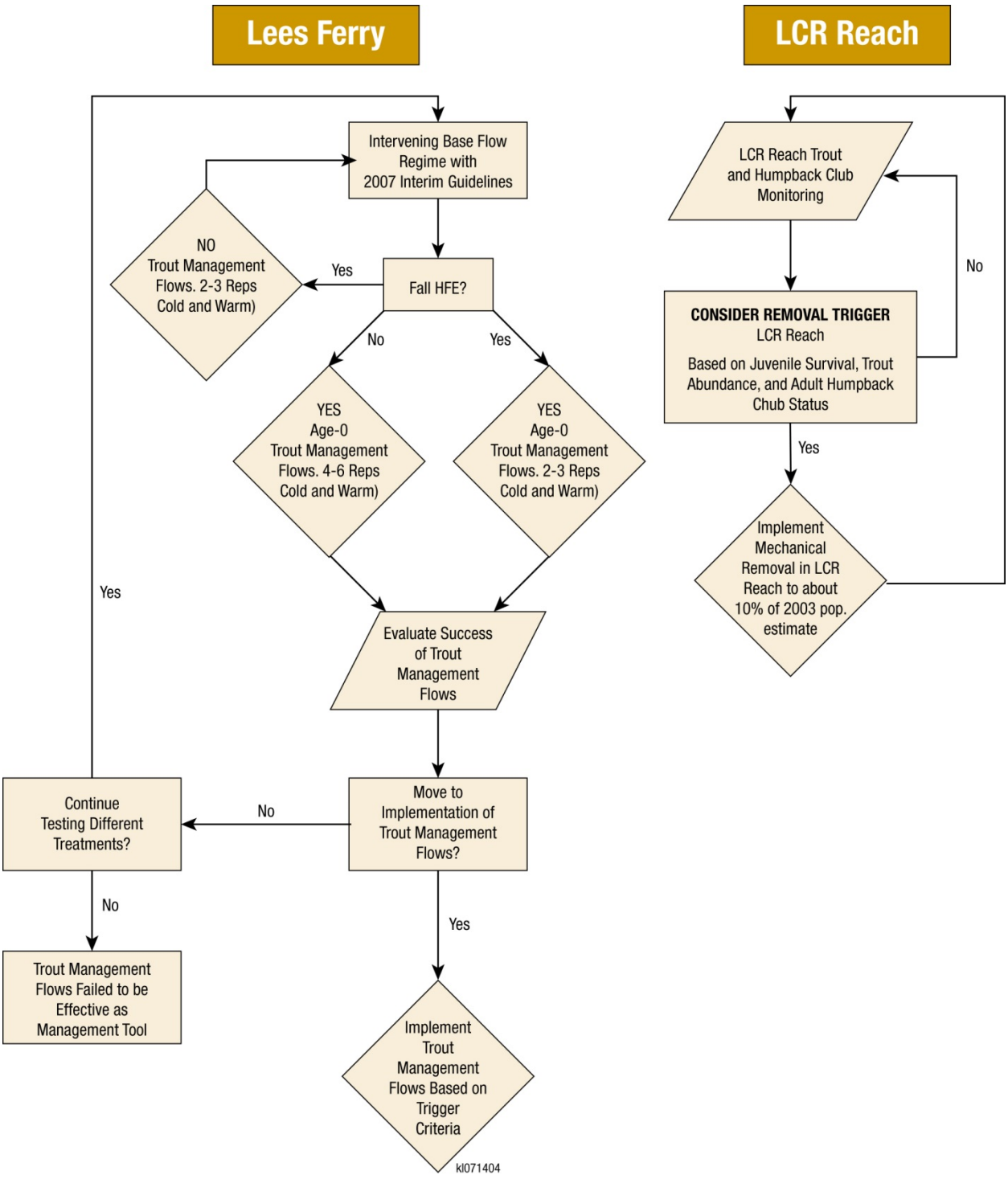


FIGURE 2-27 Decision Tree for Trout-Related Actions under Alternative E (Figure 2 in original Basin States submittal)

Sediment-Related Experiments To Be Evaluated under Alternative E

Under Alternative E, the HFE protocol would be incorporated into the LTEMP process and extended to the end of the LTEMP period. Spring and fall HFEs would be implemented when triggered using the same Paria River sediment input thresholds used under the existing HFE protocol (Reclamation 2011b). HFE releases would be 1 to 96 hr long and between 31,500 cfs and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December through March) or fall (July through October) accounting periods, the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented (see Section 2.2.1 for a brief description of the existing HFE protocol).

Under Alternative E, only fall HFEs would be conducted during the first 10-year period. This delay of implementation of spring HFEs is intended to allow for the testing of TMFs to control trout numbers and emigration rates, and is based on the response of the trout population to the spring HFE of 2008.

Under Alternative E, daily fluctuations for load-following would be reduced (except for instantaneous increases or decreases in flow to provide regulation services)[6] after significant sediment input (sufficient input to trigger an HFE) from the Paria River in August, September, or October to increase the amount of sediment available for transport and deposition by fall HFEs. These reduced fluctuations would occur until an HFE was implemented or a decision to not implement an HFE was made. Under Alternative E, within-day fluctuations in hourly flows would be reduced to a within-day range of 2,000 cfs (i.e., ±1,000 cfs of the mean daily flow).

During high-volume (≥10-maf release volume) release years (i.e., equalization years), an HFE would be conducted quickly (i.e., days) following an unusually large input of sediment from the Paria River to redistribute the new sediment from the main river channel before high-volume releases can transport it downstream. This "quick response" HFE is different from the proactive spring HFEs proposed under Alternatives C and D because it is sediment-triggered; could occur in the spring, summer, or fall of the year; and would not be limited in duration to 24 hr.

Aquatic Resource-Related Experiments To Be Evaluated under Alternative E

Mechanical removal of trout would be conducted at the confluence of the Little Colorado River under certain conditions (i.e., low survival rate of juvenile humpback chub, trout abundance exceeds the level seen in 2003 of about 6,900 individuals in the Little Colorado River reach (RM 56.3 and RM 65.7), or the number of humpback chub adults drops by 1,000 individuals (during the same time the abundance of trout exceeds 690 in the same reach). The removal protocol would follow the Nonnative Fish Control protocol (Reclamation 2011a).

6 Although instantaneous changes in flows could occur within an hour to provide for regulation services, these flow changes would not affect the mean hourly flow.

Alternative E would evaluate potential methods for using releases (TMFs) from Glen Canyon Dam to reduce production of YOY rainbow trout to improve the quality of the Glen Canyon trout fishery and potentially help conserve humpback chub and other native fishes.

This strategy has two potential benefits: (1) flow manipulations are likely to be much less expensive and intrusive than large-scale mechanical removal efforts downstream, and (2) trying to manage trout densities in the Little Colorado River reach without reducing trout production upstream will be difficult to overcome during years with high production (e.g., trout response to 2008 HFE and response to 2011 high steady flows). The goal is to develop a management action based on condition-dependent criteria. Key metrics for a high-quality trout fishery would need to be developed in consultation with the AZGFD, such as targets for adult and juvenile numbers, individual fish condition, YOY numbers, and information and value determined through creel surveys. TMFs could be used to help attain these goals with other management tools employed by the AZGFD and NPS. TMF treatments should address the following:

- Evaluate the potential for utilizing changes in down-ramp rates to strand or displace juvenile trout and reduce recruitment,
- Evaluate different types and magnitudes of TMFs, and
- Determine whether flow and non-flow actions at Lees Ferry would be effective in improving the Lees Ferry trout fishery.

TMFs would be tested in a 2 × 2 factorial design with HFEs over a 20-year period to evaluate their potential effectiveness in reducing trout recruitment levels in the Glen Canyon reach over a variety of environmental conditions. The status of the trout fishery would be considered in any decision to proceed with implementation of TMFs in a given year. The goal is to develop management tools that are robust to a range of natural and human caused conditions. The following treatment combinations would be implemented with a goal of achieving two to three replicates for each combination under warm and cold temperature conditions over the 20-year LTEMP period:

- No fall HFE and no TMF, to measure trout recruitment with neither factor in place;
- No fall HFE, but with a TMF, to test effects of TMFs alone;
- Fall HFE, but no TMF, to test effects of HFEs alone; and
- Both fall HFE and TMF, to test the effects of both in the same year.

Two options for implementation would be considered (1) begin with moderate treatments (e.g., one cycle); or (2) begin with more robust treatments (e.g., three or more cycles) to establish easily observable results. With this latter approach, successive treatments would evaluate more moderate treatments if the first tests showed an effect.

At least four types of TMFs would be evaluated: (1) YOY stranding and displacement flows from May through June, (2) YOY stranding and displacement flows from July through August, (3) YOY stranding and displacement flows without moving to high flows (e.g., 20,000 cfs) prior to dropping to a minimum, and (4) flow reductions applied only at night to the above scenarios with the objective of reducing food base impacts from desiccation.

YOY stranding and displacement flows would consist of 3 days at steady 20,000 cfs followed by a rapid drop (unrestricted down-ramp rate) to 5,000 cfs or 8,000 cfs to be held for 6 hr during daylight hours (6 a.m.–noon). Three such cycles would be conducted over the month. A 3-day flow cycle would be followed by 7 days of normal flows, and this 3- to 7-day pattern would be repeated three times over the month. This option would include tests of this method in May and June, and then in July and August if sediment retention flows were not in effect (see Figure 2-15 for an illustration of TMFs).

A test without moving to high flows first would determine if it is necessary to attract trout to higher elevations (e.g., steady 20,000 cfs) before a rapid drop. Trout generally reside at the normal minimum flow (Korman and Campana 2009). Thus, they may be susceptible to a rapid drop in flow without the need to raise flows for an extended period beforehand. This test would stabilize flows near the normal minimum (within the varial zone), and would then apply a rapid down-ramp below the minimum.

If reservoir elevations are not variable enough during the first 10 years to produce years with warm releases, a steady flow test aimed at achieving warmer temperatures would be considered. If the evaluation is warranted, implementation would be conditioned on the status of the humpback chub and other critical resources. A low summer flow experiment would not be conducted at a time when the humpback chub population is low or declining. Under Alternative E, a low summer flow experiment would only be conducted in a warm release year to increase contrast with more typical coldwater years.

The transition in flow volume from one month to the next can be substantial. Low-volume months, such as a 600-kaf month, can be followed by a month that exceeds 900 kaf. These large transitions may have a negative impact on productivity of the aquatic food base (i.e., organisms including algae, plants, and invertebrates that serve as the foundation of the aquatic food web). Alternative E would include a stepped transition between months when substantial differences in the amount of water releases occur. The decision rules for transition flows would need to be developed to take into account the difference in volume that would trigger these flows, and the amount of time necessary to provide suitable transition to minimize impacts on the food base.

2.2.6 Alternative F

The objective of Alternative F is to a provide flows that follow a more natural pattern while limiting sediment transport and providing for warming in summer months. In keeping with this objective, Alternative F does not feature some of the flow and non-flow actions of the other alternatives.

Flows under Alternative F would follow the same basic monthly pattern as the Seasonally Adjusted Steady Flow Alternative in the 1995 EIS (Reclamation 1995), but the pattern is modified to achieve higher, more variable spring peak flows, lower summer, fall, and winter flows, and warmer temperatures starting in July. Peak flows would be lower than pre-dam magnitudes to reduce sediment transport and erosion given the reduced sand supply downstream of the dam. There would be no within-day fluctuations in flow under Alternative F (see Tables 2-1 and 2-12; Figure 2-28).

Under Alternative F, peak flows would be provided in May and June, which corresponds well with the timing of the pre-dam peak. The overall peak flow in an 8.23-maf year would be 20,000 cfs (scaled proportionately in drier and wetter years); it would include a 24-hr 45,000-cfs flow at the beginning of the spring peak period (e.g., on May 1) if there was no triggered spring HFE in the same year, and a 168-hr (7-day) 25,000 cfs flow at the end of June. Following this peak, there would be a rapid drop to the summer base flow. The initial annual 45,000-cfs flow would serve to store sediment above the flows of the remainder of the peak, thus limiting sand transport farther downstream and helping to conserve sandbars. The variability in flows within the peak would also serve to water higher-elevation vegetation.

Low base flows would be provided from July through January. These low flows would provide for warmer water temperatures, especially in years when releases are warm, and would also serve to reduce overall sand transport during the remainder of the year.

Under Alternative F, the only adjustment to base operations would be sediment-triggered HFEs implemented according to the HFE protocol (Reclamation 2011b) for the entire LTEMP period. There would be no mechanical removal of trout or TMFs. However, the rapid drop from peak flow to base at the end of June could incidentally serve much the same function as a TMF, thus acting to reduce the overall high trout production rates expected under a steady flow regime.

Other than testing the effectiveness of HFEs as implemented under the HFE protocol, there would be no explicit experimental or condition-dependent triggered actions under Alternative F. As with other alternatives, an ongoing monitoring program would be used to determine the response of resources to operations, and adjustments to those operations would be made consistent with adaptive management.

2.2.7 Alternative G

The objective of Alternative G is to maximize the conservation of sediment, in order to maintain and increase sandbar size. The alternative is based on the hypothetical best-case scenario suggested by Wright, Schmidt et al. (2008) for conservation of sand inputs from tributaries downstream of Glen Canyon Dam. Under Alternative G, flows would be delivered in a steady pattern throughout the year with no monthly differences in flow other than those needed to adjust operations in response to changes in forecast and other operating requirements such as equalization (Tables 2-1 and 2-13; Figure 2-29). In an 8.23-maf year, steady flow would be approximately 11,400 cfs.

TABLE 2-12 Flow Parameters under Alternative F in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	506	0.0615	8,229	0
November	490	0.0595	8,229	0
December	506	0.0615	8,229	0
January	506	0.0615	8,229	0
February	611	0.0742	11,000	0
March	861	0.1046	14,000	0
April	1,012	0.1229	17,000	0
May	1,230	0.1494	20,000	0
June	1,190	0.1446	20,000	0
July	445	0.0540	7,229	0
August	445	0.0540	7,229	0
September	430	0.0523	7,229	0

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded.

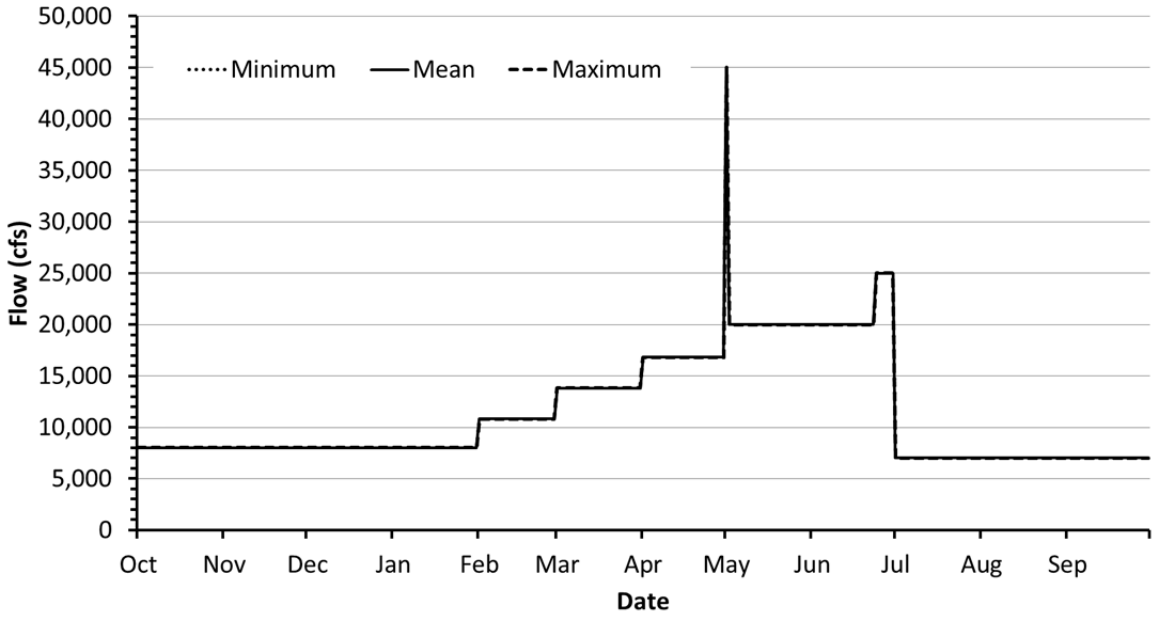


FIGURE 2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12

TABLE 2-13 Flow Parameters under Alternative G in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)[b]	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	699	0.0849	11,368	0
November	699	0.0849	11,747	0
December	677	0.0823	11,010	0
January	699	0.0849	11,368	0
February	676	0.0821	12,172	0
March	699	0.0849	11,368	0
April	699	0.0849	11,747	0
May	631	0.0767	10,262	0
June	699	0.0849	11,747	0
July	676	0.0821	10,994	0
August	699	0.0849	11,368	0
September	677	0.0823	11,377	0

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

[b] Values have been rounded. Variation among months reflects adjustments based on changing forecasts.

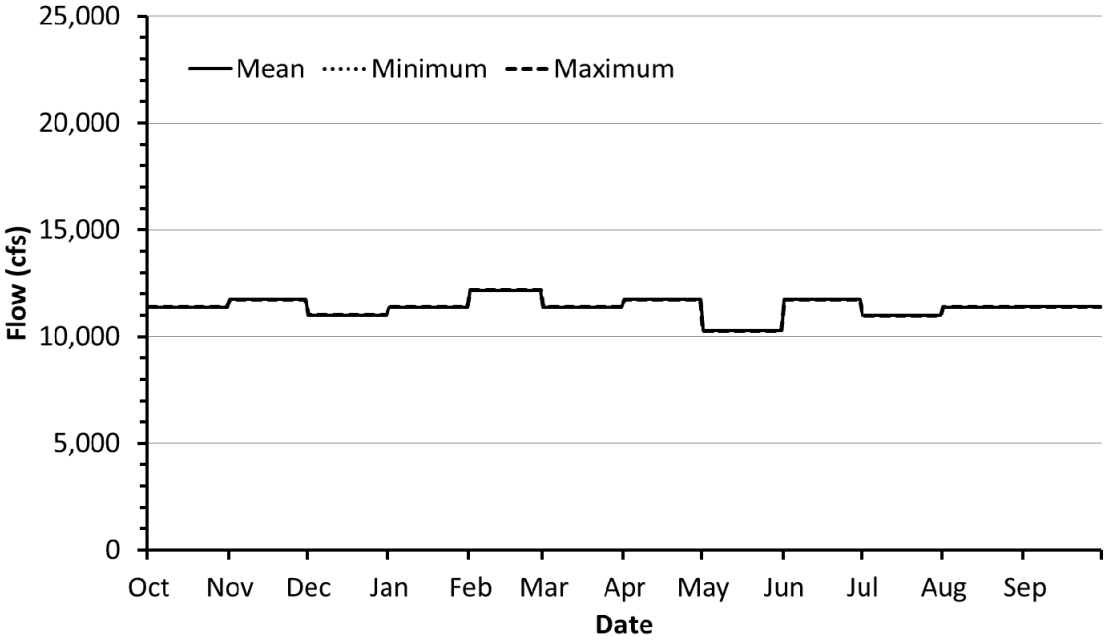


FIGURE 2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an 8.23-maf Year Based on Values Presented in Table 2-13

Under Alternative G, spring and fall HFEs would be implemented in accordance with the HFE protocol (Reclamation 2011b), but with experimental modifications as described under the Alternative C (Section 2.3.3.2) including (1) adjustments of operations before and after HFEs occur; (2) implementing spring proactive HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of longer duration (>96-hr) HFEs. Under Alternative G, however, the volume of a longer duration HFE would not be constrained by the volume of a 96-hr 45,000-cfs HFE, but instead could be as long as 336 hr (14 days), depending on the amount of sediment available for transport.

Under Alternative G, mechanical removal of trout would be implemented consistent with the Nonnative Fish Control protocol (Reclamation 2011a) in the Little Colorado River reach. Testing and implementation of TMFs as triggered by trout recruitment would occur as described for Alternative C (Section 2.3.3.3).

2.3 ALTERNATIVES CONSIDERED AND ELIMINATED FROM DETAILED STUDY

During the scoping and analysis periods for the LTEMP DEIS, a number of alternative concepts were either (1) developed and explored by the DOI's LTEMP team; (2) developed as complete alternative proposals by the Cooperating Agencies or other stakeholders; or (3) suggested by the public as alternatives that should be included in the LTEMP DEIS. Four of the alternative concepts developed by the DOI's LTEMP team are described in Section 2.2 (Alternatives C, D, F, and G). Also described in Section 2.2 are two complete alternative proposals submitted by stakeholders. Alternative E was submitted by the Basin States and Alternative B was submitted by CREDA, a non-profit association of energy customers of the Colorado River Storage Project, in response to the DOI's request to all stakeholders for alternative concepts. Other alternatives are identified below with an explanation of why they were not included as an alternative in the EIS.

2.3.1 Modified Low Fluctuating Flows with Extended Protocols

The DOI's LTEMP team identified an alternative that would be comparable to Alternative A, but that would extend the existing HFE and Nonnative Fish Control protocols past their current expiration date of 2020 through the entire LTEMP period. This alternative was in part identified to enable a more direct comparison of impacts with the remaining alternatives that would extend the protocols through the LTEMP period. Alternative A, by definition, would only implement existing decisions up to their expiration dates. Preliminary analyses indicated that this alternative would perform similarly to Alternative A, especially for hydropower generation value (based on monthly release volumes and daily flow fluctuations), and would be similar to Alternative E with respect to humpback chub, trout, and sediment resources (because of alternative-specific flow fluctuations and the frequency of HFEs). The analysis of the seven alternatives evaluated in the EIS evaluates a reasonable range of possible operational and experimental variations, including those of this alternative, without requiring additional detailed analysis for NEPA compliance purposes.

2.3.2 Naturally Patterned Flow Alternative

A Naturally Patterned Flow Alternative, similar to the Historic Pattern Alternative, described in the 1995 EIS (Reclamation 1995), was identified by the DOI's LTEMP team as a possible alternative early in the LTEMP EIS process. Under this alternative, flows would vary from month to month in conformance with the historic flow pattern and would not include daily fluctuations. HFEs would be sediment triggered, but their timing would be shifted to conform to natural flood timing. Minimum flows could be lower than the current minimum, and maximum flows as high as full bypass, scaled for the annual hydrologic condition. Transitions between months would be relatively smooth, with established limitations on the rate of change between days.

Preliminary modeling indicated that sand transport under this alternative, as originally defined, would be far higher than under other alternatives. When originally conceived, this alternative featured sediment augmentation as a critical element. Without sediment augmentation (see rationale for not including sediment augmentation or other new infrastructures in alternatives in Section 2.4.1), estimated sand transport would be too great to sustain downstream sediment resources, and, as a consequence, this alternative was considered to not meet the purpose, need, and objectives of the LTEMP. High rates of erosion were also identified for the Historic Pattern Alternative in the 1995 EIS (Reclamation 1995), and were considered as the primary reason for eliminating it from further consideration. It should be noted that Alternative F was developed by the DOI in response to the findings of the preliminary analysis of the Naturally Patterned Flow Alternative, and was included in the EIS to provide an alternative that achieved the original objectives of the Naturally Patterned Flow Alternative while reducing overall sediment transport, and thus, meeting the purpose, need, and objectives of the LTEMP.

2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative

The Seasonal Fluctuations with Low Summer Flow Alternative would feature low summer (July through September) flows each year, and was developed by the DOI's LTEMP team to provide warmer water temperatures for native fish and other aquatic resources. Excess water volume not released in the summer would be released in the winter (December through February) and late spring (May and June). Fluctuations would be low in the summer (2,000 cfs daily range), but would conform to MLFF-level fluctuations the remainder of the year. The alternative would use the existing HFE and Nonnative Fish Control protocols for the entire LTEMP period. Preliminary analyses for this alternative were completed, but it was not included as an LTEMP alternative because the analyses suggested that the alternative did not perform better than others with regard to impacts on native fish populations and other aquatic resources. This is largely a consequence of the marginal gains in temperature (about 1 or 2°C at the Little Colorado River confluence) that are expected to occur under low flows. Since the alternative did not meet its intended objectives, there was no compelling reason to include it as an alternative in the EIS. Other alternatives, such as Alternatives C, D, and E, were determined to provide benefits to native fish and aquatic resources, and therefore met the objectives of the Seasonal Fluctuations with Low Summer Flow Alternative.

2.3.4 Grand Canyon First! Alternative

A "Grand Canyon First!" Alternative was proposed as an alternative concept in a number of public scoping comments. In this alternative, consideration of the ecology and wildlife of Grand Canyon would be the paramount consideration, restoring Grand Canyon to its historical state to the extent possible. This alternative would recognize the Grand Canyon Protection Act (GCPA) as the primary source to inform the LTEMP EIS, and the operations of Glen Canyon Dam should help to preserve the natural and cultural resources of Grand Canyon. Public comment provided objectives but not an operational regime, non-flow actions, or experimental plan to achieve those objectives; therefore, this alternative was not sufficiently well-defined to include as an LTEMP alternative. Although this concept was not included as an alternative in the EIS, all LTEMP alternatives include many of the concepts that are in this proposal; for example, operations to achieve sediment and native fish objectives are included in LTEMP alternatives, including Alternatives C, D, E, F, and G.

2.3.5 Species Community and Habitat-Based Alternative

Several members of the public suggested that a Species Community and Habitat-Based Alternative be included in the LTEMP DEIS. This proposed alternative concept was intended to contribute to the conservation or recovery of endangered or extirpated species, such as the humpback chub, razorback sucker, southwestern willow flycatcher (*Empidonax traillii extimus*), and Kanab ambersnail. It would also contribute to the conservation of other non-listed aquatic and riparian species (including flannelmouth sucker [*Catostomus latipinnis*], bluehead sucker [*Catostomus discobolus*], and speckled dace [*Rhinichthys osculus*]) to reduce the need to list them under the ESA. This would include an ESA Recovery Implementation Program focused on supporting native species communities that ensures that their habitat-based needs are met. This alternative would include a management program for the trout at Lees Ferry that also provides for protection of humpback chub and other native fish populations downriver, and a quality recreational fishery at Lees Ferry. Public comment provided objectives, but not an operational regime, non-flow actions, or experimental plans to achieve those goals, and, therefore, was not sufficiently well-defined to include as an LTEMP alternative. Although this concept was not included as an alternative in the EIS, other elements of the concept, such as operations to achieve sediment, native fish, and trout management objectives, are included in several alternatives, including Alternatives B, C, D, E, F, and G. Each of these LTEMP alternatives identifies operations to protect existing ecological resources.

2.3.6 Stewardship Alternative

During public scoping, commenters suggested consideration of a Stewardship Alternative that utilized a flow regime that would best serve Grand Canyon and be aligned with the GCPA, with no consideration given to hydropower. Commenters provided objectives but not an operational regime, non-flow actions, or experimental plan to achieve those objectives, and, therefore, this alternative was not sufficiently well-defined to include as an LTEMP alternative. In addition, the suggestion that hydropower generation should not be considered as an objective

is counter to the purpose, need, and objectives of the proposed action. Although this concept was not included as an alternative in the EIS, all LTEMP alternatives include many concepts in this proposal; for example, operations to achieve sediment and native fish objectives are included in several LTEMP alternatives, including Alternatives C, D, E, F, and G. Each of these LTEMP alternatives places high priority on protecting downstream resources and identifies flow and non-flow actions to protect those resources.

2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives

Grand Canyon Trust proposed a 12-year series of three 4-year experimental blocks. Operations during the first 4-year period would be seasonally adjusted steady flows. Operations during the next 4-year block would be MLFF. The final 4-year block would feature year-round steady flows. All three flow regimes would include high-flow releases under sediment-enriched conditions. After 12 years, the three regimes would be analyzed to determine which had the most favorable results consistent with the GCPA.

This alternative was not included in the EIS, because the proposed experimental design would most likely lead to confounding of effects by the hydrologic patterns that occurred during the LTEMP period, differences in annual volumes, the potential need for equalization operations during one or more years, and differences in sediment supply between treatments. These confounding factors would make it difficult to interpret the results of the proposed experiment. The three operational regimes proposed for this alternative were, however, included as separate alternatives.

2.3.8 Decommission Glen Canyon Dam Alternative

During the public scoping period, several members of the public suggested that an alternative that would result in the decommissioning of Glen Canyon Dam should be considered. Comments suggested that the dam could be either left in place or removed. If left in place, reservoir levels would be equalized to upstream inflows. Lake Powell water levels would drop, and the sediments would begin to cut new banks and form a new channel that would flow around and through the dam. Public comments advocating the decommissioning of the dam mentioned the benefits of opening currently submerged areas to new recreational activities; restoring the environmental, recreational, and cultural resources of the Grand Canyon and the Colorado River basin to their pre-dam conditions; and positively affecting the health of the Colorado River Ecosystem. One commenter suggested transferring the contents of Lake Powell and Lake Mead to underground storage locations to avoid losing water to evaporation. The commenter stated that there are abundant nearby natural underground locations that could accommodate the volume of water from 6 years of the Colorado River's annual flow.

The Decommission Glen Canyon Dam Alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water delivery requirements, including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal

requirements and regulations, including the GCPA. This alternative was proposed by members of the public during scoping for the 1995 EIS on Glen Canyon Dam operations, and was not considered for detailed study for reasons similar to those presented above.

2.3.9 Fill Lake Mead First Alternative

The Fill Lake Mead First Alternative was proposed by members of the public during the public scoping comments. Under this alternative, primary water storage would shift from Lake Powell to Lake Mead, using Lake Powell as a backup for seasonal and flood control purposes. According to the commenters, there would likely be less water lost to evaporation and seepage, and there would be greater flexibility for implementing Grand Canyon restoration strategies. This alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water release requirements, including, but not limited to, the division and apportionment of the use of the waters of the Colorado River system under the Colorado River Compact, as well as other portions of the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b). In addition, the alternative would not comply with other federal requirements and regulations, including the GCPA.

2.3.10 Full-Powerplant Capacity Operations Alternative

During the public scoping period, members of the public suggested inclusion of an alternative that allowed for full powerplant capacity operations. Commenters suggested that pre-1996 ROD operations be considered as one alternative to allow for a better understanding of the effects of MLFF operations. The Full-Powerplant Capacity Operations Alternative was not included in the EIS because it would not meet the purpose, need, and objectives of the LTEMP, including compliance with the GCPA. Although the Full-Powerplant Capacity Operations Alternative was not considered as a separate alternative in the EIS, Alternative B described in Section 2.3.2 and analyzed in Chapter 4 includes a test of "hydropower improvement flows" that would feature wide daily fluctuations (up to 20,000 cfs in some years and months).

2.3.11 Run-of-the-River Alternative

Some members of the public suggested that Glen Canyon Dam could be re-engineered to operate as a modified run-of-the-river facility. A Run-of-the-River Alternative would restore natural water and sediment flows to the greatest extent possible by reconnecting old river bypass tunnels or constructing new tunnels to bypass Glen Canyon Dam. This alternative would utilize elements of the "Fill Lake Mead First" alternative above. This alternative was not included in the EIS because it would not meet the purpose, need, or objectives of the proposed action. The alternative would not allow compliance with water delivery requirements, including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA.

2.4 ALTERNATIVE ELEMENTS ELIMINATED FROM DETAILED STUDY

A number of elements were considered by the DOI's LTEMP team for inclusion in LTEMP alternatives, including those identified by the public during the scoping process and alternative workshop in April 2012. Many are included in the alternatives described in Section 2.2. Those eliminated from detailed study are described in this section.

2.4.1 New Infrastructure

Several infrastructure additions and modifications were initially discussed by the DOI during alternative development, including (1) sediment augmentation, (2) a TCD, (3) retrofitting of the bypass tubes to install power generation, and (4) re-engineering of the spillways if needed to allow for more frequent use. Prior to initiation of LTEMP alternative development, options for sediment augmentation, bypass generation, and a TCD were evaluated by Reclamation from engineering assessment and cost perspectives. Several of these options were described in Randle et al. (2006), Reclamation (1999b), and Vermeyen (2008).

In addition to infrastructure additions or modifications considered by the DOI, the Basin States and CREDA included several infrastructure considerations in the alternatives they proposed. These are described in the following paragraphs.

Under Alternative E, the Basin States proposed an investigation to determine the feasibility of using a pump-back system in the Paria River drainage to increase turbidity in the mainstem. This feasibility study would evaluate options, limitations, and cost-benefit. The study would investigate the possibility of installing a pumping system at Lees Ferry to transport a small amount of water up into the Paria River drainage to increase turbidity for a few weeks in the mainstem to disadvantage rainbow trout.

For Alternative B, CREDA proposed utilizing bubblers in the Glen Canyon forebay to break down the temperature differential between the surface and deeper waters and consequently provide warmer water near the turbine intakes for release downstream. To increase turbidity downstream of the dam, CREDA proposed installing one or more small check dams in the Paria River that would be used to trap sediment for release during a time when young humpback chub are entering the mainstem from the Little Colorado River, thereby enhancing their survival chances by reducing trout predation.

The DOI considers any infrastructure modifications or additions to be outside the scope of the LTEMP EIS because they are currently economically infeasible and would require additional congressional authorizations. However, the DOI does not rule out future new infrastructure if resource conditions warrant. Any infrastructure addition or modification would require additional time and study. Future potential infrastructure modifications would need to be evaluated in NEPA assessments (EAs or EISs) that fully considered the environmental impacts of construction and operation. These assessments and the construction of the infrastructure would necessarily result in some delay from the time of the LTEMP ROD and actual start of

operation of the infrastructure. It could take as many as 10 years or more to evaluate and construct a TCD or sediment augmentation.

2.4.2 Flow and Non-Flow Actions

A number of flow and non-flow actions were considered by the DOI or proposed by the Cooperating Agencies, stakeholders, or the public for inclusion in the LTEMP DEIS. For various reasons, as described below, these actions were not evaluated in any of the LTEMP alternatives.

For Alternative E, the Basin States proposed that after every three store-and-release fall HFEs, the next triggered fall HFE would be a "rapid response" HFE in which Glen Canyon Dam releases would be increased within hours or days of a significant input of sediment from the Paria River. Under the alternative, more than one rapid response HFE could occur within a given fall period in response to multiple inputs of sediment. Rapid-response HFEs were not considered in the EIS because of implementation concerns, including the difficulty in coordinating releases with tributary inputs, insufficient lead time to fully notify the public and other stakeholders, and potential safety concerns associated with insufficient notification.

For Alternative B, CREDA proposed including several experiments that were not included in the alternative as analyzed. These included ponding flows and fluctuating flow experiments. Ponding flows are those relatively high flows that produce low-velocity areas in tributary mouths for the benefit of humpback chub. However, there is little evidence that ponding flows would provide benefit to YOY humpback chub; therefore, ponding flows were not included as an experimental element in Alternative B or any other alternative. Power production experiments would be short-term flow experiments intended to investigate alternative fluctuating flow parameters that might be compatible with downstream resource objectives. Because specific details of these experiments were not provided by CREDA, they were not included as an experimental element in Alternative B as evaluated in the LTEMP EIS.

Some members of the public suggested that the equalization flows identified in the Interim Guidelines (Reclamation 2007a) be released in ways that minimize impacts and provide benefits. Adverse impacts of 2011 equalization flows on sediment resources were mentioned by several commenters. It was suggested that alternatives should consider adjusting timing and magnitude of equalization flows to coincide with available sediment from the Paria and Little Colorado Rivers to help rebuild beaches in the Grand Canyon. It was also suggested that equalization flow releases should be implemented over several years rather than in a single year, as currently implemented under the 2007 ROD. This suggested adjustment to an existing recent decision would not meet the purpose, need, or objectives of the LTEMP, which requires compliance with existing, laws, regulations, and decisions.

Members of the public suggested considering introducing variability in flows by including ≥45,000-cfs flows. It was suggested that flows of 60,000 cfs and more would be beneficial for sediment-dependent resources in the Grand Canyon. This alternative element was not considered for inclusion in alternatives because it would require use of the dam's spillway, which was designed for occasional use in cases of high inflow and dam safety. The spillway is

not engineered for repeated use during normal operations, and any modifications to the dam's infrastructure are considered outside the scope of the EIS, as discussed in Section 2.4.1. In addition, the spillways can only be used when the reservoir levels are very high; it is not possible to use the spillways at low reservoir elevations. It should be noted that, over the course of the LTEMP period, it is possible that such very high flows would occur as a result of normal hydrologic variation, as happened in the very wet years of 1983 and 1984.

Mechanical removal of trout in the Glen Canyon reach was considered initially by the DOI during the development of Alternative C. This alternative element was not included in the EIS because modeling indicated that the effort necessary to effect a reduction in the Glen Canyon trout population with electrofishing would be expensive, impractical, and largely ineffective. TMFs, as included in several LTEMP alternatives, were considered a much more practical way of managing trout population size in the Glen Canyon reach.

2.5 SUMMARY COMPARISON OF ALTERNATIVES

The analysis of alternatives used both quantitative and qualitative approaches (see Section 4.1). As described in Section 2.1, a structured decision analysis approach was used to help develop alternatives and to provide a basis for assessing the performance of alternatives. For this latter function, performance metrics for various resource goals were developed by subject matter experts in Reclamation, NPS, GCMRC, Argonne, FWS, and WAPA, with input from other Cooperating Agencies, AMWG stakeholders, and Tribes (see Appendices B and C). The structured decision analysis approach was not the only method by which the alternatives were analyzed, and a preferred alternative was identified. The identification of a preferred alternative was based on the full EIS analysis and considerations relating to qualitative and quantitative evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were also considered in this decision.

For those metrics that could be quantitatively assessed with mathematical models that estimated the response of resources to environmental conditions, a full range of potential hydrologic conditions and sediment conditions were evaluated for a 20-year period (water years 2013–2033) that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell inflow scenarios for the 20-year LTEMP were sampled from the 105-yr historic record (water years 1906–2010). This method produced 21 separate hydrology traces (sequence of monthly and annual water volumes) for analysis that represented a range of possible conditions from dry to wet. In addition to these 21 hydrology traces, three 20-year sequences of sediment input from the Paria River sediment record (water years 1964–2013) were analyzed that represented low, medium, and high sediment input. In combination, the 21 hydrology traces and three sediment traces resulted in an analysis that considered 63 possible hydrology-sediment scenarios for analysis.

Mathematical models were used to predict resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. For resource impacts that could not be modeled, a qualitative approach that relied on observed effects of flows and other factors on

resources, as published in the scientific literature, was used to assess impacts. See Chapter 4 for a description of the modeling and assessment approaches used for each resource topic.

After this modeling of Alternative D was completed, several adjustments were made to specific operational and experimental characteristics based on discussions with the Cooperating Agencies and stakeholders. These adjustments included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration (>96 hr) fall HFE. Adjustments made to Alternative D after the DEIS was published, and based on comments received from stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE. As described in Section 4.1 of the EIS, for most resources other than sediment and hydropower, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. In addition, for all resources but hydropower, the relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments.

Table 2-14 presents a summary of impacts anticipated under each alternative by resource topic. For resources where the effects of the adjustments to Alternative D mentioned in the previous paragraph could be noticeable (i.e., sediment and hydropower), the effects are identified in footnotes to Table 2-14. More detailed information on the impacts of alternatives is provided in Chapter 4.

TABLE 2-14 Summary of Impacts of LTEMP Alternatives on Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Water (hydrology and water quality)	No change from current condition in reservoir elevations, annual operating tiers, monthly release volumes, mean daily flows, or mean daily changes in flow (up to 8,000 cfs). No change in temperature or other water quality indicators.	Compared to Alternative A, no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months (up to 12,000 cfs). Hydropower improvement flows would cause even greater mean daily flow changes. Negligible differences in temperature or other water quality indicators.	Compared to Alternative A, some change from current condition related to reservoir elevations (<2 ft difference for each reservoir at end of Dec.), annual operating tiers (2.1% of years), monthly release volumes and mean daily flows (lower in Aug. and Sept.); lower mean daily changes in flow in all months (up to 6,200 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.2-ft difference for Lake Powell, no difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months (up to 8,000 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.3-ft difference for Lake Powell, 0.1-ft difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows (lower in Aug. and Sept.); higher mean daily changes in flow in all but Sept. and Oct. (up to 9,600 cfs). Some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (about a 3-ft difference for each reservoir at the end of Dec.) and annual operating tiers (2.1% of years); large changes in monthly release volumes and mean daily flows (high volume in May and June, low in other months); steady flows throughout the year. Greatest summer water temperature and increased potential for bacteria and pathogens.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.4-ft difference for Lake Powell, 1.4-ft difference for Lake Mead at end of Dec.) and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year. Some increase in summer water temperature and potential for bacteria and pathogens.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Sediment	Least HFEs of any alternative would result in lowest potential for building sandbars (highest impact of alternatives), highest sand mass balance (lowest impact of alternatives.	Compared to Alternative A, sandbar building potential would increase 10%, but higher fluctuations would result in lower sand mass balance (80% decrease).	Compared to Alternative A, sandbar building potential would increase 157%, but sand mass balance would decrease 112%.	Compared to Alternative A, sandbar building potential would increase 152%, but sand mass balance would decrease 47%.[b]	Compared to Alternative A, sandbar building potential would increase 119%, but sand mass balance would decrease 96%.	Compared to Alternative A, sandbar building potential would increase 167%, but sand mass balance would decrease 230% (highest impact of alternatives).	Compared to Alternative A, sandbar building potential would increase 176%; lowest impact of alternatives), but sand mass balance would decrease 182%.
Natural processes	Existing natural processes related to flow, water temperature, water quality, and sediment resources would continue, but replenishment of sandbars would diminish after 2020 when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be comparable nearshore habitat stability as a result of similar within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be lower nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within season variability; more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, year-round steady flows would result in the greatest nearshore habitat stability, slightly higher summer water temperatures, and the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Aquatic ecology	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Compared to Alternative A, slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows; habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced; lower trout abundance; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; habitat quality and stability for nonnative and native fish may be higher; higher trout abundance even with implementation of TMFs and mechanical removal; no difference in humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; experimental macroinvertebrate production flows (only featured in this alternative) may further increase productivity and diversity; habitat quality and stability for nonnative and native fish are expected to be slightly higher; negligible change in trout abundance with implementation of TMFs, and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base, and similar or increased drift; habitat quality and stability for nonnative and native fish would be slightly lower; lower trout abundance with implementation of TMFs and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year; positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives; higher trout abundance; slightly lower humpback chub abundance.	Compared to Alternative A, relatively high productivity of aquatic food base and long-term drift; greater habitat stability for nonnative and native fish; higher trout abundance even with implementation of TMFs and mechanical removal; slightly lower humpback chub abundance.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Vegetation	Overall index = 3.66 reflecting an adverse impact relative to current condition resulting from: narrowing of Old High Water Zone; an expected decrease in New High Water Zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Compared to Alternative A, a 6% increase in overall index reflecting an improvement in vegetation conditions (but a decline under hydropower improvement flows); impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in arrowweed, an increase in native diversity (decrease under hydropower improvement flows), an increase in native/nonnative ratio (decrease under hydropower improvement flows), and a decrease in wetland community cover.	Compared to Alternative A, a 13% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone; decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, an 8% increase in overall index reflecting an improvement in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, an increase in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover. Lowest impact of alternatives.	Compared to Alternative A, a 3% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, an increase in arrowweed, and a decrease in wetland community cover.	Compared to Alternative A, a 14% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative), a decrease in arrowweed, and a decrease in wetland community cover. Highest impact of alternatives.	Compared to Alternative A, a 7% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, a decrease in New High Water Zone native plant community cover, a decrease in native diversity, a decrease in native/nonnative ratio, a decrease in arrowweed, and a decrease in wetland community cover.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows; less decline of wetland habitat; however, hydropower improvement flows would cause a greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; least decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; increased production of aquatic insects due to more even monthly volumes could benefit species that eat insects or use nearshore areas, but benefits may be offset by higher within-day flow fluctuations.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greatest decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Cultural resources	No change from current conditions regarding the slumping of terraces in Glen Canyon during HFEs (Glen Canyon flow effects index [GFEI] = 22.7); availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (wind transport of sediment index [WTSI] = 0.16); stability of Spencer Steamboat; and visitor time off river (time off river index [TORI] = 0.82).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); no change in the stability of Spencer Steamboat or visitor time off river. Experimental hydropower improvement flows would increase the potential for slumping compared to Alternative A (1.6% increase in GFEI and a decrease in the availability of windblown sand (−9.5% decrease in WTSI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (137% increase in WTSI); negligible effect on stability of Spencer Steamboat or visitor time off river (<1% change in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, a decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (96% increase in WTSI); negligible effect on stability of Spencer Steamboat; a decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI), an increase in the availability of sand for wind transport to protect the stability of archaeological sites in the Grand Canyon (88% increase in WTSI); negligible effect on stability of Spencer Steamboat; an increase in visitor time off river (8.9% decrease in TORI).	Compared to Alternative A, an increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI), an increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI); negligible effect on the stability of Spencer Steamboat; a decrease in visitor time off river (2.1% increase in TORI).

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact on Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact on culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows, when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.[c]	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal resources (Cont.)						or mechanical trout removal. A small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	
Recreation, visitor use, and experience	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, few lost day-rafting visitor days (49 over 20-year period), and declining camping area.	Compared to Alternative A, a comparable number of HFEs and higher fluctuations result in more lost day-rafting visitor days (45% increase) in Glen Canyon, highest number of large trout (13% increase), lowest trout catch rates, most navigability concerns, and similar camping area (5% increase in index).	Compared to Alternative A, more HFEs and lower fluctuations result in more lost day-rafting visitor days in Glen Canyon (543% increase), similar number of large trout (3% decrease), higher trout catch rates; fewer navigation concerns, and more camping area (170% increase in index).	Compared to Alternative A, more HFEs and comparable fluctuations result in more lost day-rafting visitor days in Glen Canyon (610% increase), similar number of large trout (5% increase), similar trout catch rates, similar navigation concerns, and more camping area (158% increase in index).	Compared to Alternative A, more HFEs, higher fluctuations, and more frequent flows below 8,000 cfs result in more lost day-rafting visitor days in Glen Canyon (261% increase), more large trout (8% increase), lower trout catch rates, more navigation concerns, and more camping area (118% increase in index).	Compared to Alternative A and all other alternatives, frequent HFEs, steady flows, and lack of trout management actions result in most lost day-rafting visitor days in Glen Canyon (1,776% increase), higher trout catch rates, but fewest large trout (22% decrease); very few navigability concerns, and more camping area (191% increase in index).	Compared to Alternative A, more HFEs and steady flows result in few additional lost day-rafting visitor days in Glen Canyon (4% increase), higher trout catch rates, but fewer large trout (9% decrease); very few navigability concerns, and greatest potential increase in camping area (220% increase in index).

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Wilderness	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Compared to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Compared to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, and greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Compared to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Visual resources	No change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.	Negligible change from current condition.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon Dam hydropower economic and retail rate impacts	No change from current condition. Second-highest firm capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period. No change in average electric retail rate or average monthly residential electricity bill.	Compared to Alternative A, a 0.3% decrease in average daily generation (MWh) and a 3.8% increase in firm capacity (MW); a 0.02% decrease in the cost of generation, a 0.45% decrease in the cost of capacity, and a 0.04% decrease in total cost to meet electric demand over the 20-year LTEMP period; a small decrease in the average electric retail rate (−0.27%) and the average monthly residential electricity bill (−$0.27) in the year of maximum rate impact.	Compared to Alternative A, a 0.8% decrease in average daily generation (MWh) and a 17.5% decrease in firm capacity (MW); a 0.08% increase in the cost of generation, a 6.09% increase in the cost of capacity, and a 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.43%) and average monthly residential electricity bill ($0.40) in the year of maximum rate impact.[d]	Compared to Alternative A, a 1.1% decrease in average daily generation (MWh) and a 6.7% decrease in firm capacity (MW); a 0.12% increase in the cost of generation, a 3.12% increase in the cost of capacity, and a 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.39%) and average monthly residential electricity bill ($0.38) in the year of maximum rate impact.[e]	Compared to Alternative A, a 0.7% decrease in average daily generation (MWh) and a 12.2% decrease in firm capacity (MW); a 0.06% increase in the cost of generation, a 3.52% increase in the cost of capacity, and a 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period; a small increase in average retail electric rate (0.50%) and average monthly residential electricity bill ($0.47) in the year of maximum rate impact.[f]	Compared to Alternative A, a 1.9% decrease in average daily generation (MWh) and a 42.6% decrease in firm capacity (MW) (lowest of alternatives); a 0.42% increase in the cost of generation, a 4.03% increase in the cost of capacity, and a 1.17% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period; highest increase in average retail electric rate (1.21%) and average monthly residential electricity bill ($1.02) in the year of maximum rate impact.	Compared to Alternative A, a 1.7% decrease in average daily generation (MWh) and a 24.2% decrease in firm capacity (MW); a 0.34% increase in the cost of generation, a 7.39% increase in the cost of capacity, and a 0.73% increase in total cost to meet electric demand over 20-year LTEMP period; a small increase in average retail electric rate (0.64%) and average monthly residential electricity bill ($0.59) in the year of maximum rate impact.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Hoover Dam hydropower economic impacts	No change in the value of generation.	Compared to Alternative A, no change in the value of generation.	Compared to Alternative A, a 2.0% increase in the value of generation.	Compared to Alternative A, a 1.0% increase in the value of generation.	Compared to Alternative A, a 1.2% increase in the value of generation.	Compared to Alternative A, a 4.1% increase in the value of generation.	Compared to Alternative A, a 1.4% increase in the value of generation.
Socioeconomics	No change from current conditions in use values or economic activity, with no change in reservoir levels or river conditions. Lowest non-use value of alternatives.	Compared to Alternative A, no change in use values and economic activity associated with Lake Powell recreation, and declines in use values (up to 5.2%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Minimal decrease in use values (<0.1%), and no change in economic activity associated with Lake Mead recreation. Minimal increase in economic activity	Compared to Alternative A, declines (0.7%) in use values and economic activity (0.6%) associated with Lake Powell recreation, and in use values (up to 11.5%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 11.7%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity	Compared to Alternative A, declines in use values (0.5%) and economic activity (0.5%) associated with Lake Powell recreation, and in use values (up to 14.0%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from	Compared to Alternative A, declines in use values (1.1%) and economic activity (1.1%) associated with Lake Powell recreation, and in use values (up to 8.9%) associated with most forms of river recreation. An increase in use values (0.5%) associated with Upper and Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.5%) and economic activity (0.5%) associated with	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 13.2%) associated with most forms of river recreation. An increase in use values (0.3%) associated with Lower Grand Canyon private boating. A decrease in economic activity for angling, with declines during HFEs. Increases

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Socioeconomics (Cont.)		(<0.1%) from lower residential electric bills compared to Alternative A. Annual increase in non-use value of $1,511 million at the national level.	minimal decrease in economic activity from higher residential electric bills (< 0.1%). Annual increase in non-use value of $3,985 million at the national level.	expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Highest non-use value of alternatives. Annual increase in non-use value of $4,486 million at the national level.	capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,963 million at the national level.	Lake Mead recreation. Increased economic activity from capacity expansion (up to 9.3%), and minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $2,353 million at the national level.	in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and a minimal decrease in economic activity from higher residential electric bills (<0.1%). Annual increase in non-use value of $3,524 million at the national level.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Environmental justice	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and <1 year, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 6 years and 0–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 8 years and 2–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and 0–2 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in 11 years and 3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Air quality	No change from current conditions in air quality or visibility.	Compared to Alternative A, a negligible increase (0.01%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.01%) in SO_2 emissions and no change in NO_x emissions; no change in visibility.	Compared to Alternative A, no change in SO_2 emissions and negligible increase in NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible increase (<0.005%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.04%) in SO_2 and NO_x emissions; no change in visibility.	Compared to Alternative A, a negligible decrease (–0.03%) in SO_2 and negligible increase in NO_x emissions; no change in visibility.
Climate change	No change from current conditions.	Compared to Alternative A, a 0.011% increase in GHG emissions.	Compared to Alternative A, a 0.033% increase in GHG emissions.	Compared to Alternative A, a 0.042% increase in GHG emissions.	Compared to Alternative A, a 0.030% increase in GHG emissions.	Compared to Alternative A, a 0.081% increase in GHG emissions.	Compared to Alternative A, a 0.074% increase in GHG emissions.
Cumulative impacts	Contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.	Compared to Alternative A, similar sandbar building, lower trout numbers, slightly higher humpback chub numbers, greater value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly higher humpback chub numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, similar trout numbers, and slightly lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, much higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.	Compared to Alternative A, more sandbar building, higher trout numbers, slightly lower humpback chub numbers, and lower value of hydropower generation and capacity.

Footnotes on next page.

TABLE 2-14 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G

[a] The quantitative results presented here are from modeling conducted prior to making several adjustments to Alternative D, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and an adjustment in the monthly release volumes such that releases in August would be 50 kaf higher (800 kaf instead of 750 kaf) and releases in May and June would each be 25 kaf lower. The actual number of HFEs would be about 19.8 (1.3 fewer). As described in Section 4.1 of the EIS, for most resources, these adjustments to Alternative D are expected to result in little if any change in impacts relative to those predicted for the earlier modeled version of Alternative D. In addition, for all resources but hydropower, the relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. Potentially noticeable effects are identified for sediment and hydropower in footnotes (b) and (e).

[b] Impacts on sediment presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]). The actual number of HFEs would be lower and would result in a slightly lower sand load index (SLI) and higher sand mass balance index (SMBI). Change in monthly release volumes would result in a slight increase in sediment transport (1.2%), resulting in a lower SLI and a lower SMBI. Elimination of load-following curtailment would result in a 0.6% decrease in SMBI. The relative performance of Alternative D as compared to that of other alternatives is not expected to change as a consequence of these adjustments. See Section 4.1 for more detail.

[c] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the impacts on Hualapai docks under Alternative D.

[d] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative C compared to Alternative A, estimated at $148 million, by about $24.5 million resulting in a total cost difference of about $173 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.41% increase in cost to a 0.48% increase in cost. The relative ranking of Alternative C compared to other alternatives would not change as a result of adding the cost of experimental low summer flows.

[e] Impacts on hydropower resources presented for Alternative D in this table were based on modeling performed prior to making several adjustments to the alternative (see footnote [a]), and they do not include the cost of experimental low summer flows. Experimental low summer flows would increase costs by $15 million, while the adjustments would reduce costs by $58.9 million. Combined, the cumulative effect of these adjustments may reduce the relative cost of Alternative D compared to Alternative A, estimated at $104 million, by approximately $44 million over a 20-year period; the resulting difference from Alternative A would be $60 million. These adjustments reduce the percent difference relative to Alternative A from a 0.29% increase in cost to a 0.17% increase in cost. These adjustments would also result in slight reductions to the retail rate costs. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost. See Section 4.13.3.4 for more detail.

[f] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative E compared to Alternative A, estimated at $91 million, by about $9.95 million resulting in a total cost difference of about $101 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.25% increase in cost to a 0.28% increase in cost. The relative ranking of Alternative E compared to other alternatives would change from third to fourth lowest cost.

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3 AFFECTED ENVIRONMENT

Chapter 3 describes the environmental resources (physical, biological, cultural, recreational, and socioeconomic) that could be affected by the range of alternatives for implementing the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP), as described in Chapters 1 and 2. The extent to which each specific resource may be affected by each alternative is discussed in Chapter 4, Environmental Consequences.[1]

3.1 PROJECT AREA

The project area includes the area potentially affected by implementation of the LTEMP (including normal management and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead (Figure 3.1-1). More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. This section of the river runs through Glen, Marble, and Grand Canyons in Coconino and Mohave Counties in northwestern Arizona.

Although this EIS focuses primarily on the Colorado River Ecosystem, the affected area varies by resources and extends outside of the immediate river corridor for some resources and cumulative impacts. Portions of Glen Canyon National Recreation Area (GCNRA), GCNP, and Lake Mead National Recreation Area (LMNRA) outside the Colorado River Ecosystem are also included in the affected region for certain resources due to the potential effects of LTEMP operations. For resources such as socioeconomics, air quality, and hydropower, the affected region was larger and included areas potentially affected by indirect impacts of the LTEMP.

3.1.1 Colorado River Setting

The Colorado River rises in the Rocky Mountains of Colorado, flows southwesterly about 1,450 mi, and terminates in the Gulf of California. Its drainage area of 242,000 mi^2 in the United States represents one-fifteenth of the area of the country. As presented in the Colorado River Basin Water Supply and Demand Study (Reclamation 2012h), almost 40 million people in the seven western states of Arizona, California, and Nevada (Lower Division States), and

[1] Pre-dam conditions are discussed in this chapter to provide historical context on certain resources that exist in an already altered environment; however, such references are not intended to form the basis for comparison of the alternatives in this Environmental Impact Statement (EIS), or to provide goals for achieving resource conditions. The action alternatives are compared to the No Action Alternative (Alternative A), as is the standard practice for National Environmental Policy Act of 1969 as amended (NEPA), compliance.

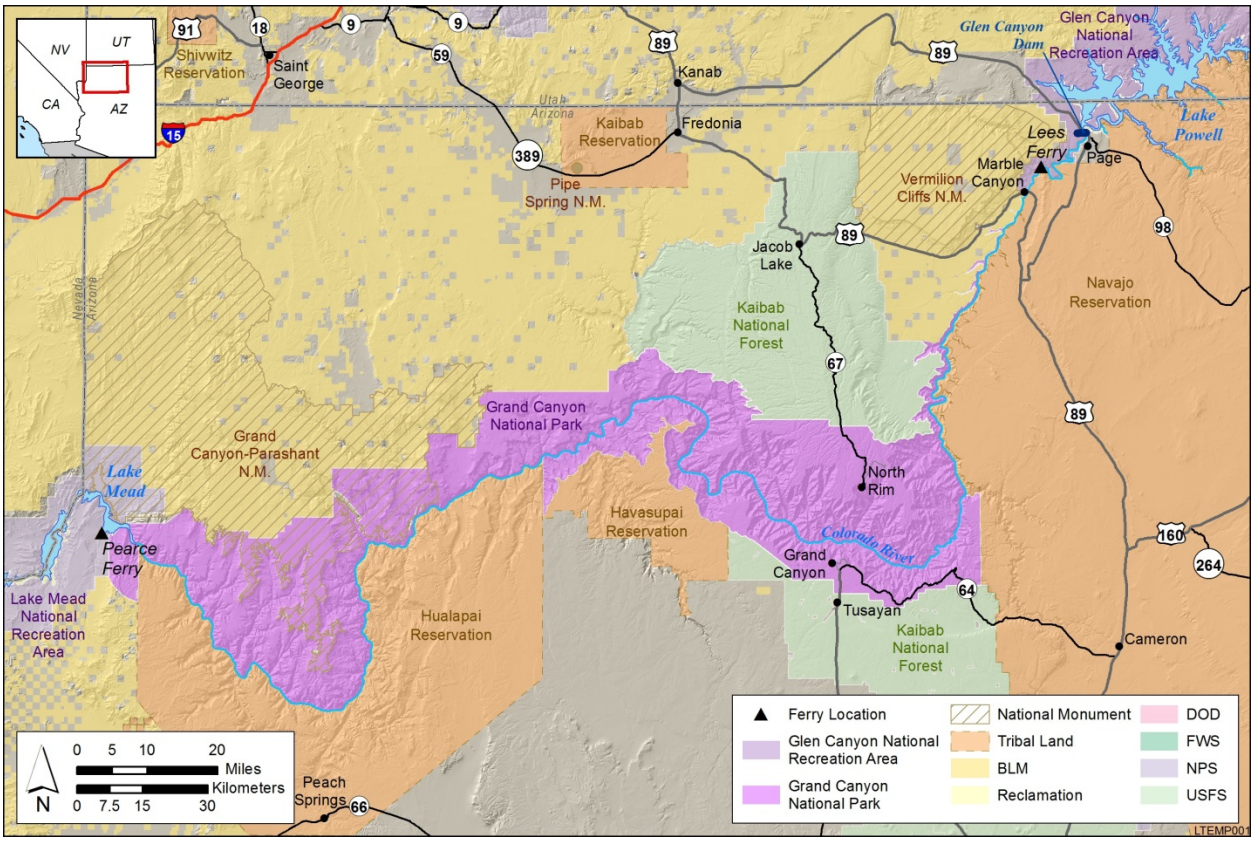

FIGURE 3.1-1 LTEMP Project Area and Surrounding Lands (This map is for illustrative purposes, not for jurisdictional determinations; potential area of effects varies by resource as described in this chapter and in Chapter 4.)

Colorado, New Mexico, Utah, and Wyoming (Upper Division States) rely on the Colorado River and its tributaries to provide some or all of their municipal water needs. Colorado River water is used to irrigate nearly 5.5 million ac of land in the Basin, which produces about 15% of the nation's crops and about 13% of its livestock. The Colorado River is the lifeblood for at least 22 federally recognized American Indian Tribes , 7 National Wildlife Refuges, 4 National Recreation Areas, and 11 National Parks.

Hydropower facilities along the Colorado River supply more than 4,200 megawatts (MW) of electrical capacity to help meet the power needs of the West and reduce the use of fossil fuels (Reclamation 2012h). The primary units of the Colorado River Storage Project (CRSP)—Glen Canyon, Flaming Gorge, Blue Mesa, Morrow Point, and Crystal—provide the majority of the hydroelectric power for the Upper Basin. CRSP has a combined installed capacity of more than 1,800 MW, with Glen Canyon accounting for approximately 73% of the CRSP facilities' total generating capacity.

Given the many and varied uses that depend on Colorado River water, as well as the significant public interest in the region, it is important yet difficult to achieve a suitable balance in the use of the Colorado River. Out of the 1,450-mi length of the Colorado River, it is the

284-mi reach that flows through Glen Canyon Dam and the Grand Canyon that is the affected reach under discussion in this EIS. It is against this background that the resources of the Colorado River Ecosystem are discussed and evaluated.

3.1.2 Geologic Setting

For more than 5 million years, the forces of geologic uplift, weathering, and downcutting of the Colorado River and its tributaries have carved the Grand Canyon. The canyon is about a mile deep and varies in width from a few hundred feet at river level to as much as 18 mi at the rim. The erosive forces of the river cut only a narrow gorge; other geologic forces, including flowing water over the canyon walls, freezing and thawing temperatures, and abrasion of rock against rock cut the wider canyon. The Colorado River acts like a huge conveyor belt transporting finer sediment particles to the ocean.

In cutting the canyon, the river has exposed rocks of all geologic eras, covering a span of nearly 2 billion years. The rocks of the Grand Canyon are part of the Colorado Plateau, a 130,000-mi^2 area covering most of the Colorado River Basin. The elevation of the canyon rim varies between about 5,000 and 8,000 ft above mean sea level (AMSL), with the North Rim being about 1,000 ft higher than the South Rim.

Glen Canyon cuts through the massive Navajo Sandstone of the Mesozoic Era and is about 200 million years old. Downstream from Lees Ferry, a sequence of nearly horizontal sedimentary rocks of the Paleozoic Era appears at river level, beginning with the Kaibab Formation that caps much of the canyon rim. In Marble Canyon, the river passes through cavernous Redwall Limestone. The river is narrower here and in other places where the Paleozoic rocks are relatively hard, but becomes wider through the more easily eroded formations. The shelves of Tapeats Sandstone (more than 500 million years old) at the base of the Paleozoics appear near the mouth of the Little Colorado River. Farther downstream, the narrowest reaches are cut through the dense, dark-colored Vishnu Schist of the Proterozoic era (about 1.7 billion years old). In the Toroweap area, the youngest rocks in the canyon are exposed, which are remnants of lava flows that poured over the North Rim about 1 million years ago during the Cenozoic era. The hardened lava still clings to the canyon walls, and basalt boulders still affect river flow at Lava Falls Rapid. The Grand Wash Cliffs mark the southwestern edge of the Colorado Plateau and the mouth of the Grand Canyon at the headwaters of Lake Mead.

3.1.2.1 Tribal Perspectives on Geologic Setting[2]

The Colorado River, through the Glen Canyon, Marble Canyon, and Grand Canyon (Canyons), has a prominent place in the traditional cosmology of the Havasupai Tribe, Hopi

[2] Sections in this EIS entitled "Tribal Perspectives" are intended to represent the viewpoints of the Tribes who participated as Cooperating Agencies based on their input. The text was provided by the Tribes, and only minor typographic modifications were made prior to insertion into the EIS.

Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes and continues to have an important place in their contemporary cultures and economies. For example, Navajo oral history concerning the Grand Canyon and its tributaries states that it was developed during the time of creation of this world. Water was everywhere, and the world was named Ni′ Hodisq—the Glittering World. The people were given this world to live in after a series of trials with the native inhabitants (Chiishta Dootl′ izh, Chiishta Litso, and Chiishta Ligaii). The people discussed ways to make the world habitable; after much talk, they decided that rivers, creeks, and streams would be created to drain the world, which in turn would become the veins of the earth. The Colorado River is one of those veins. Haashch′ eeh yalt′ i′ i, the Talking God, and Haasch′ eehoghaan, the Evening God, became the advisors to the people, and under their direction, the world was created as it is today. In other oral histories, people say that Ghaa′ ask′idii, the Humpback God, created the Grand Canyon. After this world was given to humans by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created the rivers, creeks, and streams, which became the veins of the earth. The essence of the Humpback God is manifested by bighorn sheep and mountain goats as seen in the Grand Canyon today (Roberts et al. 1995).

3.1.3 Climatic Setting

Climatic conditions in the area vary considerably with elevation. At Bright Angel Campground (elevation 2,400 ft) near Phantom Ranch, the climate is characterized by mild winters, hot summers, and low rainfall. Average high temperatures range from about 15°C (59°F) in winter to 39°C (103°F) in summer. Low temperatures range from about 4 to 24°C (39 to 76°F). Average annual precipitation, mostly in the form of rain, is about 11.2 in.

In contrast, the climate at the North Rim (elevation 7,800 to 8,800 ft) is characterized by cold winters, cool summers, and abundant precipitation with snowfall. Average high temperatures range from 4°C (39°F) in winter to 24°C (75°F) in summer; low temperatures range from about –8 to 6°C (18 to 43°F). Average annual precipitation is 33.6 in. The South Rim (elevation 7,000 ft) receives about 16 in. of precipitation annually. Average high temperatures range from 5°C (41°F) in winter to 29°C (84°F) in summer; average low temperatures range from –8°C (18°F) in winter to 12°C (54°F) in summer.

The Upper Colorado River Basin (drainage basin above Lee Ferry[3]) is generally classified as semiarid and the Lower Basin (drainage basin below Lee Ferry) as arid. The climate varies from cold-humid at the headwaters in the high mountains of Colorado, New Mexico, Utah, and Wyoming, to dry-temperate in the northern areas below the mountains, and arid in the lower southern areas. Annual precipitation in the higher mountains occurs mostly as snow, which

[3] "Lee" Ferry is the reference point that marks the division between the Upper and Lower Colorado River basins. The point is located in the mainstream of the Colorado River 1 mi below the mouth of the Paria River in Arizona. "Lees" Ferry is the historic location of Colorado River ferry crossings (1873 to 1928) and the current site of the U.S. Geological Survey (USGS) stream gage above the Paria River confluence.

results in as much as 60 in. of precipitation per year. Thousands of square miles in the lower part of the basin are sparsely vegetated because of low rainfall and poor soil conditions. Rainfall in this area averages from 6 to 8 in., mostly from cloudburst storms during the late summer and early fall.

3.1.4 Glen Canyon Dam Releases and Flow

The major function of Glen Canyon Dam (and Lake Powell) is water storage to support a multitude of uses. In this EIS, river flows below the dam are referred to as releases or flows. River flow is measured in cubic feet per second (cfs). Annual and monthly volumes are measured in acre-feet (ac-ft). The amount of water and its pattern of release directly or indirectly affect physical, biological, cultural, and recreational resources within the Colorado River Ecosystem.

Hydropower generated from Glen Canyon Dam is cleaner in terms of air emissions, and its generation is more flexible and more responsive than many other forms of electrical generation. As such, the Glen Canyon Powerplant is an important component of the electrical power system of the western United States. The powerplant has eight generating units with a maximum combined capacity (i.e., the maximum electric output of the eight generating units) of 1,320 MW. When possible, higher releases are scheduled in high-demand winter and summer months to generate electricity when demand is greatest.

Water releases from Glen Canyon Dam fluctuate on a daily and hourly basis to maximize the value of generated power by providing peaking power during high-demand periods. More power is produced by releasing more water through the dam's generators. Daily releases can range from 5,000 to 31,500 cfs, but actual daily fluctuations have been constrained to less than this maximum range as a result of implementing the 1996 Record of Decision (ROD) (Reclamation 1996). These constrained fluctuations result in a downstream "fluctuation zone" between low and high river stages (i.e., the water level associated with a given flow) that is inundated and exposed on a daily basis.

Glen Canyon Dam also affects downstream water temperature and clarity. Historically, the Colorado River and its larger tributaries were characterized by heavy sediment loads, variable water temperatures, large seasonal flow fluctuations, extreme turbulence, and a wide range of dissolved solids concentrations. The dam has altered these characteristics in the Colorado River between Glen Canyon Dam and Lake Mead. Before the dam, water temperature varied on a seasonal basis from highs around 27°C (80°F) to lows near freezing. Now, water released from Glen Canyon Dam averages 9°C (48°F) year round, although release temperatures vary depending on the water level in Lake Powell and other factors, and water temperature warms by about 1°C (1.8°F) for every 30 mi traveled downstream during warmer months of the year (Reclamation 1999b). Lake Powell traps sediment that historically was transported downstream. The dam releases clear water, and the river becomes muddy when downstream tributaries contribute sediment, as during summer monsoon storms.

3.1.5 Colorado River Ecosystem Resource Linkages

The Colorado River Ecosystem formed in a sediment-laden, seasonally flooded environment. Virtually all of the Colorado River Ecosystem resources are associated with or dependent upon water and sediment. Interactions among water volume and releases patterns, sediment transport, and downstream resources support a complex ecosystem. The construction of Glen Canyon Dam altered the natural dynamics of the Colorado River. It is understood that Glen Canyon Dam collects and stores water for beneficial purposes and in the process traps sediment and associated nutrients that previously traveled down the Colorado River. The regulated releases from Glen Canyon Dam and Lake Powell have resulted in an altered aquatic and terrestrial ecosystem compared to that which existed before Glen Canyon Dam.

This EIS is focused on potential changes to current operations at Glen Canyon Dam, the impacts they may have on Colorado River Ecosystem resources, water management and hydropower generation, and the determination of whether such changes can further improve resource conditions in the Colorado River Ecosystem. Specifically, the question is whether the alternative actions and experiments identified in this EIS can lead to changes in the current Modified Low Fluctuating Flow (MLFF) operation in a manner that improves resource conditions in the Colorado River Ecosystem consistent with existing laws.

The following discussion addresses the current resources of the affected environment and how dam operations affect them either directly or through linkages among resources.

3.2 WATER RESOURCES

This section presents information about the water resources of the affected area, including Lake Powell, the Colorado River and portions of its tributaries below Glen Canyon Dam, and Lake Mead (especially the inflow area of the reservoir). Information is organized within the broad topics of hydrology and water quality and includes information on the operation of Glen Canyon Dam and current conditions in these topical areas.

The hydrology of the Colorado River, as discussed in this EIS, refers to the water volumes, flow rates, and open channel hydraulics (i.e., characteristics of the conveyed flow such as depths and velocities) of the reservoirs, the river, and its tributaries. These aspects of Colorado River hydrology are directly affected by the proposed action of changes in operations at Glen Canyon Dam. Hydrology directly affects water quality variables in the downstream river environment such as temperature, salinity, and turbidity. Sediment transport and channel and floodplain morphology (e.g., pools, rapids, sandbars, and terraces) are controlled and shaped by the river's hydrologic properties.

From a human needs perspective, the construction and operation of Glen Canyon Dam, in addition to other dams in the basin, allow the distribution of Colorado River water as envisioned by the Colorado River Compact and the related Law of the River. These dams also provide the opportunity to deliver water to the farms, ranches, and communities that depend on Colorado River water.

From an ecosystem and habitat perspective, dam operations define and can change the Colorado River Ecosystem attributes that support aquatic and terrestrial species and communities. This EIS examines whether current operations at Glen Canyon Dam can be modified in a manner, consistent with existing law, to protect and improve these resources as contemplated in the Grand Canyon Protection Act of 1992 (GCPA).

From a recreational perspective, the dam and dam operations provide both flat water and river-based recreational opportunities. Dam operations provide predictable and relatively stable flow conditions that allow a viable year-round recreational opportunity that might otherwise not have existed. Certain dam operations impact the quality of a river recreational experience, such as fewer or smaller sandbars to recreate on and fewer high flows for whitewater rafters. But, with the addition of flat water recreation on the reservoir and predictable dam operations, there are also recognizable benefits to recreation and the regional economy.

From a power generation perspective, hydropower provides a cleaner (in terms of air emissions) and flexible renewable energy source that provides peaking power to help maintain a stable power grid. In the case of Glen Canyon Dam, the major component of the CRSP, revenues from power generation provide funds for repayment of the federal investment in the CRSP facilities, the infrastructure to support existing and additional water development in the Upper Basin, as well as environmental programs such as the Upper Colorado and San Juan Recovery Implementation Programs for the four Colorado River Endangered Fish, and the Glen Canyon Adaptive Management Program.

From a Tribal perspective, the Colorado River is considered the lifeblood of ancestral Tribal lands. The Fort Mojave Tribe, Havasupai, Hopi, Hualapai, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes depend upon the Colorado River and the land it supports for water supply; economic growth; business; and historical, cultural, and spiritual connection.

3.2.1 Hydrology

The primary source for the total annual water flow in the Colorado River Basin is mountain snowmelt emanating from the Rocky Mountains in the Upper Colorado River Basin. Therefore, unregulated river flows are typically very high in the late spring and early summer and diminish rapidly by midsummer, although flows in late summer through autumn sometimes increase following monsoonal rain events (Reclamation 2007a). In general, the average annual natural flow of the Colorado River at Lees Ferry over the 105-year period (water years 1906 through 2010) has averaged around 15 million acre-feet (maf), but has ranged between approximately 5.4 and 25.4 maf (Reclamation 2007a, 2013a). The period from water years 2000 to 2010 was the driest 11-year period in the more than 100-year historical record for the Colorado River Basin (average annual flow of 12.1 maf); the period from water years 1999 to 2010 was the second-driest 12-year period (12.5 maf) on record (Holdren et al. 2012; GCMRC 2015a). Based on historical (1922–2015) Lees Ferry flow data from Grand Canyon Monitoring and Research Center (GCMRC) (2015a), the most recent 10-year period (2006–2015) was drier than 77% of all 10-year periods since 1922, and the most recent 20-year period (1996–2015) was drier than 73% of all 20-year periods since 1922. These two periods had average annual

cumulative flows of 9.0 maf and 9.6 maf, respectively. Average annual natural flow is forecast to decline in the future (Seager et al. 2007; Vano et al. 2013; Reclamation 2012e).

3.2.1.1 Lake Powell Hydrology

Lake Powell, illustrated in Figure 3.2-1, along with its associated major tributaries, is the second-largest man-made reservoir on the Colorado River (Lake Mead is the largest) and the largest reservoir constructed by the Bureau of Reclamation (Reclamation) under the authority of the Colorado River Storage Project Act of 1956 (CRSPA). Lake Powell has a maximum live storage capacity of around 24.3 maf. At full pool capacity, the mean depth is approximately 165 ft, with a maximum depth of about 560 ft in the forebay area of the dam. Lake Powell provides water storage for use in meeting the compact obligations consistent with the Law of the River (Reclamation 2007a). Specifically, Lake Powell provides storage needed to assist the Upper Division States in meeting their Colorado River Compact obligations. Releases from Glen

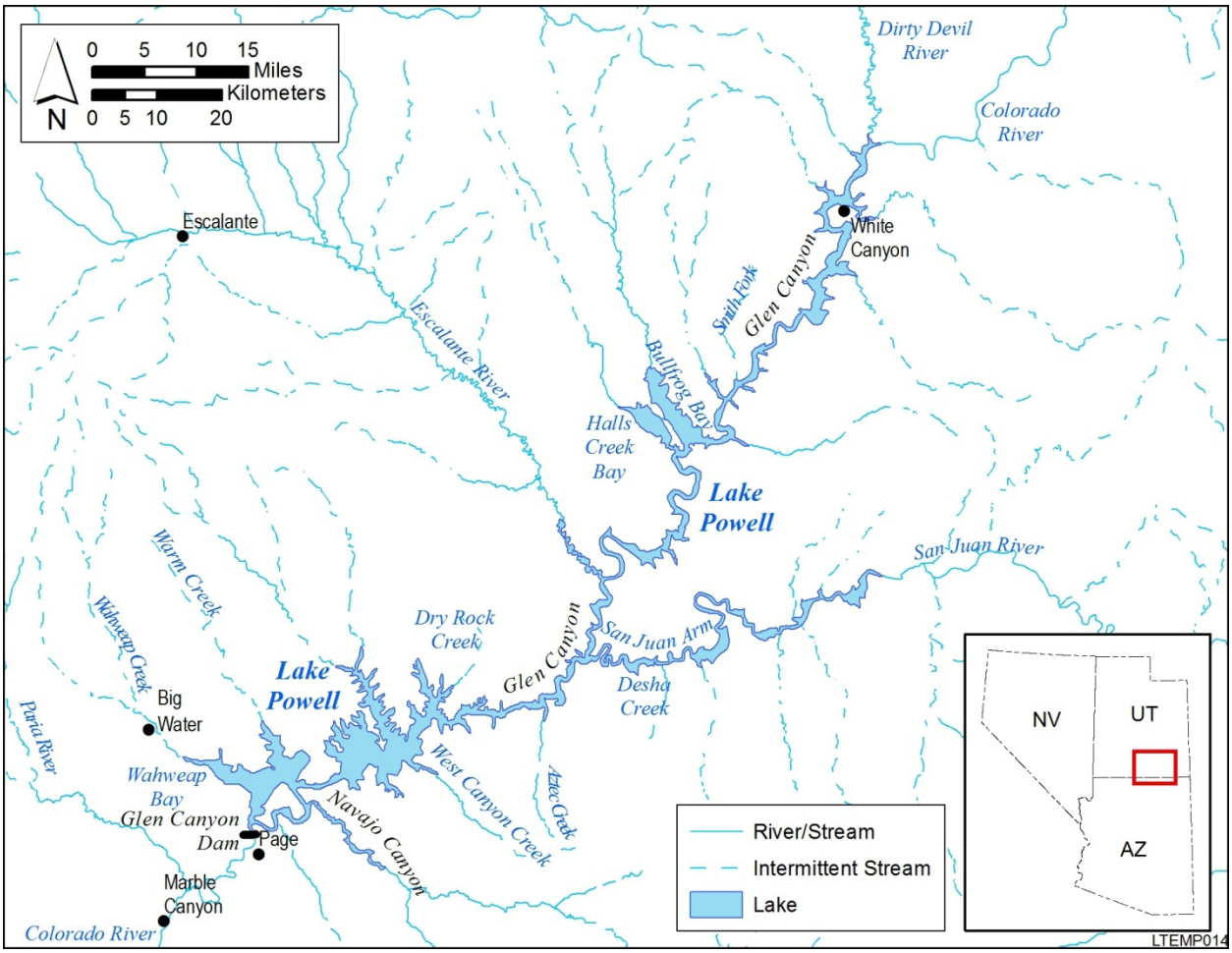

FIGURE 3.2-1 Map of Lake Powell and Associated Major Tributaries

Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC), and its current implementation through the Interim Guidelines, provide the operational guidance needed to currently comply with the Colorado River Compact and related Law of the River. Water released from Lake Powell for compliance with the provisions of the Colorado River Compact also generates hydroelectric power through the Glen Canyon Dam powerplant and provides benefits to recreation. The reservoir is also used as a municipal water source for the City of Page, Navajo Community, Chapter of LeChee, and industrial water for the Navajo Generating Station.

The reservoir is long and narrow, more than 180 mi long and often less than a mile wide at the surface. Glen Canyon Dam is designed to operate between the outlet works intakes at elevation 3,370 ft AMSL and the top of the live storage pool at elevation 3,700 ft AMSL. Hydropower production would cease if Lake Powell drops below approximately 3,490 ft in elevation, or minimum power pool. As the water level changes, the surface of Lake Powell varies in size from about 52,000 ac at the top of the minimum power pool to 163,000 ac at the top of live storage, and the corresponding shoreline fluctuates from approximately 990 to 1,960 mi long. At the full pool elevation of Lake Powell, this reach includes approximately 25 mi of Cataract Canyon, more than 50 mi of the San Juan River, and approximately 170 mi of Glen Canyon (Reclamation 1995, 2007a). Almost half of the reservoir's capacity lies in its upper 100 ft, a zone where the lake overtops many local plateau surfaces. The floor of the reservoir is the incised bed of the former Colorado River, ranging from around 500 to 800 ft in width at its bottom, with a nearly uniform grade of 0.038% (Johnson and Merritt 1979). Lake Powell contains more than 90 major side canyons that have unique orientations and morphologies owing to differences in size, orientation, inflow contributions (springs and tributary flows), mixing processes, and visitor activities; however, it appears that side canyon portions of the reservoir generally have the same chemical and physical stratification as that of the main reservoir body (Taylor et al. 2004).

The hydrology of Lake Powell is primarily influenced by basin-wide hydrology and subsequently annual inflow into the reservoir. The elevation of Lake Powell and the timing, volume, and water quality of inflow into the reservoir influence the water quality of releases from Glen Canyon Dam, which has subsequent effects on the downstream water quality of the Colorado River in Glen and Grand Canyons and Lake Mead. The proposed action cannot affect Lake Powell inflow patterns.

One of the most important factors driving short-term and long-term processes in Lake Powell is the inflow hydrology, characterized by the volume and quality of inflows to the reservoir and their seasonal variation (Vernieu and Hueftle 1998). Overall, approximately 95% of the reservoir's inflow originates from the mainstream of the Colorado River and two major tributaries, the San Juan and Green Rivers (Stanford and Ward 1991; Reclamation 1995, 2007a; Wildman et al. 2011). Specifically, since water year 2005, the Upper Colorado River Basin has experienced significant year-to-year hydrologic variability. The unregulated inflow (i.e., the inflow that would occur if no upstream reservoir storage regulation existed) to Lake Powell has averaged a water year volume of 10.22 maf (94% of 30-year average for the 1981–2010 period) during the period from 2005 through 2012. The hydrologic variability during this same period (from 2005 to 2012) resulted from a low water year unregulated inflow volume of 4.91 maf

(45% of the 30-year average) in water year 2012 and a high water year unregulated inflow volume of 15.97 maf (147% of the 30-year average) in water year 2011 (Reclamation 2013c).

The majority of the inflow into Lake Powell, around 60%, occurs in late spring and early summer as a result of snowmelt in the Rocky Mountains and Upper Colorado River Basin (Iorns et al. 1965; Evans and Paulson 1983; Vernieu et al. 2005). This runoff tends to be warm, low in salinity, and turbid (i.e., sediment laden) as a result of its passage through the canyonlands and, because of its temperature, it represents the lowest-density water entering the reservoir during the year. Consequently, this water travels along the top of the reservoir as an overflow density current, leaving the waters below the penstock level (i.e., elevation 3,470 ft) essentially untouched (Johnson and Merritt 1979; Vernieu and Hueftle 1998; Vernieu et al. 2005; Reclamation 1995).

Winter inflows are cold and saline and represent the highest-density inflows to the reservoir during the year. Depending on the relative density of the existing hypolimnion (i.e., the lower layer of water in a stratified lake) in Lake Powell, winter inflows may flow along the bottom of the reservoir as an underflow-density current (Johnson and Merritt 1979), routing fresh water to the hypolimnion and displacing older oxygen-poor saline water upward toward the dam release structures. During the spring of each year from 1999 to 2008, winter inflows moving through Lake Powell had sufficient density to flow along the bottom of the reservoir (Vernieu 2010). If winter inflows are less dense than the water in the hypolimnion, as might happen following years of low runoff that establish saline conditions, they will flow into intermediate layers as an interflow-density current, eventually being discharged through the penstock outlet and leaving deeper waters stagnant (Vernieu and Hueftle 1998; Reclamation 1995; Vernieu et al. 2005). This condition was observed at Lake Powell from 1991 to 1998 (Vernieu 2010). Regardless of whether the winter inflow density current overrides or displaces the hypolimnion, there is a consistent annual pattern of colder and more saline water around the penstock withdrawal zone during the winter months.

Early dam operations were pursuant to the 1970 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs and influenced by the Filling Criteria for Lake Powell, which were formally terminated when the reservoir filled on June 22, 1980. Operations during the relatively full period from 1980 to 1987 were controlled by the LROC, focusing on water delivery and power generation. Beginning in 1988, operations returned to the objective minimum release of 8.23 maf, as specified in the LROC. Since the early 1990s, operations have continued to focus on meeting water allocation requirements and producing power, but they were modified to address and comply with environmental values and constraints designed to minimize the effects of Glen Canyon Dam on downstream resources (Reclamation 1995). The 1996 Glen Canyon Dam ROD identified MLFF as the operating regime for Glen Canyon Dam and adopted an adaptive management framework to monitor and assess changes in operations to Glen Canyon Dam (Reclamation 1996). MLFF set monthly release ranges, minimum and maximum daily release limits, daily fluctuation limits, and ramping rates to minimize the effects of Glen Canyon Dam releases on downstream resources (Reclamation 1995). During the period following adoption of the MLFF, numerous experimental flows and non-flow actions for scientific and environmental purposes were conducted.

3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam

Annual water release volumes are established pursuant to the LROC, which is currently implemented through the Interim Guidelines for Coordinated Operations of Lake Powell and Lake Mead (Reclamation 2007a). The interim guidelines for coordinated operations of Lake Powell and Lake Mead define four operation tiers: (1) the Equalization Tier, (2) the Upper Elevation Balancing Tier, (3) the Mid-Elevation Release Tier, and (4) the Lower Elevation Balancing Tier. Releases are based upon the elevations of Lake Powell and Lake Mead as identified in Appendix D. Notably, when operating in the Equalization Tier, the Upper Elevation Balancing Tier, or the Lower Elevation Balancing Tier, scheduled water year releases from Lake Powell would be adjusted each month based on forecast inflow and projected September 30 elevations at Lakes Powell and Mead.

The annual releases since the dam was completed have included annual volumes above 8.23 maf numerous times. In general, each period of higher release was followed by a reduction in the salinity of the hypolimnion (Vernieu and Hueftle 1998). Monthly release volumes accomplish the annual releases implemented pursuant to the LROC and are based on anticipated power demands, forecasted inflows, and other factors such as storage equalization between Lake Powell and Lake Mead. High release volumes do not always coincide with peaks in reservoir inflow; instead, they coincide with times of increased power demands (e.g., January and August). Therefore, the timing of these high releases may or may not facilitate the drawing and replacement of hypolimnetic waters near the dam (Vernieu and Hueftle 1998).

The Lees Ferry gaging station (river mile [RM] 0), which has been operated by the U.S. Geological Survey (USGS) since May 1921, is approximately 15.5 mi downstream from the Glen Canyon Dam and approximately 1 mi upstream of the Paria River mouth. Its location allows a comparison of pre-dam flows with post-dam flows downstream of Glen Canyon Dam because it is located close to the dam, but is unaffected by the presence of tributary inflows. This section primarily utilizes the Lees Ferry data and analysis. Figure 3.2-2 illustrates the changes in the pattern of annual flows at Lees Ferry for the pre-dam period (from 1922, when continuous records began, through 1962) and post-dam period (1963 through 2015) (GCMRC 2015a).

The average pre-dam peak annual discharge was found to be approximately 92,000 cfs (Topping et al. 2003). The largest recorded peak flow during the pre-dam period (data record from 1921 to 1963) occurred in June 1921, soon after the installation of the Lees Ferry gage. This flood was estimated to have a peak flow of 170,000 ± 20,000 cfs; the return period of this event was estimated to be 40 years (Topping et al. 2003; O'Connor et al. 1994). The average 2-year recurrence interval flood peak was calculated from the discharge record to be 85,000 cfs (Topping et al. 2003). There is also evidence of a flood in 1884 that peaked at approximately 213,500 cfs (+ 14,500 cfs) at Lees Ferry (Topping et al. 2003). Paleoflood research has determined that during the last 4,500 years, 15 floods at Lees Ferry had peak discharges larger than 120,000 cfs. Of these floods, 10 had peak discharges greater than 140,000 to 150,000 cfs during the last 2,100 to 2,300 years, and one flood that occurred 1,200 to 1,600 years ago had a peak discharge exceeding about 300,000 cfs (Topping et al. 2003).

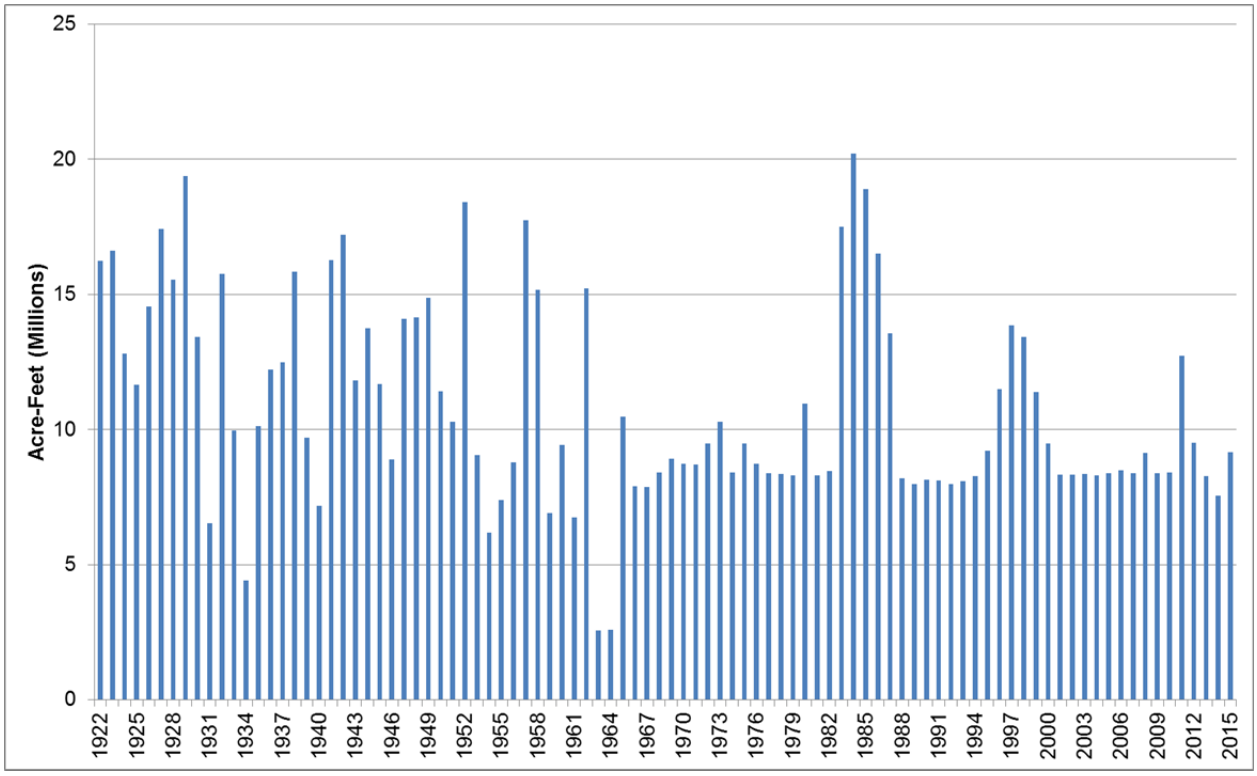

FIGURE 3.2-2 Pattern of Annual Historic Flows at Lees Ferry (Source: GCMRC 2015a)

Compared to pre-dam flows, post-dam flows exhibited a reduction in the percentage of very high flows (i.e., flows >40,000 cfs) and very low flows (flows <5,000 cfs). Post-dam monthly median flow has ranged from 10,200 cfs in October to 16,400 cfs in August (Topping et al. 2003). No post-dam months have had a median flow less than 9,000 cfs (Topping et al. 2003). The median post-dam within-day flow variation was 8,580 cfs; the within-day range exceeded 10,000 cfs on 43% of all days (Topping et al. 2003). Note that since the 1996 ROD, maximum within-day flow variation has been limited to 8,000 cfs (except during high-flow experiments [HFEs]). Within-day flow variation in releases continues downstream for the entire length of the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead, but decreases as flows pass through Marble and Grand Canyons. For example, the difference between the peak and base release on October 1, 2014, was 5,470 cfs. This resulted in a difference from peak to base of approximately 3,930 cfs 13 hours later at RM 61 (just upstream of the confluence with the Little Colorado) and approximately 3,100 cfs 43 hours later at RM 225 (near Diamond Creek at the western end of Grand Canyon).

Periodic releases of relatively short duration that bypass the hydropower plant have also occurred at the Glen Canyon Dam. Recent examples of releases that have utilized the bypass outlet works or the spillways include mid-1980s flood years (using outlet works and spillways); and HFEs conducted in 1996, 2004, 2008, 2012, 2013, and 2014 (using outlet works only).

3.2.1.3 Lake Mead Hydrology

Lake Mead, illustrated in Figure 3.2-3, along with its associated major tributaries, is located approximately 30 mi east of Las Vegas, Nevada, in the Mojave Desert. It is the second of four major reservoirs on the mainstem Colorado River and was formed by the Hoover Dam, which first began impounding water in 1935 (Turner et al. 2011; Reclamation 2008a). Lake Mead has a live capacity of 26.399 maf at elevation 1,221.4 ft, and can store twice the average annual flow of the Colorado River (Reclamation 2012a). Lake Mead provides water storage to regulate the water supply and meet the water demands of the Lower Division states and Mexico consistent with the Law of the River (Reclamation 2007a). Similar to Lake Powell, its waters are also used for recreation and generation of hydroelectric power, through the Hoover Dam powerplant. Hoover Dam also provides flood control benefits. The reservoir is located within the LMNRA, which is administered by the National Park Service (NPS); however, Reclamation retains authority and discretion for the operation of both Hoover Dam and Lake Mead (Reclamation 2007a).

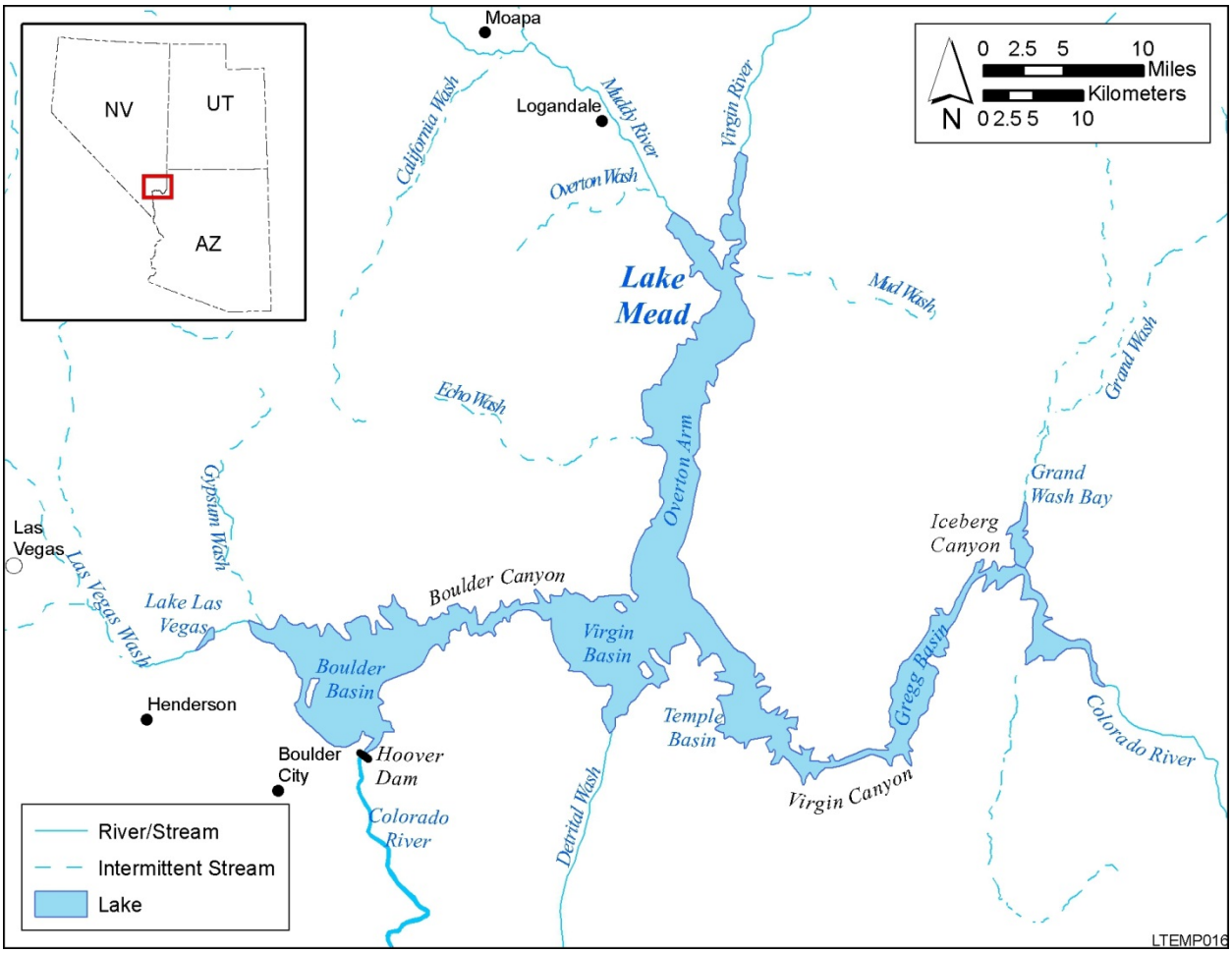

FIGURE 3.2-3 Map of Lake Mead and Associated Major Tributaries

Lake Mead is a large, deep-storage reservoir with a maximum depth of approximately 490 ft and a mean depth of nearly 170 ft. It is approximately 110 mi long, extending from the mouth of the Grand Canyon at Pearce Ferry to Hoover Dam in Black Canyon. With a width that varies from several hundred feet in the Canyons to more than 9 mi, Lake Mead has the largest surface area of any reservoir in the Northern Hemisphere, covering about 160,000 ac (250 mi^2) with a shoreline that is more than 550 mi long (Reclamation 2012a; Turner et al. 2011; Evans and Paulson 1983). The hydraulic residence time of Lake Mead depends upon reservoir release and inflow patterns (which are dependent upon Glen Canyon Dam releases). Estimates have calculated residence times on the order of about 2.6 years, based on average inflows and reservoir volumes (Turner et al. 2012; Holdren 2012). When the reservoir is thermally stratified, the epilimnion (i.e., the surface layer of water in a stratified lake) occurs from approximately 0 to 65 ft, the metalimnion (i.e., middle layer of water in a stratified lake) occurs from approximately 65 to 100 ft, and the deep hypolimnion occurs from approximately 100 ft to the bottom of the reservoir.

Lake Mead can be divided along the historical Colorado River channel into four large sub-basins: Boulder, Virgin, Temple, and Gregg; four narrow canyons: Black, Boulder, Virgin, and Iceberg; and the 30-mi-long Overton Arm, which extends from the Virgin and Muddy Rivers to the Virgin Basin (Figure 3.2-3). The Colorado River enters the eastern end of Lake Mead at the upper end of Gregg Basin.

Prior to closure of Glen Canyon Dam in 1963, Colorado River inflow into Lake Mead was unregulated and reflected natural hydrologic variability; volumes depended upon the annual snowmelt and rainfall received on the west side of the Rocky Mountains. Regulation of inflow began in 1963, when Glen Canyon Dam was constructed approximately 280 mi upstream. The formation of Lake Powell and operation of Glen Canyon Dam have altered the physical characteristics of the Colorado River inflow to Lake Mead. In general, gaged annual inflows to Lake Mead averaged about 10.9 maf between 1935 and 2001, with a pre-dam (1935–1963) value of 11.3 maf and a post-dam (1963–2001) value of 10.6 maf (Ferrari 2008). Flows decreased from 1999 through 2010 as the entire Colorado River Basin experienced drought conditions. Annual inflows to Lake Mead for the period of 1999–2010 have averaged approximately 9.0 maf, which included about 8.23 maf, with additional inflow of approximately 0.7 maf contributed by other tributaries, thus providing a total average operational inflow into Lake Mead of 9.0 maf (Holdren et al. 2012; Turner et al. 2012).

3.2.1.4 Seeps and Springs

Although the Colorado River flows through the Grand Canyon, its waters do not originate there. The Grand Canyon's only native waters (i.e., waters derived in place) come from the more than 1,000 springs and seeps that are recharged by precipitation on the high plateaus surrounding the canyon (i.e., Coconino on the South Rim and Kaibab on the North Rim) and discharged along the walls below the rim. Some springs, such as Pumpkin Spring and Fence Spring, are within the area of the Colorado River Ecosystem that is potentially affected by the proposed action.

Although springs make up less than 0.01% of the Grand Canyon's landscape, they are ecologically important (Rice 2013). Each spring is unique and supports a distinctive array of flora and fauna, many of which are endangered and endemic (i.e., found nowhere else) (NPS 2014a). It has been estimated that species diversity is 100 to 500 times greater in the vicinity of the springs than in the surrounding areas (NPS 2014a). Any changes or declines in flow of a small spring or seep may change a perennial system into an intermittent one, or dry the system out completely. Thus, species such as riparian plants, fish, amphibians, and invertebrates that rely on these water sources may be lost because they do not often have a mechanism to move across the desert landscape to a new water source (Rice 2013).

Tribal Perspectives on Seeps and Springs

Many springs and seeps also hold cultural significance for Native Americans in the region. For example, from the Zuni perspective, the earth is circular in shape and is surrounded on all sides by ocean. Under the earth is a system of covered waterways, all ultimately connecting with the surrounding oceans, springs, and lakes, which are the openings to this system (Bunzel 1932) and are regarded as sacred to the Zuni because they provide water, a life-giving substance that is necessary to maintain life within the Southwest's harsh environment. Springs are specifically "considered to be the most precious things on Earth" (Hart 1980). The Grand Canyon contains numerous springs that are utilized among all religious groups for traditional and religious practices and play an integral role in water collecting by the Zuni people for ceremonial use.

The Hualapai consider *Ha'thi-el* (Salty Spring), a sacred spring within the Canyon, to contain a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010). Other springs, such as Pumpkin Spring at RM 213 and Medicine Spring at the downstream end of Lava Falls Rapid, are warm mineral springs and are considered to have healing properties. Pumpkin Spring is immediately above the level of typical operational flows, although in the pre-dam past it would have regularly been inundated and flushed during the frequent flood episodes. During periods when it has not been frequently inundated and flushed, concentrations of algae, bacteria, and minerals may affect the health of the spring.

All springs in the Canyons have a spiritual importance to the Hopi; water in general is a central feature in all of Hopi philosophy, and springs in particular are considered to be altars (Hough 1906). Water is collected at a number of springs in the Canyons for ceremonial use by Hopi, and prayers are offered to all of the spring locations. The Sipapuni, the origin location for the Hopi people, is a spring. Springs provide habitat for culturally important plants and animals that are rare in the otherwise arid region. Finally, springs have a key historical importance as water sources for the Hopi ancestors who resided in the Canyons.

The Havasupai are dependent on the springs that emit from the shallow and deep aquifers on their reservation and in GCNP. The spring water that flows through the Village of Supai and over the spectacular waterfalls on the reservation delivers approximately 49,000 ac-ft per year to the Colorado River. The Havasupai consider all springs to be sacred, with some having particular

significance in tribal religious and cultural practices. They have also historically farmed at the major springs, including what is now called Indian Garden in GCNP (Hirst 1985).

3.2.2 Water Quality

3.2.2.1 Lake Powell Water Quality

The stratification of Lake Powell influences many chemical and biological processes in the reservoirs and, as a result, influences the characteristics and quality of water that is released to the Colorado River below the dam (Hart and Sherman 1996). As described previously, Lake Powell is thermally and chemically stratified into density layers that differ vertically and longitudinally. In general, vertical stratification varies seasonally and is determined by the relative density of different layers of the reservoir; longitudinal variation in water quality is the result of currents moving through the reservoir (Vernieu et al. 2005). The physical, chemical, and biological characteristics of Lake Powell have a direct effect on the quality of water drawn from and released below Glen Canyon Dam.

Lake Powell is thermally stratified through much of the spring, summer, and early fall (typically April–October) (Figure 3.2-4). In general, the epilimnion of Lake Powell, which

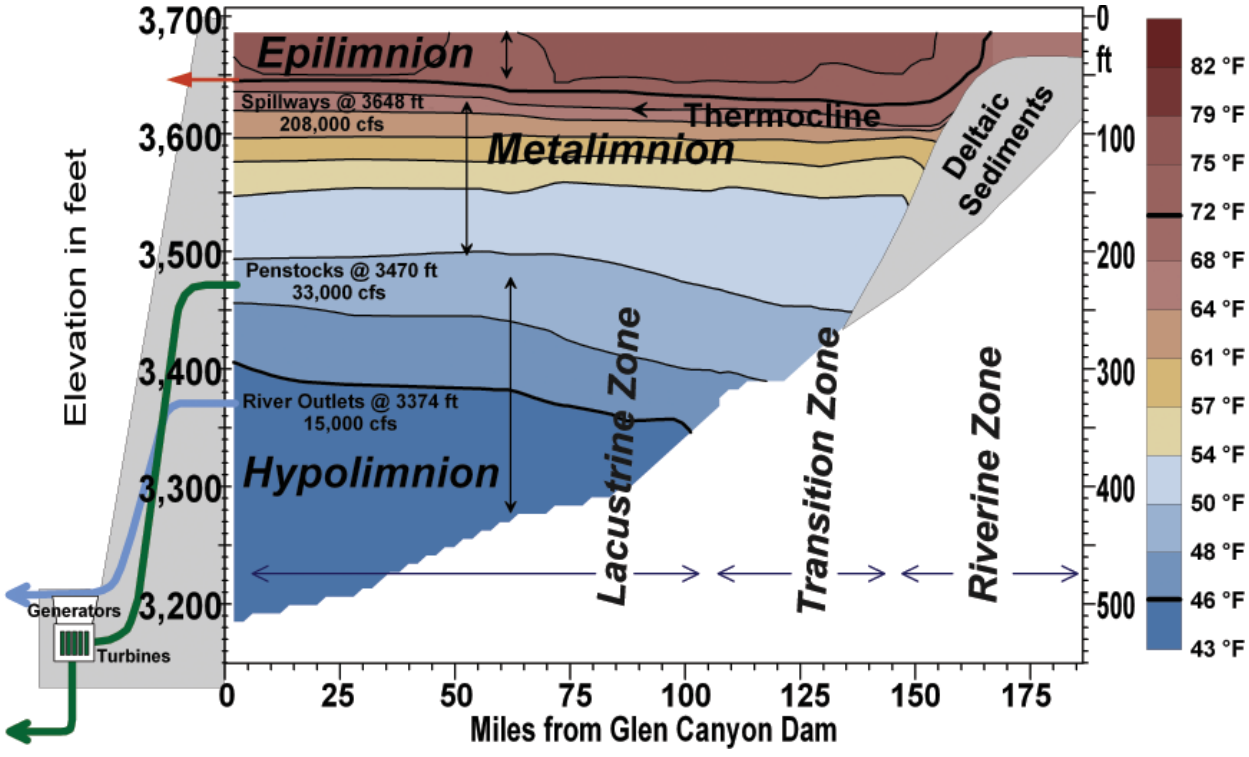

FIGURE 3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River (Source: Vernieu et al. 2005)

ranges from the reservoir surface to a depth of about 60 ft, depending on season and location (Hart and Sherman 1996; Vernieu et al. 2005), exhibits the highest temperatures within the reservoir and varies little with depth. Warmed by spring inflows, ambient air temperature, and solar radiation, summer temperatures can reach around 25–30°C (77–86°F), while winter temperatures may drop to 6–10°C (45–50°F) (Stanford and Ward 1991; Vernieu et al. 2005; Reclamation 1995, 1999b). The metalimnion typically ranges from 60 to 180 ft in depth and exhibits decreasing water temperatures with depth because sunlight's ability to warm water also decreases with depth (Hart and Sherman 1996; Reclamation 1995). The hypolimnion, which begins around 180 ft below the surface of the reservoir, is typically too deep for sunlight to reach, and water temperatures are lower and remain nearly constant at about 6–9°C (43–48°F) (Vernieu et al. 2005; Hart and Sherman 1996; Reclamation 1995).

During the winter period (November–March), the thermal stratification breaks down as cooling surface waters are mixed with deeper water by the wind and vertical currents. By the end of the calendar year, mixing typically progresses to the depth of the penstock withdrawals. At this point, the release waters begin to exhibit characteristics of the epilimnion, which contains the warmest water in the reservoir at that time of year, despite the cooler weather conditions (Vernieu et al. 2005). Thus, the warmest release temperatures of the year occur in late fall to early winter, then temperatures begin to cool again as vertical currents mix the reservoir down to the penstocks depth, which occurs before thermal stratification begins to reestablish.

During the ongoing drought in the 2000s, Lake Powell levels generally declined and release temperatures gradually began to warm (Vernieu et al. 2005). Since then, total Colorado Basin storage has experienced year-to-year fluctuations in response to wet and dry hydrology, but water temperatures have continued on a general warming trend compared to the early 1990s (refer to Section 3.2.2.3 for further details on Colorado River water temperature). Figure 3.2-5 presents the water temperatures measured at the Lees Ferry gage (the official point of measurement for satisfying compact obligations is at Lee Ferry, Arizona) from 1991–2013, illustrating the aforementioned warming of the Glen Canyon Dam releases. Note that in water year 2011, there was a higher snowpack in the Colorado Mountains which resulted in higher inflows to Lake Powell and unusually large releases of warmwater.

Because of the position of the penstocks (i.e., elevation 3,470 ft), water temperatures can vary both annually and throughout the course of a year because the locations of the epilimnion, metalimnion, and hypolimnion (Figure 3.2-4) depend on season, reservoir level, hydrodynamics, timing and strength of stratification, and magnitude of withdrawals (Vernieu et al. 2005). When reservoir levels are high, releases tend to originate from within the hypolimnion and releases are cooler; when levels are low, withdrawals may come from the metalimnion or upper hypolimnion and releases are warmer (Hart and Sherman 1996). It appears that the water quality of Lake Powell above the dam has been largely unaffected by dam operations, particularly since 1991. Instead, the water quality of the reservoir appears to be more strongly linked to annual to decadal climatological variations, inflow hydrodynamics, and continuing basin-wide depletions (Lovich and Melis 2007; Hueftle and Stevens 2001; Vernieu and Hueftle 1998).

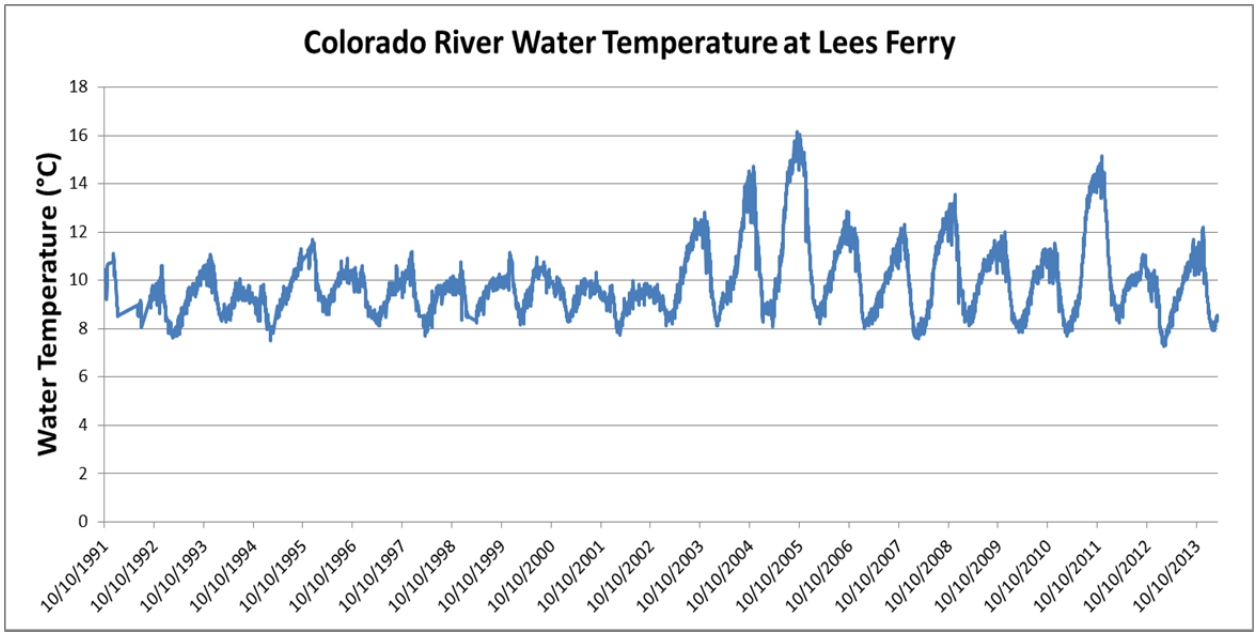

FIGURE 3.2-5 Water Temperature at Lees Ferry (Source: GCMRC 2015a)

Releases from Glen Canyon Dam can have minor effects on water quality and stratification in Lake Powell; such effects can include changes in temperature, salinity, and dissolved oxygen (DO) (Vernieu 2010). The effects on Lake Powell are dependent on the volume and duration of discharges from the dam and on preexisting conditions associated with stratification patterns, location of the layers relative to the release structures, and the fate of inflow currents in the reservoir. In general, the various discharges can cause increased mixing in the reservoir and result in increased movement of horizontal currents through the reservoir, at withdrawal-structure elevations (Vernieu 2010).

DO concentrations in reservoirs are affected by variations in inflow volume and temperature, seasonal reservoir circulation, and biological production and decomposition. In years of high inflows and when the reservoir elevations are low, flows cut through deltaic sediments, resuspending organic matter and nutrients that contribute to both chemical and biological oxygen demand as the inflow water passes down through the reservoir water column. The resulting plumes of low-oxygen water drive water column concentrations lower. When deltaic sediments and organic matter are not resuspended, oxygen demand is decreased and DO concentrations remain higher. Downstream of dams, turbulence, exposure to the atmosphere, and primary productivity reaerate the water column. The DO concentration reaches saturation downstream of Glen Canyon Dam before the confluence with the Little Colorado River (Hall et al. 2012) after passing through several major rapids.

Releases utilizing the bypass structures are made from depths beneath the powerplant intakes. The release waters tend to have lower temperatures, higher salinity, and lower oxygen levels than the water discharged from the dam during normal operations (Lovich and Melis 2007; Hueftle and Stevens 2001).

3.2.2.2 Colorado River Water Quality

The limnology and stratification of Lake Powell, particularly with respect to the location of the penstock intakes, defines the quality of Glen Canyon Dam releases. In general, outflow waters are drawn from the deep zone of the forebay metalimnion into the hypolimnion and characterized as generally even in quality throughout the year, being uniformly cold, clear, below saturation in DO, and low in nutrients (refer to individual Lake Powell parameters in Section 3.2.2.1 for more details). In addition, operation of the dam for peaking power generation has resulted in the removal of much of the seasonal and annual variability that occurred under natural conditions, replacing it with daily fluctuations constrained by set ramping rates (Vernieu and Hueftle 1998; Lovich and Melis 2007). After its release from the dam, changes to the chemical and physical quality of the water are affected by ambient meteorological conditions, primary production and respiration from the aquatic environment, aeration from rapids, inputs from other tributary sources and overland flow, and various aspects of dam operations (Vernieu et al. 2005).

Previous HFEs have been shown to affect the water quality of Lake Powell, the release waters, and Colorado River below Glen Canyon Dam, resulting in slight reductions in downstream temperature and slight increases in salinity, as well as a temporary increase in turbidity (i.e., suspended sediment) from scouring (Reclamation 2011b). In addition, under normal powerplant discharges, limited aeration of the river occurs in the tailwater reach of the river just below the dam compared to reaches farther downstream. However, during HFEs (e.g., high flows in 1996, 2004, 2008, 2012, 2013, and 2014), the effects of the spray and resulting turbulence were sufficient to bring the undersaturated release water up to full or supersaturation oxygen levels immediately below the dam and through the tailwater (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). During HFEs, diurnal DO patterns were still present but were overshadowed by jet tube aeration. These fluctuations recover quickly (within hours) when there is a return to lower flows, although net respiration is typically reduced from pre-flood levels due to the sheared biomass (Hueftle and Stevens 2001). The magnitude of the dam discharges also influences the amount of sediment in suspension, and high water volumes can greatly affect the degree of downstream distribution. Large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Downstream of the dam, larger tributaries (e.g., Little Colorado River and Paria River) that enter the Grand Canyon can affect water quality of the Colorado River below Glen Canyon Dam. In general, these tributaries tend to carry water at higher temperatures than the mainstem river, thus warming the regions where they join. In addition, tributaries, such as the Paria River and Little Colorado River, can carry large amounts of fine sediment and organic materials during flood events, which limit light availability for primary production and may enhance conditions for native fish that use turbid water for cover from predation (Cole and Kubly 1976; Shannon et al. 1994; Topping et al. 2000a,b; Vernieu et al. 2005). Some tributaries, such as the Little Colorado River, are also significant sources of salinity for the mainstem Colorado River, while other tributaries are more dilute (Cole and Kubly 1976; Vernieu et al. 2005). There are also

a number of smaller spring-fed tributaries that originate within the Grand Canyon reach, which tend to have very different physicochemical properties than the mainstem; however, their mean flows are so low that their contribution to water quality during base flow is not significant.

Colorado River Temperature

Prior to the construction of Glen Canyon Dam, the water temperatures of the Colorado River in the Grand Canyon would range from near freezing (0°C, or 32°F) in the winter to around 30°C (86°F) in the late summer, with a mean of approximately 14°C (57°F) (Cole and Kubly 1976; Johnson and Merritt 1979; Reclamation 1995; Vernieu and Hueftle 1998; Lovich and Melis 2007; Stevens 2007). Before 1973, during the reservoir's initial filling stage, release temperatures were greatly affected by surface or epilimnetic withdrawals because of the proximity of the reservoir's surface to the penstock withdrawal zone. Thus, the maximum release temperatures during that period occurred during the months of August and September, reflecting the surface warming of the reservoir (Vernieu et al. 2005).

Trends in tailwater temperature stabilized from 1973 to 2003, when the reservoir surface elevations were above 3,600 ft. During this time, overall seasonal fluctuations diminished to approximately 5°C (9°F), and release temperatures were greatly reduced because the penstocks of the dam were located well below the surface of Lake Powell in the hypolimnion. The Glen Canyon Dam tailwater temperatures ranged between about 7 and 12°C (45 and 54°F) and averaged about 9°C (49°F) as measured at Lees Ferry, with minor excursions beyond this range during periods of spillway releases (Reclamation 1995, 1999b; Vernieu et al. 2005; Hamill 2009). In addition, an asymmetric annual temperature pattern developed over this period, with tailwater temperature measurements reflecting the seasonal changes of the water at the penstock depth. In general, the highest river temperatures immediately below the dam occurred in late fall or early winter (e.g., December), most likely a result of winter vertical mixing in the upper layers of the reservoir. This is followed by a sudden drop of the river's minimum temperature within a few months, with the lowest temperatures occurring in late winter (e.g., February or March), that likely occurs due to reservoir mixing (Vernieu and Hueftle 1998). Daily warming of the tailwater has also been observed, with the maximum warming (about 1.3°C, or 2.3°F) during the day occurring in June, near the summer solstice (Flynn et al. 2001).

Since the early 2000s, total Colorado Basin storage has experienced year-to-year increases and decreases in response to wet and dry hydrology. However, Lake Powell water levels have generally declined as a result of basin-wide drought conditions, and subsequently release temperatures warmed. For example, in November 2004, the annual maximum mean daily temperature reached its height at around 15°C (59°F) (Vernieu et al. 2005) at the Little Colorado River. Beginning in water year 2005, overall reservoir storage in the Colorado River Basin has increased (Reclamation 2013c), which has apparently caused river temperatures to decline slightly, although they still range between around 8 and 12°C (46 and 57°F) at Lees Ferry. Figure 3.2-5 (in Section 3.2.2.1) presents the water temperatures measured at Lees Ferry from 1991 to 2013, which illustrates the aforementioned warming trend of dam releases.

River temperatures increase as the water moves slowly downstream. This correlation is a function of the distance and time from Lake Powell, as well as the input from tributaries (which are usually warmer than the mainstem) (Cole and Kubly 1976). However, it has been generally estimated that water temperatures increase about 1°C (1.8°F) for every 30 mi traveled downstream (Reclamation 1999b). This downstream warming trend can be seen in Figure 3.2-6, which presents Colorado River water temperatures at four stations along the river from Lees Ferry to Diamond Creek.

The greatest warming occurs during the period from June through August because of the transfer of heat from the warmer surrounding air mass, heat stored in the canyon walls adjacent to the river, and solar radiation. The mean annual downstream river temperatures ranged between 9 and 18°C (48 and 64°F), depending on year and distance downstream of the dam (Reclamation 1995, 1999b; Hamill 2009). In general, water temperature in lower reaches of the river is affected by three physical properties: discharge rate, which affects residence time (Anderson and Wright 2007; Wright, Anderson et al. 2008); channel aspect, which affects light availability; and air temperature, which is generally greater in the western portion of the Grand Canyon (Yard et al. 2005; Ralston 2011). Mainstem water temperatures near the mouth of the

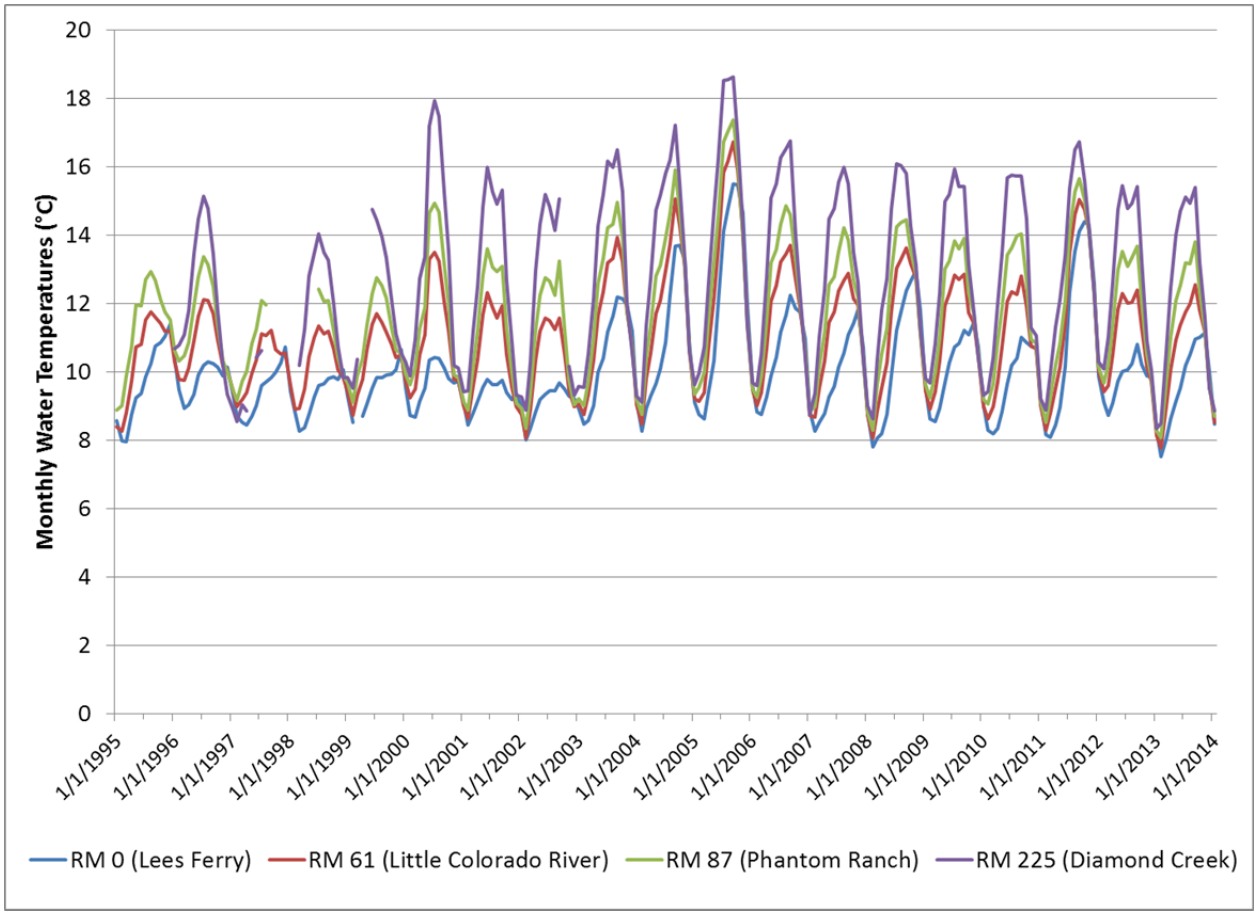

FIGURE 3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 (Source: GCMRC 2015a)

Little Colorado River have not reached 16°C (61°F) in July and August unless release temperatures approached 14°C (57°F) (Wright, Anderson et al. 2008). Warmer mainstem temperatures are attainable in the western part of the Colorado River in July, when releases from Glen Canyon Dam are 12°C (54°F), because of the longer residence time of water in the river channel (Ralston 2011).

As illustrated in Figure 3.2-7, a comparison of the increase in weekly average water temperature between Glen Canyon Dam and Diamond Creek to the average weekly flow during mid-June from 1994 to 2004 demonstrates the effect of Glen Canyon Dam releases on warming patterns in the Colorado River in the Grand Canyon. For example, the 1997 high steady flows of approximately 26,000 cfs resulted in 5°C (9°F) warming at Diamond Creek, whereas the low steady flows of 8,000 cfs in 2000 exhibited a 10°C (18°F) warming. This difference is because large volumes of water have greater mass and a lower surface area to volume ratio, as well as less residence time for atmospheric heat exchange that is due to higher velocity, reducing the amount of warming from ambient temperatures and solar radiation. The warming occurring at low discharges also affects water temperatures in the lower Grand Canyon to a greater degree than the elevated release temperatures (Vernieu et al. 2005).

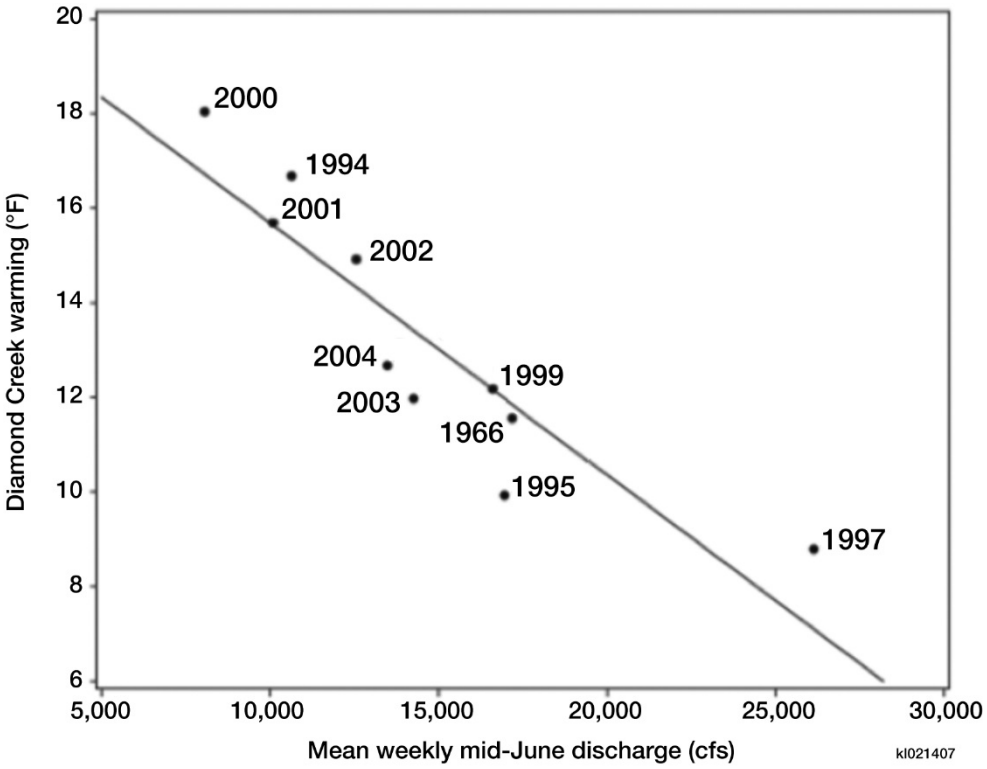

FIGURE 3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge (Source: Vernieu et al. 2005)

Lateral variation in river temperature has also been found to occur throughout the Grand Canyon. Substantial warming takes place in various near-shore environments, ranging from shallow, open-water areas to enclosed backwaters. Water in these environments becomes isolated from mixing with the main channel current and warms (depending on the season) as a result of solar radiation and equilibration with ambient air temperatures (Vernieu et al. 2005; Ralston 2011). According to 2000 data, water-surface temperatures along the shorelines varied from 9 to 28°C (48 to 82°F), with temperatures between 13 and 14°C (55 and 57°F) accounting for the largest proportion of all shoreline areas (Davis 2002; Ralston 2011). Backwaters specifically showed the largest contiguous areas with surface temperatures greater than 16°C (61°F) during the warmest periods. In addition, the area near the confluence with the Little Colorado River shows significant local warming as a result of the tributary inflow. According to 2000 data, mainstem surface temperatures near the Little Colorado River averaged about 13.5°C (56°F), because the cooler mainstem temperatures (typically 12°C [54°F], even in the summer months) are mixed with those of the warmer tributary (typically greater than or equal to 16°C [61°F]) (Voichick and Wright 2007; Protiva et al. 2010; Ralston 2011). In contrast to the mainstem, the Little Colorado River and other tributaries do not appear to have much interannual variation in the range of natural variability after 1990, when regular monitoring began (Stevens 2007).

Colorado River Salinity

Historically, salinity has been a major concern, not only to ecological habitats, but also to water users in both the United States and Mexico. In June 1974, Congress passed the Colorado River Salinity Control Act, which directed the Secretary of the Interior, acting through Reclamation, to implement a basin-wide salinity control program to protect and enhance the water quality of the Colorado River. Since 1974, significant salinity control measures have been implemented and substantial reductions in salinity have been achieved throughout the basin (Reclamation 2013c).

Since the construction of Glen Canyon Dam, the existence of Lake Powell and the amount of water passing through the system has acted to moderate and stabilize salinity levels in both the reservoir and the tailwater (Reclamation 1999b). Salinity below Glen Canyon Dam is typically in the range of 300 to 600 mg/L for total dissolved solids (TDS), with sodium and calcium as the dominant cations and sulfate as the dominant anion (Hart and Sherman 1996; Taylor et al. 1996; Vernieu et al. 2005; Reclamation 1999b, 2005a, 2011c; CRBSCF 2011).

The specific conductance of the Colorado River between the Glen Canyon Dam and Lake Mead has been found to range from 310 to 4,600 µS/cm (approximately 200–2,700 mg/L TDS), with the lowest levels near the mouth of Bright Angel Creek and the highest concentration near the mouth of the Little Colorado River (Taylor et al. 1996; Voichick 2008; Hart and Sherman 1996).

Research has indicated that salinity below the dam changes little with the seasons and shows no regular daily pattern (Flynn et al. 2001; Reclamation 1995). In fact, post-dam salinity fluctuations downstream vary less over several years than the pre-dam cycles changed on the

order of months (Reclamation 1995). However, large or widely fluctuating releases draw water from a thicker withdrawal zone than do low or steady releases. Thus, during these events, water has the potential to be either cooler and more saline (if drawn from below the thermocline or released through the jet tubes), or warmer and less saline (if drawn from above) than that typically released (Vernieu et al. 2005).

Colorado River Turbidity

Turbidity levels are of interest in the downstream environment because water clarity affects the amount of light available for photosynthesis for downstream algal communities, which are an important part of the overall food base for native and nonnative fishes. Turbidity also affects the behavior and distribution of various native and nonnative fishes in providing cover from various predators or by affecting sight-feeding abilities (Vernieu et al. 2005). Turbidity is related to several characteristics of suspended sediment (as noted above in Section 3.2.2.2); thus, suspended-sediment measurements have been used as a proxy for determining turbidity in the system. Voichick and Topping (2010) specifically correlated these two values for the Grand Canyon section of the Colorado River and determined a statistically significant relationship between them.

Prior to construction of Glen Canyon Dam, the Colorado River has historically had very turbid water with suspended load averaging between 1,450 and 6,140 mg/L, depending on month, at Lees Ferry (data for the years 1930–1964) (USGS 2013a) and around 8,000 mg/L downstream 80 mi (Cottonwood Creek), with a maximum historical record of more than 150,000 mg/L measured between the mouth of the Little Colorado River and Bright Angel Creek (Cole and Kubly 1976; Johnson and Merritt 1979).

In the post-dam river, the annual supply of sediment has been altered and reduced. More recent measurements have found the concentration of suspended sediment at Lees Ferry to range from approximately 1 to 150 mg/L (data for the years 1996–2012) (Reclamation 2002; USGS 2013b). The amount of suspended sediment downstream of the dam depends primarily on tributary runoff into the Colorado River below Lees Ferry, which can contribute high concentrations to the mainstem during large floods on those tributaries (Voichick and Topping 2010). It also depends on the magnitude and frequency of planned HFEs, which can temporarily increase suspended sediment as a result of scouring in the reach downstream of the dam. Consequently, suspended sediment varies over an even larger range now than it did prior to the completion of Glen Canyon Dam. Post-dam suspended sediment concentrations near the mouth of the Little Colorado River range from approximately 20 to 133,000 mg/L depending on season and year (Cole and Kubly 1976; Taylor et al. 1996). At Phantom Ranch, approximately 87 RM below Lees Ferry and below several tributaries (Paria River, Little Colorado River, and Clear Creek), the suspended sediment concentrations have been found to range from 6 to 47,100 mg/L (Reclamation 2002).

Colorado River Nutrients

Nutrients like nitrogen and phosphorous are necessary for healthy waters, but high levels of nutrients can cause a number of problems, ranging from nuisance algae blooms and cloudy water to threatening drinking water quality and harming aquatic life. In general, releases from Glen Canyon Dam and downstream Colorado River waters are relatively low in nutrients. Tributaries below the dam (e.g., Paria River, Little Colorado River) have somewhat higher nutrient contents than the mainstem, but they appear to contribute little to overall mainstem nutrient concentrations (Reclamation 1995).

Dense populations of the New Zealand mudsnail (*Potamopyrgus antipodarum*) may also affect available nutrients. Dense populations can consume nutrients, and, because they are relatively immune to predation, sequester those nutrients making them unavailable to other species in the food chain (Sorensen 2010). Sections 3.5.1.4 and F.2.1.3 (Appendix F) provide additional information on the New Zealand mudsnail.

The high biomass of filamentous green algae (dominated by *Cladophora glomerata* until 1995; currently *Ulothrix zonata* and *Spirogyra* spp. dominate) observed in the Glen Canyon stretch of the Colorado River below the dam suggests that nutrients may not be a limiting factor. The uptake and cycling of nutrients may be quick enough that there is very little opportunity to sample free dissolved nutrients in the water column of the river; alternately, constant delivery of low concentration nutrient levels are sufficient for the algae to grow (Reclamation 1999b).

Colorado River Dissolved Oxygen

The ideal DO for fish, particularly those in early life stages, is between 7 and 9 mg/L. Most fish cannot survive when DO falls below 3 mg/L (i.e., acute stress), and DO values less than 5 mg/L are considered a chronic stress for fish. DO concentrations in the Glen Canyon Dam tailwater at Lees Ferry typically range from a low of around 6 mg/L in the fall (e.g., October–November) up to a high between 9 and 11 mg/L in the spring (e.g., April–May) (GCMRC 2015a). However, it is significant to note that unintentional fish kills in the Glen Canyon reach were documented in 2005 as a result of low DO levels (approximately 3.5 mg/L), and DO levels in 2014 approached the lethal limit for trout (Arizona Council of Trout Unlimited, Inc. 2015). Thus, while DO levels over the long term do not typically affect the aquatic ecosystem in Glen Canyon, occasional short-term low DO events can negatively impact fish (Kennedy 2016).

The seasonal variation in DO of the Glen Canyon reach of the Colorado River reflects changes in the DO concentration in the water of Lake Powell at the depth of the penstocks (Flynn et al. 2001). In general, Lake Powell DO concentrations are at their highest near the surface of the reservoir in the spring to early summer when inflows are well oxygenated and photosynthetic activities, atmospheric reaeration, and wind-induced mixing are high. During the summer and into the fall, the DO concentrations decrease, primarily as a result of biological reactions. Then, by early winter when the temperatures drop, DO concentrations gradually increase as a result of the higher oxygen-carrying capacity of coldwater and natural mixing processes created by the winter underflow current (Johnson and Merritt 1979; Vernieu and

Hueftle 1998). In addition, as the reservoir ages or if there are periods of extended drought, resuspension of decaying organic matter in upstream deltas can lead to low-DO (less than 5 mg/L) water being released from the dam increase (Vernieu et al. 2005).

DO concentrations increase with distance downstream as a result of aeration, particularly in rapids. Concentrations typically reach full saturation downstream of House Rock Rapid in Marble Canyon (Hall et al. 2012). As previously noted, HFEs can also act to increase oxygen levels immediately below the dam and through the tailwater; however, these effects will recover quickly when there is a return to lower flows (Hueftle and Stevens 2001; Vernieu et al. 2005; Vernieu 2010; GCMRC 2015a). Daily oscillations in DO in the tailwater have also been observed at Lees Ferry as a result of activity by the Colorado River algal community. During daylight hours, DO concentrations increase through photosynthesis; at night, a decrease in DO occurs when respiratory processes become dominant (Flynn et al. 2001; Vernieu et al. 2005). The amplitude of the daily DO change at Lees Ferry ranges from around 0.5 mg/L to more than 3.0 mg/L depending on season, with the lowest fluctuations occurring in winter and greatest in spring and summer (GCMRC 2015a).

Colorado River Bacteria and Pathogens

The Grand Canyon's water quality varies greatly in terms of bacteria and pathogens. As development and recreation along the river continue, the potential for an increase of bacterial contamination will continue. Coliform bacteria are a large group of bacterial species that are most commonly associated with water quality. *Escherichia coli* (*E. coli*), one species of fecal coliform bacteria present in the fecal matter of warm-blooded animals, is commonly used in recreational water quality sampling as an indicator of fecal contamination and the potential presence of other harmful organisms (ADEQ 2006a). For fresh recreational waters, the *E. coli* standard criteria is set at 126/100 mL (3.38 oz), with Arizona further defining a single sample maximum of 235 for full body contact and 576 for partial body contact (EPA 2003).

Research has indicated that episodic precipitation cycles and arid watershed hydrology are the principal factors influencing occurrence of bacteria in the river system. Bacterial testing has not indicated a chronic problem in the river, although local occurrences of high coliform bacterial count can and have occurred (ADEQ 2006a; NPS 2005a; Dodson 1995; Tinkler 1992). Fecal coliform in the river and in most tributaries were found to range from 10 to 20 counts/100 mL (3.38 oz) during drought cycles. During wet cycles and storm flows, fecal coliform densities were highly variable and often exceeded recreational contact standards (Tunniclif and Brickler 1984).

Most of the tributaries have high bacterial counts at least some of the time. This bacteria may not be of human origin, but may still result in illnesses. Any stream exhibiting high fecal coliform or fecal streptococcus counts may also carry *Giardia* (NPS 2012a).

3.2.2.3 Lake Mead Water Quality

This section describes the historic and existing water quality constituents that could potentially be affected by the proposed federal action. These water quality constituents of concern include salinity, temperature, sediment, and DO. Other water-quality-related issues and parameters were also considered, but they were determined unlikely to be affected by the LTEMP alternatives, or there was insufficient data to provide an assessment and they are therefore not discussed here.

The Colorado River is the primary hydrologic input into Lake Mead, providing approximately 97% of the total annual inflow. Thus, it is reasonable to assume that the quality of the Colorado River water flowing into the reservoir will have a significant and direct influence on the resulting water quality of Lake Mead. Although a suite of water quality parameters was evaluated for this EIS, four water quality variables were found to be important relative to the effects of Glen Canyon Dam operations. Temperature, salinity, turbidity, and DO of the inflow of the Colorado River into Lake Mead can be affected, particularly by large-volume flows such as HFEs. Because Lake Mead serves as a water supply for Las Vegas and large regions of Arizona, California, and Mexico, changes in Lake Mead water quality have the potential to affect the quality of this water supply.

The temperature of the Colorado River water that enters Lake Mead is influenced by the temperature of water in Lake Powell and to a lesser degree, by monthly and daily release patterns from Glen Canyon Dam. Colorado River inflow temperature is a contributing factor to the small, isolated algae blooms that have occurred in Lake Mead. Two examples of uncommon algal blooms are discussed below to demonstrate how inflow temperatures may affect biological productivity in Lake Mead.

Between February and July of 2001, a reservoir-wide algae bloom occurred and consisted of predominantly the non-toxic green algae *Pyramichlamys dissecta*. The Lake Mead Water Quality Forum's Algae Task Force reviewed the potential factors contributing to the reservoir-wide bloom in 2001, but they could not point to a direct cause of the bloom. Instead, the Algae Task Force indicated four factors that potentially contributed to the 2001 bloom: (1) excessive nutrient runoff from above average winter and early spring rain events; (2) warmwater inflows from the Las Vegas Wash that flowed on the surface of Lake Mead; (3) biological mobilization of phosphorus-rich sediment at the confluence of the Las Vegas Wash and Lake Mead; and (4) seasonally high phosphorus inflows from wastewater treatment plants discharging to the Las Vegas Wash. Although the *Paramichlamys* bloom was not considered a human health risk, the bloom was a deterrent to recreational uses in Lake Mead and contributed to low DO concentrations detrimental to fish. The extent to which the Colorado River flowing into Lake Mead influenced the 2001 algae bloom is unknown, including the attempt to warm river temperatures during the June–September low steady flow experiment conducted the year before the bloom.

Most recently, in 2015, increases in the temperature of water entering Lake Mead contributed to dispersed and periodic blooms of blue-green algae (i.e., cyanobacteria, *Microcystis*) throughout the reservoir, including Gregg's Basin. This type of algae produces

multiple toxins, including microcystin and anatoxin, which can affect humans and wildlife. *Microcystis* toxins in water samples from Lake Mead were measured for the first time in 2015.

Colorado River water has a higher density due to its lower temperature and, to some extent, its suspended sediment load. As a result, the Colorado River most often enters Gregg Basin as an underflow, which at times can be seen all the way into Boulder Basin and at the Hoover Dam (Turner et al. 2011; Holdren et al. 2012). This phenomenon also limits nutrient delivery and productivity in the upper levels of the reservoir. During summer months when the temperature differential between Lake Mead and the Colorado River is at its greatest, water entering Lake Mead from the Colorado River plunges to a depth of 65–100 ft in the reservoir's metalimnion, approximately 6 mi downstream of Pearce Ferry (Grand Wash). From this point on, water from the Colorado River exists as a metalimnion interflow and retains its identity, as characterized by lower conductivity, for much of the distance through the reservoir. During winter months, a similar flow pattern occurs; however, the plunge line moves downstream several miles. Cooler winter water temperatures in Lake Mead provide greater mixing due to the decreased amount of energy needed to mix the Colorado River water into the reservoir.

Once Colorado River water plunges, instead of riding the metalimnion just below the thermocline, it drops to a depth of about 260–330 ft, at which point it reaches equilibrium with the reservoir water. The distance traveled before the plume loses its identity is also shorter in the winter due to the greater mixing that occurs, and because of the reduced temperature differential between the two bodies of water (Horn and LaBounty 1997).

Effects on Lake Mead water quality that can occur as a result of changes at Glen Canyon Dam or Hoover Dam, could include changes in salinity, turbidity, and DO in the reservoir (Tietjen 2013), as well as the temperature and water column dynamics influenced by the inflow. In general, higher inflow temperatures have the potential to alter the stratification of the water column, which has resulted in the formation of anoxic conditions in the past. Higher temperatures will also increase metabolic activity in Lake Mead and its sediments. The loading of dissolved and total organic matter to Lake Mead by the Colorado River further influences water quality in the upper reservoir. This material drives oxygen consumption in the sediments and water column in the riverine zone of most reservoirs, and, as such, contributes to observed hypoxia and anoxia.

In Lake Mead, DO concentrations periodically decrease in the bottom waters of Las Vegas Bay, as a result of nutrient and organic matter contributions from Las Vegas Wash and algal growth. In the past and in recent years, low DO conditions have been documented in some isolated parts of Lake Mead near the Colorado River inflow. Ongoing monitoring and investigations are being conducted to determine the cause of such decreases. Currently, elevated temperatures in the Colorado River inflow are the most likely driver. Through an ongoing, multi-agency water quality monitoring program, anoxic conditions were observed in the upper region of Lake Mead in 2014 for a period of 2 months. The warmer Colorado River inflow to Lake Mead altered the typical inflow dynamic, resulting in the river water entering the middle of the water column. This reduced the addition of oxygen to the sediment-water interface and resulted in the development of a 14-mi hypoxic and anoxic region in upper Lake Mead. As with Lake Powell, the stratification of Lake Mead influences many processes in the reservoir, and,

consequently, influences characteristics and quality of the water that is released to the Colorado River below the Hoover Dam. Further, DO has not been documented as an issue in downstream reaches.

The formation of Lake Powell in 1963 resulted in marked reductions in suspended sediment loading to Lake Mead, by trapping nearly all of the upstream Colorado River suspended sediment and effectively removing around two-thirds of Lake Mead's previous sediment-contributing drainage area (Ferrari 2008). It has been estimated that between 1935 and 1963, about 0.091 maf of sediment was deposited in Lake Mead each year. However, with the construction of Glen Canyon Dam and the great reduction in suspended sediment load, the life of Lake Mead is now essentially indefinite (Reclamation 2012c). A rough estimate of Lake Mead's current annual sediment accumulation from the Colorado River in the very upper delta portion of the reservoir is less than 7,200 ac-ft (assumes the continual trapping of sediments in Lake Powell and ongoing consolidation of the finer sediments entering Lake Mead) (Ferrari 2008). The amount of finer material entering and settling in the lower reaches of the reservoir is unknown. Dam operations can affect turbidity of the Colorado River inflow to Lake Mead. HFEs may produce increased turbidity in the inflow, although this is also influenced by Lake Mead elevation, stratification, and inflow temperature (Tietjen et al. 2012). Changes in turbidity in upper Lake Mead following HFEs have been observed to persist for weeks following the event and to span more than 25 mi. While the short-term nutrient impacts have been limited, changes in sediment loading to Lake Mead may increase biological productivity in the long term, which may exacerbate the occasional low DO conditions that are already observed. However, HFEs have also been shown to help eliminate low oxygen concentrations or the anoxic region that may develop in the Greggs Basin region of Lake Mead.

The salinity (or specific conductance) of the water in Lake Mead is controlled by a set of interrelated factors, including relatively low values originating from the Colorado River, higher values in the small Muddy and Virgin River inflows; concentration of salts by the evaporation of surface waters, and the influence of water column stratification in seasonally limiting water column mixing and dilution. As a result, salinity concentrations have cycled during this time period (conductivity values were spread over an approximate 100 µS/cm range), specifically in response to the volume and quality of Colorado River water being released from Lake Powell (Tietjen et al. 2012). For example, as Lake Powell releases water of lower or higher salinity into the Colorado River downstream, the average salinity levels of Lake Mead's water column will similarly decrease or increase, respectively.

3.2.3 Tribal Perspectives on Water Resources

It is important to note that, in the broadest sense, all sources of water (e.g., springs, washes, ponds, pools, lakes, and rivers) are culturally and spiritually important to the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and the Southern Paiute Tribes.

For the Hopi, water is the most precious resource, because it is the basis of life. The cycle of water is at the core of all Hopi ceremonies, and all things related to water—including the plants and animals associated with it—need to be respected and protected. It is a link between current Hopis and their ancestors. It forms the basis for the farming lifestyle that has sustained the Hopi people for thousands of years. Finally, the Colorado and Little Colorado Rivers figure prominently in Hopi clan and ceremonial history.

The Havasupai are the Havsu w 'Baaja, the people of the blue-green water in their native language. Both the Havasupai and Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2006a). The importance of water is evident for the both Tribes as evidenced by inclusion of water in their Tribal seals. The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape, connecting the canyon and the riparian ecosystems that sustain the Tribe. The historic trails in the Canyons and across the Coconino Plateau include sacred springs as stopping points. The Havasupai religion and culture are closely connected to springs through songs and stories (Hirst 1985).

The Zuni religion is focused on the blessings of water, a gift that is considered to be the ancestors themselves (Chimoni and Hart 1994). The waters of the Colorado River are described as "definitely sacred," according to Alex Seowtewa. Even dry washes are important. The Zunis deem them "passageways" for water, whether or not water flows there year-round. Long before the Americans first ever saw and named the Colorado River, the Zuni named this watercourse *K'yawan' A:honanne*. The name itself speaks to a time before the U.S. government dammed the river, when its waters flowed red from the crimson-hued soils its currents carried. Zunis feel a general sense of sacredness for this body of water. As Octavius Seowtewa explained, "Our respect, our heritage and traditions believe this river has significance for our religion and way of life."

Excerpt from a Ne'we:kwe Medicine Society's ceremonial prayer (shared by Seowtewa)

When the world was created, within the four Great Oceans and waterways (North Pole, South Pole, and Atlantic, Pacific Oceans)
Our Father that stayed behind and flourished
The Feathered Serpent
The Water Snakes
The Fish
The Turtle
The Tadpoles
The Toads
The Frog
The Water Boatman and all aquatic life . . .

And all the protectors of the waters
The Crane
The Geese
The Ducks
The Coots
The Grebes
The Orioles
The Mockingbirds
The Nuthatch
The Wren
The Egrets
The Father Sun – Mother Moon
The Creator
These are the Givers of the Breath of Life
The Aged and the Wisdom
The Water of Life
The Seed of Life
The Belongings of Life
The Offsprings of Life
The Strength
And the rest of the Givers of Life

I ask for their breath
If all goes accordingly and the breath of our fathers are respected
We will all see our fathers rising and setting sun
Arm in Arm
Strength in connection
We will all grow old in wisdom
Now I ask the fathers for that Breath
For the Breath of Life for all

The river is associated with the Zuni people's emergence and first migrations; it is home to aquatic life that is important to Zuni traditions; the water from the river is used in ceremonies; and the waterway is a literal trail and a metaphorical umbilical cord that is linked directly to the Zuni home area via the Little Colorado River (Hart 1995). Seowtewa continued, "My medicine society talks about all the water life; it's all mentioned in my prayers. So any disturbance of water life impacts my religion and way of life. I was taught to respect all life and now damming the river and pumping water [creates…] a spiritual impact on our medicine practices. When you are a religious head you have to take care of even the lowliest form of life, even the stink bug, even the rocks, anything that is on the land." This statement parallels previously documented Zuni values of the river. As Dongoske et al. (2010) wrote, "The Colorado River itself is regarded as an important conscious living being that has feelings, and is expressive of calmness and anger. The river can offer happiness, sadness, strength, life, sustenance, and the threat of death. According to many of the Tribal beliefs, if a land and its resources are not used in an appropriate manner, the Creator will become disappointed or angry and withhold food, health, and power from humans."

Zunis pray for water; they pray at water sources; and they use water in religious ceremonies. Cushing wrote that the Zuni "consider water as the prime source of life" (Green 1979). As Dickie Shack, a Zuni religious leader and cultural advisor, explained, "The whole world has water and it's all precious to us. We get it and bring it here for our religious stuff. We use it in paint for our prayer sticks—it's so important to get rain. So this water is precious to us. If I go to the Grand Canyon, I'll get me water there. I believe the rain is our fathers. Anywhere there are springs we hold out hand and say, 'come with us to Zuni village' and we pour the water on our heads." Mr. Shack added, "In my Rain Priest doings, we pray for all directions, to the ocean, to our grandfather, Ko'lowisi, the serpent, in all directions. We say prayers so that they'll help us with rain. So all this water around the world, even the ponds, it's very important to us, for us to say prayers because we need rain in Zuni" (Colwell-Chanthaphonh et al. 2011).

Further emphasizing the importance of all water life to the Ne'we:kwe Medicine Society, the textbox provides an excerpt from one of the ceremonial prayers shared by Seowtewa. Speaking about Glen Canyon Dam, Seowtewa stated, "They put the dam in without consultation, and ... the dam restricted the umbilical cord. It's like when you're in your mother's womb and there's a knot in the cord, then there's a problem" (Colwell-Chanthaphonh et al. 2011).

The present Navajo world begins at Hajiinai, the Place of Emergence. The people began their journey through several underworlds until they finally emerged into this world filled with water. After this world was given to us by the Holy People, they cleared the water away. The Humpback God stood in the center of the world and dragged his cane from east to west and created the canyon. The water drained and created rivers and creeks which then became the veins of the earth. In the canyon there are also places of clan origins and migrations, specifically for the Tl 'izilani (Manygoats) clan and a branch of the Anaasazi Tachii 'nii clan. Sodizin (prayers) are still offered at these places and will continue to be in the future. Plants from the Canyon are used for food and medicine, and minerals such as salt and red ocher are still gathered for use in ceremonies and in everyday life (Roberts et al. 1995).

3.2.4 Hydrology and Climate Change

Global climate models,[4] covering a range of possible future emissions scenarios, project that temperatures will increase globally by about 1.1 to 6.4°C (2 to 11.5°F) by the end of the 21st century (2090–2099; relative to 1980–1999 values) (Solomon et al. 2007). Although global predictions and trends cannot predict changes at the regional level with certainty, regional temperatures are also expected to increase. Average estimates for the Colorado River Basin indicate a projected 5 to 6°C (9 to 10.8°F) increase during the 21st century, with slightly higher increases projected in the upper Colorado Basin (Reclamation 2011e). Predictions also suggest a general drying trend (although the full range of predictions includes both wetter and drier conditions) for mid-latitude areas such as the Colorado River Basin (Reclamation 2007a; Vano et al. 2013; IPCC 2007).

Observations and studies have also shown that many natural systems are being affected by regional climate changes, particularly the aforementioned temperature increases, and that these changes will likely affect the hydrological cycle, with associated impacts on water resources. The following sections summarize the potential effects of increasing temperatures on the broad-scale features of Colorado River Basin hydrology and water resources; other aspects related to climate change (e.g., meteorology and air quality) are discussed in Section 3.16 of this EIS.

3.2.4.1 Basis for Runoff Estimates

The most likely hydrological changes expected as a direct consequence of warmer temperatures are linked to water variability and availability (described in more detail in Section 3.2.4.2), which is mostly influenced by the amount of runoff in the basin (Reclamation 2007c). The conventional assumption used in water resources planning is that the past record of runoff can be used to represent future conditions; in other words, that the future will look like the recent past. However, there are limitations to these assumptions; it is possible that future flows may include periods of wet or dry conditions that are outside the range of sequences observed in the historical record, particularly considering the effects of climate change and the potential for increased hydrologic variability. Furthermore, considerable evidence from paleontological records indicates that the observed record of the last 100 years does not capture the full range of variability of historical stream flows in the Colorado River (Reclamation 2007c; Vano et al. 2013). In fact, the early 20th century, which is the basis for water allocation decisions in the basin, was a period of unusually high flow (Vano et al. 2013). Tree ring records indicate that the Colorado River Basin has experienced severe droughts in the past and could do so again, even without human-caused climate change (Vano et al. 2013). Thus, although paleoclimatic information may not necessarily represent future climate conditions, this information is valuable

[4] Refer to Solomon et al. (2007) for further detail related to the global climate models used for the projected temperature rise.

and may be useful in understanding variability in future hydrologic sequences, particularly with respect to the potential for drought (Reclamation 2007a).

3.2.4.2 Water Variability and Availability

In general, the water supply of the Basin is strongly dependent on snowmelt from high-elevation portions of the Upper Basin, with about 15% of the watershed area producing about 85% of the entire basin's average annual runoff. Annual precipitation ranges from less than 4 in. in southwestern Arizona to nearly 63 in. in the headwaters in Colorado, Utah, and Wyoming (Reclamation 2011e). The western states have heated up more than the world as a whole has (Saunders et al. 2008). In 2003–2007, the global climate has averaged 1°F (0.56°C) warmer than the 20th century average. For the same period, the 11 western states averaged 1.7°F (0.94°C) warmer than the 20th century average. By state, average temperature increases range from 1.3°F (0.72°C) in New Mexico to 2.2°F (1.2°C) in Arizona. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008).

Water storage is very sensitive to changes in mean inflows and to sequences of wet and dry years. As noted previously, although precise regional estimates of the future impacts of climate change on runoff throughout the Colorado River Basin at appropriate spatial scales are not currently available, these impacts may include decreased mean annual flow and increased variability, including more frequent and severe droughts. Overall changes to precipitation would likely decrease the rain and snow that drains into the Colorado River Basin; however, estimates have suggested that by 2050, Upper Basin precipitation may increase slightly (i.e., 2.1%), while that in the lower basin declines similarly (i.e., 1.6%) (Reclamation 2011e). Furthermore, warmer temperatures alone would be expected to increase water losses (e.g., evapotranspiration from vegetation, evaporation from reservoirs, and sublimation) and reduce runoff flow (Reclamation 2007a; Vano et al. 2013; Reclamation 2012e).

Estimated declines of future runoff for the Colorado River Basin range from less than 3.5% to 45% by the mid-21st century (Vano et al. 2013; Reclamation 2011e). The wide range in projected flow decreases results from the following factors:

- Variability among climate models and future emissions scenarios used to generate the estimates;
- Spatial resolution of the model, which is important for capturing topography and its effect on the distribution of snow in the Colorado River's mountainous headwaters;
- Representation of land-surface hydrology, which determines how precipitation and temperature changes affect the land's ability to absorb, evaporate, or transport water;

- Methods used to statistically downscale from the roughly 124-mi resolution used by global climate models to the 6.2- to 12.4-mi resolution used by regional hydrology models; and

- Model uncertainties, including the uncertainty in the climate response, as well as the uncertainty due to differences in methodological approaches and model biases (Vano et al. 2013; Reclamation 2007a).

As discussed in the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012h), the general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (due to lower precipitation), greater evaporation and evapotranspiration losses (due to higher temperatures), and increased demand (due to increased population size). Combined, these factors increase the probability and likely duration of delivery shortages in coming decades. It has been estimated that the shortfall created by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any given deficit period (Reclamation 2012e). When climate change considerations are taken into account, this value increases to around 7.4 maf per year during the deficit period (Reclamation 2012e). These considerations would affect all of the LTEMP alternatives equally.

3.2.4.3 Seasonal Timing Shifts

Warmer conditions are also expected to lead to shifts in the precipitation events and seasonal timing of runoff (i.e., transitioning snowfall to rainfall) with increased winter runoff (December to March) and decreased summer runoff (April to July) (Reclamation 2011d,e, 2013c; Brekke et al. 2009). This shift in timing could present challenges in managing streamflow, especially under current reservoir operational constraints. Storage opportunities during the winter runoff season currently are limited by flood-control considerations, and increased winter runoff under climate change will not necessarily translate into increased storage of water leading into the spring season. Conversely, reservoir storage capture of snowmelt runoff traditionally has occurred during the late spring and early summer seasons. Reductions in runoff during this season likely would translate into reductions in storage capture and, likewise, reductions in water supply for warm season delivery (Reclamation 2013b). Increasing temperature may also increase potential evapotranspiration from vegetation and land surfaces and may thereby decrease the amount of water that then reaches streams, lakes, and reservoirs (Brekke et al. 2009).

There may also be changes in seasonal patterns in relation to extremes of precipitation. Depending on location, these possible changes can and have led to concerns that droughts and floods, defined relative to past experiences, will occur more frequently and/or be more severe under future climate conditions. However, because of uncertainties in climate models and flood record analyses, the nature of changes in specific locations remains uncertain and will require detailed study (Brekke et al. 2009).

3.2.4.4 Water Quality

Water quality is also greatly affected by the changing precipitation and temperature that result from climate change. For example, increasing air temperatures may lead to increased water temperature, which can affect the chemical properties of water and habitat suitability. Altered water temperature in the reservoirs also influences the potential for algal blooms, which can further reduce oxygen levels. In addition, changes to precipitation intensity and frequency (i.e., water availability) can also influence concentrations of suspended sediment, nutrients, and chemical contaminants originating from tributaries, as well as non-point-source pollution from runoff (e.g., agricultural fields, roads, and other land surfaces) (Brekke et al. 2009).

3.3 SEDIMENT RESOURCES

This section describes the sediment resources of the affected area. Sediment is defined as unconsolidated material derived from the weathering of rock that is transported and deposited by water or wind. Sediments can be described based on their particle size such as clay, silt, sand, gravel, cobble, and boulder (Section 3.3.2.1). In this EIS, the use of the term sediment refers to the full range of sediment sizes found in Glen, Marble, and Grand Canyons and references specific sediment size ranges using the terminology described in Section 3.3.2.1. For this EIS, the sediment size of greatest concern is sand. Dam operations have an important effect on sand distribution in the affected area, and sand transport and deposition are greatly affected by the characteristics of dam operations. Sand deposits above the elevation of normal operations provide for important areas for vegetation, wildlife, and visitors to GCNRA and GCNP.

3.3.1 Background: Geomorphology of the Colorado River

Geomorphology describes the geologic evolution and configuration of landforms and the processes that shape them. The processes by which sediment is formed, transported, and deposited within the system are largely functions of the geomorphic setting through which the Colorado River and its tributaries flow, and the characteristics of rock formations, faulting, and fluvial processes. These factors generate several distinct geomorphic features, such as turbulent rapids, tranquil pools, talus slopes (rock slides), channel-margin areas, terraces, canyon walls, debris-flow deposits, fan-eddy complexes, and sandbars (see Figure 3.3-1). There have been numerous studies regarding these geomorphic features within Glen, Marble, and Grand Canyons. This research has been used to develop conceptual models of how these geomorphic features interact with river hydraulic and sediment-transport processes.

The Colorado River follows a meandering path as it flows between the canyon walls. Below Glen Canyon Dam, the river varies with respect to its channel geometry (width, depth, and slope), sediment inputs, bed materials, and hillslope deposits, as well as the topography and geology of the surrounding watershed. Valley width is most affected by the type of rocks near the river level, such that resistant rocks exposed at or near river level (e.g., Vishnu Schist) create narrow valleys, and easily eroded rocks (e.g., Bright Angel Shale) create wide valleys. The level

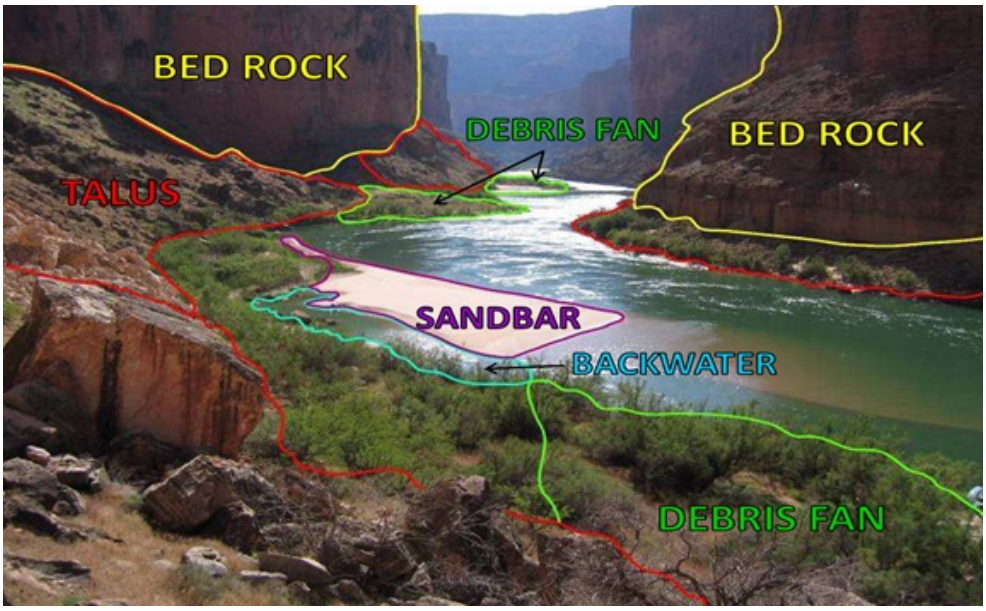

FIGURE 3.3-1 Geomorphic Features of the Colorado River

of bedrock fracturing, which is also a function of bedrock resistance, affects the frequency of tributary debris fans and deep pools (Howard and Dolan 1981).

Schmidt and Graf (1990) defined 11 geomorphic reaches within Marble and Grand Canyons based on parent geologic materials, width-to-depth ratios, slope, and relationship to the confluences with major tributaries. These 11 geomorphic reaches are often described as either narrow or wide reaches based on the width of the canyon in that region. A coarser view of the study area, as used in this EIS, considers three main sections bounded by Glen Canyon Dam, the Paria River, Little Colorado River, and Lake Mead. Beginning at Glen Canyon Dam, the first portion of the river is the 15-mi stretch that runs downstream through Glen Canyon to just upstream of the Paria River at Lees Ferry (RM 0). Glen Canyon has a substantially different geomorphic structure compared to the reaches farther downstream, and it has a limited sediment supply. The next section of river is the approximately 62-mi stretch that runs through Marble Canyon. This stretch starts at the mouth of the Paria River at Lees Ferry (RM 0) and extends to just upstream of the Little Colorado River (RM 61.5). The sediment load of this reach is dominated by Paria River inputs. The third section runs through the Grand Canyon and comprises the remainder of the river downstream of the Little Colorado River. The sediment load of this third portion is the cumulative supply provided by contributions from the Paria River reach, the Little Colorado River, and various other small tributaries**.**

3.3.1.1 Geomorphic Features of the Colorado River

Fan-Eddy Complexes

The areas along the river where a tributary debris fan partially blocks the flow are commonly referred to as fan-eddy complexes (Schmidt and Rubin 1995; Schmidt et al. 2004). Formed at the mouths of tributary canyons, debris fans are sloping deposits of poorly sorted sediment ranging in size from clays and silts to larger boulders. Deposited by tributary debris flows, debris fans and their associated processes play a significant role in defining the geomorphic characteristics of the Colorado River in Marble and Grand Canyons (Webb et al. 1988; Reclamation 1995; Yanites et al. 2006).

Debris fans extending into the Colorado River obstruct the channel, making it narrower and raising the bed elevation, which forms rapids (or riffles) through the point of constriction, and the downstream-directed current becomes separated from the riverbank (Griffiths et al. 1996) (see Figure 3.3-2). Downstream from the constriction, the channel is typically wider, the main current reattaches to the riverbank, and some of the water is redirected upstream (Schmidt and Graf 1990). This change in flow direction forms a zone of low-velocity recirculating water (i.e., an eddy) between the points of separation and reattachment and between the main channel and riverbank (Rubin et al. 1998). These conditions allow for sediment to become entrained within the recirculation zone where the lower velocities enhance the potential for sediment deposition (Schmidt and Graf 1990; Schmidt and Rubin 1995). Figure 3.3-3 presents a cross-sectional diagram demonstrating how these complexes can trap sediment and work to build sandbars. In this instance, water with relatively high sand concentration (near the streambed) moves toward the eddy and builds a sandbar; water with relatively low sand concentration (near the surface) moves from the eddy back to the main channel (Reclamation 1995).

The deep pools that form upstream from rapids (see Figure 3.3-2) provide space for the temporary storage of substantial amounts of riverbed sediment (e.g., sand and gravel). For a given flow, the constriction width and riverbed elevation at a rapid control the velocity and water surface elevation of the upstream pool, which in turn control the amount of sand and gravel that can be deposited in the pool. Aggraded debris fans will allow the channel to store more sand in the associated pools and eddies.

Nearly all sandbars in the Grand Canyon are associated with fan-eddy complexes. In general, these complexes generate consistent sandbar features, which include separation bars and reattachment bars, based on their specific locations within the recirculation zone (Schmidt and Grams 2011a). They continuously exchange sand with the river. Thus, the sandbars commonly found along the banks of the Colorado River are generally dynamic and unstable. Separation bars form along the downstream face of a debris fan, and reattachment bars form outward from the downstream point where the recirculation zone meets the channel bank (see Figure 3.3-2).

Sandbars form a fundamental element of the river landscape (Figure 3.3-1) and are important for vegetation, riparian habitat for fish and wildlife, cultural resources, and recreation (Wright, Schmidt, et al. 2008; Reclamation 1995). For example, they form the substrate for

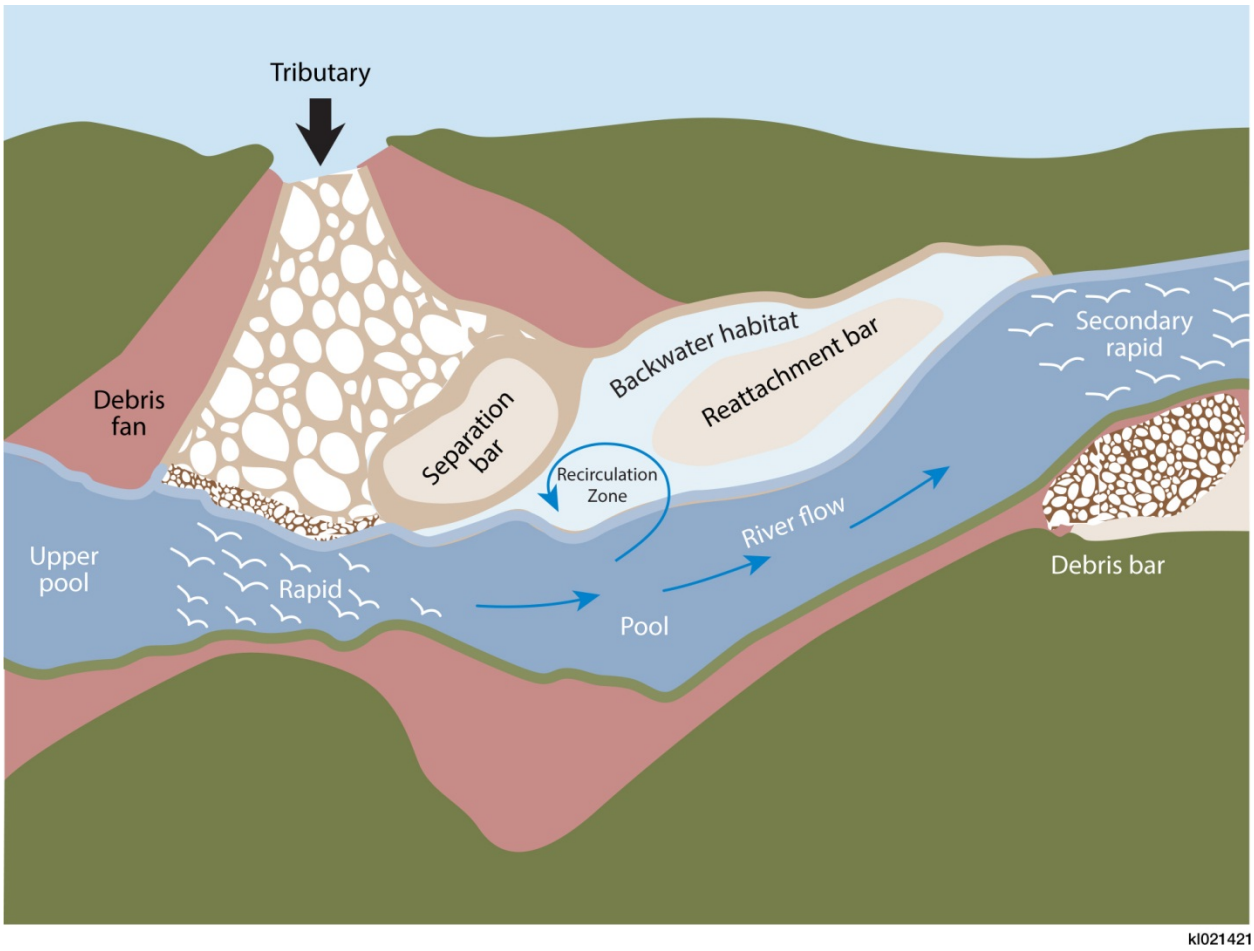

FIGURE 3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River (Source: Webb and Griffins 2001)

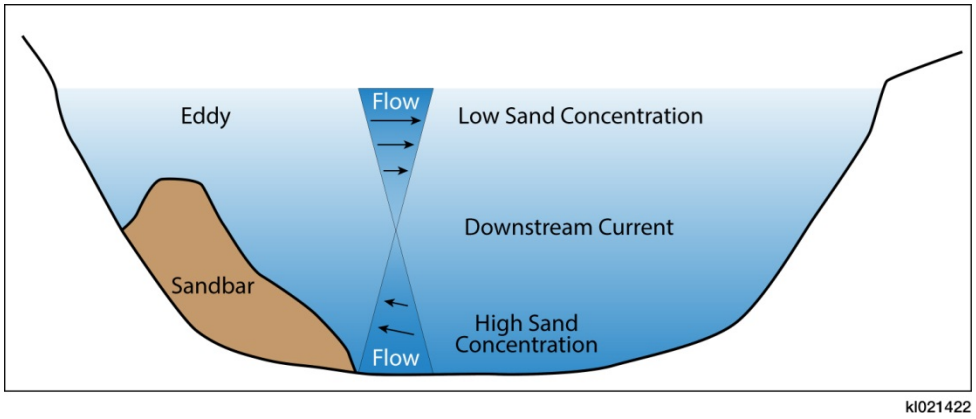

FIGURE 3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building (Source: Reclamation 1995)

limited riparian vegetation in the arid environment. Low-elevation sandbars create zones of low-velocity aquatic habitat (i.e., backwaters) that may be utilized by juvenile native fish. These low-elevation sandbars are also a source of sand for wind transport that may help protect archaeological resources. In addition, beaches provide recreational value for visitors (e.g., camping areas for river and backcountry users). For recreational use (e.g., camping and boating), visitors generally prefer separation bars over reattachment bars because they are composed of finer grained sand, experience less frequent inundation by rising river levels, and have lower velocity conditions for mooring boats (Reclamation 1995).

Fan-eddy complexes also produce important ecologic niches in the canyon. For example, stagnant return-current channels within eddies can support riparian vegetation, attract native fish (e.g., humpback chub), and provide stable substrate for other aquatic organisms (e.g., algae) (Schmidt et al. 2007; Webb and Griffiths 2001).

High Terraces

High-elevation terraces found in reaches of Glen and Grand Canyons support native vegetation and desert riparian communities and may contain buried or partly buried archeological remains. These terraces can be referred to as Holocene terraces because they were formed during the Holocene Epoch (i.e., the time since the last ice age). They were originally formed as sandbars as part of fan-eddy complexes during large natural pre-dam flood events (100,000 cfs and greater; for comparison, current operations have a maximum discharge of 45,000 cfs under normal operations). In general, larger flood flows resulted in higher terraces, and higher terraces are generally indicative of older deposits (Schmidt and Grams 2011a; Reclamation 1995); however, other factors, such as new large tributary debris flows, can also produce terraces under similar flow conditions.

Aeolian, or windblown, deposits can occur on high-elevation terraces and on sandbars near the river, as pictured in Figure 3.3-4. These deposits are generally supplied by sediment blown by wind from the active river channel and are termed “source-bordering” aeolian (dune) deposits (Draut 2012a; East et al. 2016). The supply of aeolian sediment from the active river channel can vary due to environmental factors and river regulation for source-bordering aeolian sediment deposits (Draut 2012a; East et al. 2016). As such, source-bordering aeolian deposits that are not currently significantly supplied by windblown sediment from the active river channel are classified as relic and are considered to be largely derived from older sediment emplaced in high terraces (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Source-bordering aeolian deposits that are contemporarily supplied with sediment blown by wind from the active river channel and sandbars are classified as modern (East et al. 2016; Draut 2012a; Draut and Rubin 2008). Relic deposits are river sediment that is largely inactive with respect to aeolian transport because of a lack of replenishment of sediment from the active river channel and colonization by vegetation and biological soil crusts (Draut 2012a; East et al. 2016). For modern deposits, activity is largely controlled by prevailing wind direction and the amount of bare, dry sand surface area available on the deposit and the upwind sediment source area (Draut 2012a; East et al. 2016).

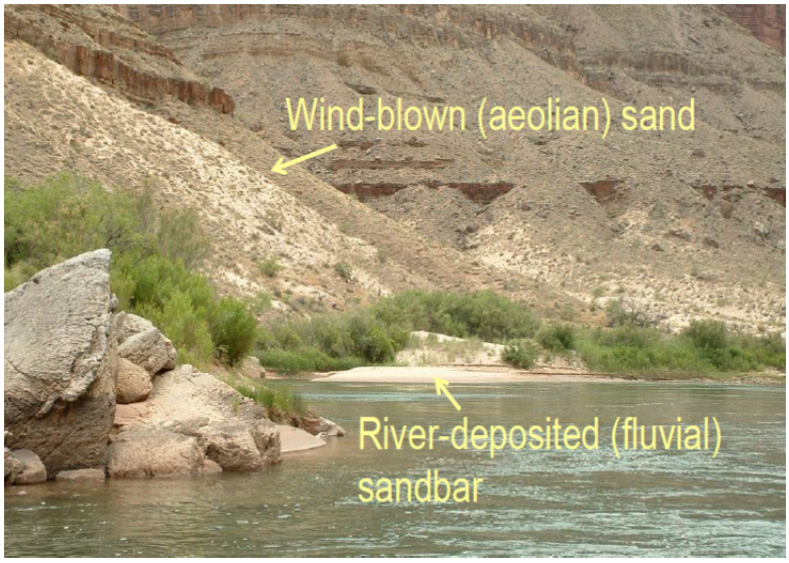

FIGURE 3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River (Source: Draut 2012b)

3.3.1.2 Glen Canyon Geomorphology

The river immediately downstream of Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows, with the intent of raising the elevation of Lake Mead and scouring the reach immediately below the dam in order to increase the efficiency of the powerplant (Topping et al. 2003). During the initial pulse flows, approximately 5.0 million tons of fine sediment was scoured from Glen Canyon between the dam and Lees Ferry over a period of 3 months. In addition, approximately 17.62 million tons of material was scoured from the reach between Lees Ferry and Grand Canyon gaging stations near Phantom Ranch (Topping et al. 2003; Wright et al. 2005). These pulse flows, coupled with other dam operation activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored (Grams et al. 2007).

Glen Canyon exhibits a low gradient and has few debris-fan deposits and small riffles. The Colorado River through Glen Canyon can be generally characterized as a stable gravel and cobble-bedded channel that is more similar in character to a cold Alpine headwater stream than a lowland desert river (Schmidt and Grams 2011b). For example, the average grain size of bed material has increased from 0.25-mm sand particles in 1956 to gravel particles larger than 20 mm in 1999 (Grams et al. 2007).

The flow and sediment supply conditions created by the closure and operation of the dam have resulted in bed incision, sediment evacuation, and abandonment to a large degree of any significant sandbar or terrace development in Glen Canyon. Despite this, several large sandbars exist at established recreational sites. The amount of material scoured is equivalent to a cumulative volume about 10.7 million m^3, or a 6- to 10-ft drop in channel elevation averaged

over the entire reach, ending at the Paria riffle (Schmidt et al. 2004; Wright et al. 2005). This material is not being re-deposited because no major sediment source exists upstream of the Paria River, making sediment a non-renewable resource in modern-day Glen Canyon (Grams et al. 2007). Previously active sandbars, which have been transformed to gravel bars, are also no longer inundated. Based on repeated surveys in Glen Canyon, the channel appears to have adjusted and stabilized to the regulated flow regime, and the rate of erosion has declined since 1984 (Grams et al. 2007). Although the rate of erosion has declined, the remaining pre-dam high-terrace deposits in Glen Canyon are subject to ongoing erosion processes from the Colorado River and ephemeral tributaries (Anderson 2006; Pederson et al. 2011).

3.3.1.3 Marble and Grand Canyon Geomorphology

The longitudinal profile of the river consists of long, flat pool reaches with intermixed short, steep rapids. The water surface elevation of the Colorado River drops from 3,116 ft to 1,336 ft over the 226 mi from Lees Ferry to Diamond Creek. However, the majority of this elevation change (between 50 and 66%) occurs through the numerous rapids in less than 10% of the river's length (Leopold 1969; Magirl et al. 2005). The rapids are typically associated with debris-fan deposits formed by tributary debris flows (i.e., fan-eddy complexes described in Section 3.3.1.1), which constrict the channel width, causing an upstream pool formation, steep rapids, and downstream scour hole and pool formation (Dolan et al. 1978; Howard and Dolan 1981; Melis et al. 1995) (Figure 3.3-2). For the Colorado River below Lees Ferry, the locations of debris-fan deposits and rapids, as well as the associated changes in channel width and surface water elevations, have also been quantified (Magirl et al. 2008). Figure 3.3-5 depicts the number of debris fans per RM and the variation in water-surface elevation and channel width for modeled river flows of the Colorado River below Glen Canyon Dam (Schmidt and Grams 2011a).

Sandbars throughout the Colorado River, particularly those below Lees Ferry, tend to be associated with fan-eddy complexes and located in pool regions immediately downstream of debris fans (Dolan et al. 1978; Howard and Dolan 1981). It has been estimated that fan-eddy complexes cover approximately 20% of the total water surface area of the river downstream of Lees Ferry (Schmidt et al. 2004). As described previously in Section 3.3.1.1, sandbars are dynamic because of the continual reworking of the sandbar by erosional and depositional processes, which are further described in Section 3.3.2. In general, sandbars are erosional features that can aggrade due to deposition during flood flows.

One of the main resource considerations for sandbars in Marble and Grand Canyons relates to available campsites and campable areas, which is based on considerations of the size, slope, sediment material, and vegetation abundance of a sandbar (see Section 3.11.2 for more details). A comparison of sandbars used as campsites, based on inventories conducted in 1973, 1983, and 1991 (Figure 3.3-6), indicated that the number of campsites increased in both narrow and wide river reaches as a result of a flood in 1983. However, by 1991, erosion reduced the number of campsites to levels closer to the 1973 inventory values. The same study also noted that vegetative overgrowth further reduced the number of campable sites (Kearsley and Warren 1993). According to a study compiled by USGS and cooperating scientists, the open

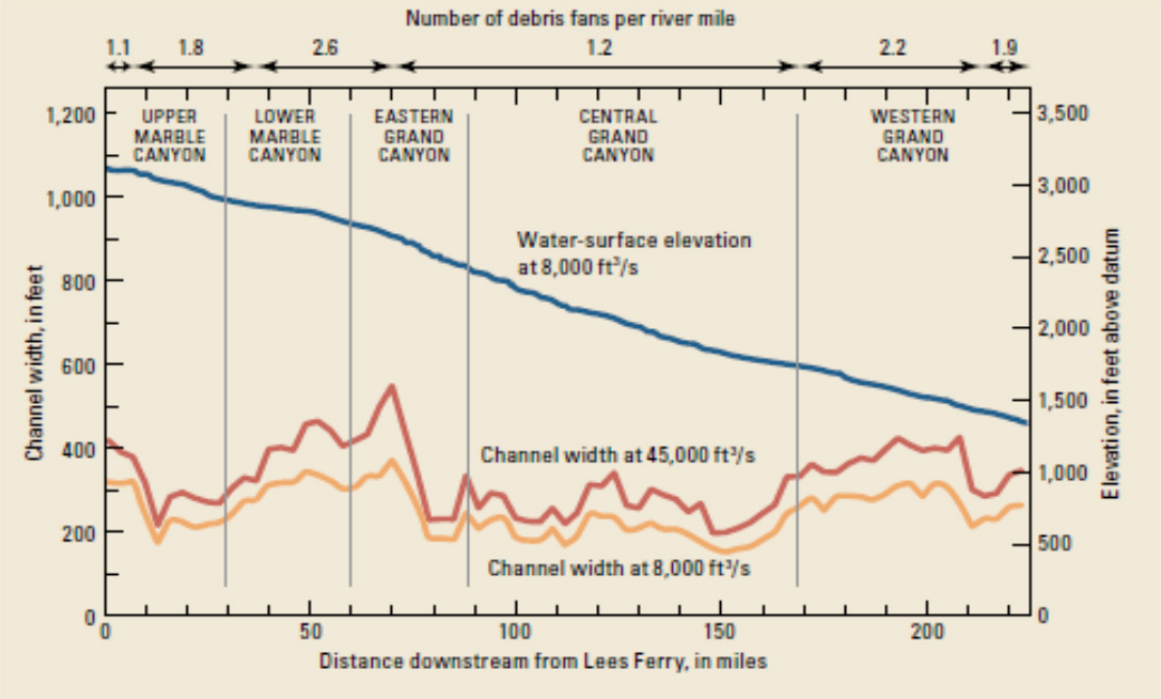

FIGURE 3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam (Source: Schmidt and Grams 2011a)

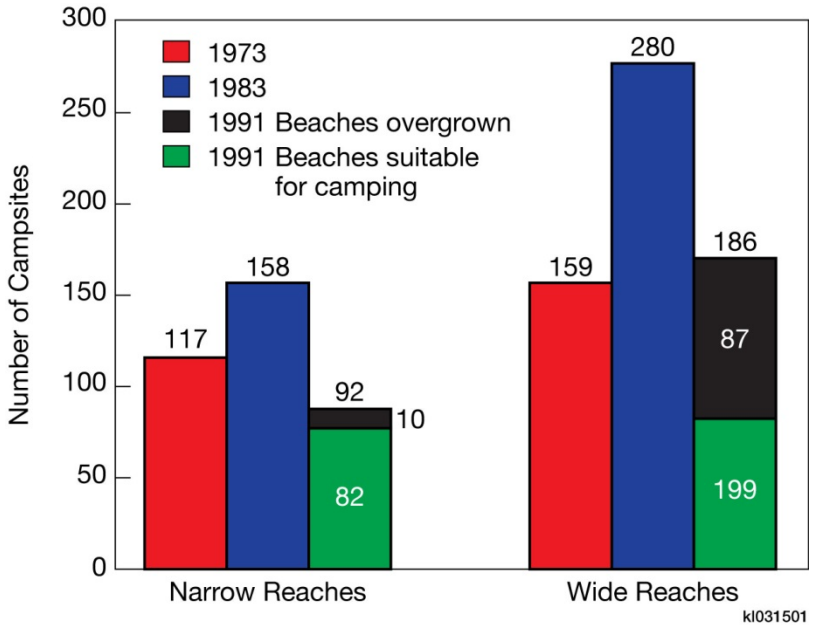

FIGURE 3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 (Source: Kearsley and Warren 1993)

sand area preferred by recreational campers has decreased by 55% since 1998, with an average rate of decline of about 15% per year (Kaplinski et al. 2005).

Debris fans continue to be replenished and enlarged by debris flows from tributaries. Thus, the formation of new rapids and the steepening of existing ones will continue in Marble and Grand Canyons. However, it has also been noted that the presence of the Glen Canyon Dam has greatly reduced both the magnitude and frequency of flood flows and, thereby, the capability of the river to move boulders from the rapids (Reclamation 1995). As a result, many debris fans may experience a buildup of boulders and an accumulation of smaller sediment particles (Melis and Webb 1993). Dam releases above powerplant capacity flows (i.e., >31,500 cfs) can partially rework debris-fan deposits, but this reworking is at a rate that is slower than the aggradation from tributary debris-flow deposits (Yanites et al. 2006). Pre- and post-MLFF flows have the same maximum potential release value (31,500 cfs); however, because MLFF has a maximum normal release value of 25,000 cfs and pre-MLFF had a maximum normal release of 31,500 cfs, the effect on debris flows of post-MLFF operations may be slightly less.

3.3.2 Sediment Characteristics and Transport Mechanisms

Sediment, especially as it occurs in sandbars along the Colorado River below Glen Canyon Dam, is an important and dynamic resource. The GCMRC has been focused on gathering sediment-related data, and understanding of important aspects of sediment science has evolved since the 1995 EIS (Reclamation 1995).

Glen Canyon Dam, completed in 1963, affects stream flow, sand supply, and sand transport in the Colorado River in Glen, Marble, and Grand Canyons. Historically, the Colorado River conveyed high suspended sediment concentrations throughout most seasons and had much larger flood flows and lower base flows (Schmidt and Grams 2011a). Because sediment sources for the Colorado River are not uniformly distributed in the Colorado Plateau, the placement of Glen Canyon Dam effectively cut off approximately 94% of the historical sediment supply from the upper watershed (Andrews 1991; Topping et al. 2000a; Wright et al. 2005). The conditions for sediment replenishment downstream of the dam are now imposed by the tributaries (e.g., Paria River and Little Colorado River), which contribute to the Colorado River downstream of the dam and affect the mechanisms that control sandbars in Glen, Marble, and Grand Canyons. Because of the dam, the capacity of the Colorado River to transport sand and other sediment in the Colorado River Ecosystem is reduced. Sediment transport in the Colorado River was already in decline in the pre-dam era as a result of changes in seasonal rainfall patterns, increased upstream diversions and dam construction, and the slowing of stream entrenchment (Howard and Dolan 1981). Maximum releases from the dam are substantially less than the historic annual peak flows. The high-water zone has been lowered to the level corresponding to managed releases as a result of the dam. These changed conditions have reduced the height of annual deposition and increased the rate of erosion of sediment (Reclamation 1995), and contributed to the loss of beaches and sandbars for many years. Figure 3.3-7 illustrates some of the common changes that have occurred from 1955 to 2008.



FIGURE 3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River (These photographs show a portion of the bank of the river in Grand Canyon, 150 mi downstream from the dam. View is downstream from the right (north) bank of the Colorado River. The top image [Source: USGS 2002], taken in 1952, shows a large sandbar. The middle image [Source: USGS 2002], taken in 1995, shows little remaining sand. The bottom image [Source: J. Schmidt, GCMRC], taken in June 2013, shows that some sand was deposited by the November 2012 HFE.)

The sediment resource goal for the LTEMP EIS is to increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the current average base flow for ecological, cultural, and recreational purposes. As a resource, the primary considerations for sediment relate to the spatial and temporal dynamics of sediment storage throughout the Colorado River below Glen Canyon Dam. The focus of this section is the sediment characteristics and transport mechanisms that interact with flow regimes dictated by releases from Glen Canyon Dam to govern erosional and depositional processes affecting sandbars. The processes that generate sandbars are linked to several factors, including particle size, sediment supply, flow velocity, channel geomorphology (described previously), and river stage, so it is necessary to consider all these factors when assessing impacts on sediment resources.

3.3.2.1 Particle Size and Sediment Supply

Sediments are typically classified by particle size, and they include the following classes:

- Silt and clay (<0.06 mm);
- Sand (0.06 mm–2.0 mm);
- Gravel and cobbles (2.0 mm–200 mm); and
- Boulders (>200 mm).

In general, the term "fine sediment" refers to sediments that are sand-sized or smaller. This group makes up the most abundant sediment size class found along the river, especially in GCNP below the Paria River. GCNRA has little to no fine sediment input and contains mostly coarse sediment until the river reaches its first major tributary, the Paria River. The majority of the sediment delivered to and transported by the Colorado River is defined as silt and clay, which are carried in suspension by most dam releases. The quantity of silt and clay transported depends mainly on tributary supply. Sandbars contain some silt and clay, but their existence primarily depends on the transport of sand.

Sand is stored throughout Glen and Grand Canyons in bars (or patches) on the riverbed, in eddies, and on terrace sandbars. Sandbars and terraces are used as campsites by boaters and are substrate for vegetation and wildlife habitat. The next-largest sizes are gravel and cobbles, which, together with small boulders, armor the streambed in some places. Certain fish species use shallow gravel beds for spawning. The largest particles are boulders, some larger than automobiles, which fall from the canyon walls or reach the river in debris flows from steep tributary canyons. Boulders create and modify most of the major rapids and are also a factor in the creation of sandbars. Although its riverbed is bedrock in some places, the Colorado River generally is a cobble- and gravel-bed stream through which sand is transported (Graf 1995).

3.3.2.2 Sediment Transport Capacity

The river's capacity to transport sediment increases non-linearly, as a power function of the volume of water flowing in the river. The turbulence of flowing water can increase the amount of sediment in suspension and available for transport. Once the weight of the sediment particles exceeds the suspension force from the water current, the sediment is deposited. The greater the river's flow, the greater its velocity; the greater the turbulence, the greater its sediment load-carrying capacity. Finer particles (i.e., clay and silt) are carried in suspension by nearly all dam releases. Flows in the river are often large enough to carry sand grains in suspension or roll them along the riverbed, temporarily depositing the grains in areas where water velocity is insufficient to move them. Higher flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting a flood large enough to move them even short distances along the riverbed.

The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the pattern of water released from the dam, and the amount of sand already deposited on the riverbed at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high releases.[5]

3.3.2.3 River Stage

River stage defines the water level associated with a given discharge, which may be a result of both dam release and tributary inflow. Fluctuations in river stage are particularly important to cycles of deposition and erosion within sandbars. While fine sediments are readily transported by the Colorado River, the height of their deposition depends on river stage. Seepage-induced erosion is also affected by fluctuations in river stage because groundwater levels within exposed sandbars rise and fall with increases and decreases in river stage. When the river stage declines faster than groundwater can drain from the sandbar, the exposed bar-face becomes saturated, forming rills that move sand particles toward the river (Reclamation 1995; Alvarez and Schmeeckle 2013).

3.3.3 Sediment Sources

Sediments in the Colorado River are delivered by tributary streams and ephemeral washes. Although most of the water in the Colorado River originates in the Rocky Mountains, most of its sediment load originates from more arid regions in the interior of the river basin (Schmit and Schmidt 2011). In the post-dam era, the Colorado River is no longer the source of sediment to the river downstream of the dam. As a result of the closure of the Glen Canyon Dam,

[5] In an average pre-dam year, sand in Marble Canyon and the upper Grand Canyon would accumulate during 9 months of low flow (July through March); higher flows in April through June (from spring snowmelt) would then erode and transport the stored sand. Since the closure of Glen Canyon Dam, there is no discernible seasonal pattern of accumulation in the Canyons (Topping et al. 2000a; Hazel et al. 2006).

the annual sediment supply past Lees Ferry dropped from a pre-dam level of around 57 million metric tons per year (MT/yr) to about 0.24 million MT/yr during the post-dam period from 1966 to 1970, a reduction in sediment supply at Lees Ferry of more than 99% (Topping et al. 2000a).

The Paria River, Little Colorado River, and nearly 800 smaller gaged and ungaged tributaries now serve as the primary sources of sediment to this reach of the river (Webb et al. 2000; Schmidt and Grams 2011a). Taken together, the contributions of sand from various sources provide the Grand Canyon with approximately 16% of its pre-dam sand levels (Wright et al. 2005). Mass balance sand budgets in the Colorado River below the dam vary within and among years, depending on the amount of tributary sediment input and the monthly volume releases from the dam. Because of this dynamic nature, it is only possible to provide an estimate of the relative sediment budget that is representative of the river channel. In general, the lesser tributaries in the upper Marble Canyon upstream of RM 30 together contribute roughly 10% of the amount of sand annually supplied by the Paria River; downstream from RM 30, the lesser tributaries supply negligible amounts of sand (Griffiths and Topping 2015). However, the sediment inputs from these tributaries appear to be decreasing over time (see the following sections for further details related to gaged and ungaged tributary sediment inputs). Sediment supply is one of the important uncertainties related to managing this resource.

Debris flows have been documented in nearly 740 tributaries in the Marble and Grand Canyons between Lees Ferry and Diamond Creek; tributaries between the dam and Lees Ferry were found to produce only stream flow (Webb et al. 2000). Debris flows tend to be high-magnitude, short-duration events. Debris flows create and maintain the rapids (i.e., hydraulic controls), control the size and location of eddies, and serve as potential sources of sand to replenish sandbars of the Colorado River in the Marble and Grand Canyons.

The coarse sediments associated with debris-fan deposits can only be mobilized during flood flows and do not constitute a significant contribution to sediment loads transported by the river. However, their dynamics are important with respect to their retention of fine sediments and the development of geomorphic structures (e.g., fan-eddy complexes). While it has been predicted that the reduction in flood flows caused by Glen Canyon Dam could result in a greater accumulation of coarse sediment on debris fans, it has been shown that flood flows during the post-dam era also have the potential to transport coarse sediments from debris flows and eroding sandbars (Schmidt and Grams 2011a).

The occurrence and size of both debris flows and flash floods are influenced by geologic and geomorphic conditions within the watershed (see Section 3.3.1.1 for more detail on the geomorphic features of the Colorado River within the project area). They are also affected by the prior history of flows and the amount and intensity of precipitation. For example, Havasu Creek has not had a debris flow in recent geologic time, but it had an enormously destructive flash flood in September 1990. In general, slope failures in the steep tributary valleys commonly trigger debris flows; however, the geologic conditions favorable for debris flows from side canyons vary greatly throughout the area. Therefore, the potential for sand delivery from these tributaries to the mainstem Colorado River also varies throughout the canyon (Webb et al. 2000).

3.3.3.1 Gaged Tributaries

The two largest sediment-contributing tributaries to the Colorado River downstream of the Glen Canyon Dam are the Little Colorado River and Paria River. Sand contribution from the Paria and Little Colorado Rivers, estimated at USGS gaging stations, varies greatly from year to year (see Figure 3.3-8). Together, these two tributaries supplied about 10 to 15% of the total sand load in the pre-dam era (Topping et al. 2000a). Today, they are the two principal suppliers of sand to the Colorado River downstream of the dam through the project area.

The amount of sediment supplied by the Paria River is one of the highest among watersheds on the Colorado Plateau. From 1997 to 2014, the mean annual load has been estimated to be about 2.24 million MT/yr (GCMRC 2015a). Long-term records of sand inputs for the Paria River have suggested that approximately 75% of the average sand supply is delivered during the summer and fall when monsoonal storms are most likely to erode hill slopes in the upper basin and carry more fine sediments (Topping et al. 2010; Wright and Kennedy 2011). The historical median diameter of Paria River sand is approximately 0.13 mm; based on more recent data from 1994 to 2000, about 92% of the influx of sand from the Paria River is finer than 0.25 mm (Topping 1997; Hazel et al. 2006).

The annual average sediment load for the Little Colorado River, using data from 1994 and 2009, has been estimated to be about 4.34 million MT/year, of which approximately 30 to 40% was sand (GCMRC 2015a). Research from the mid-1980s through the early 2000s showed that the Little Colorado River contributed substantially less sand than the Paria River over a decadal time scale, despite the fact that the Little Colorado River basin is nearly 18 times larger than the Paria River basin (Wright et al. 2005; Rubin et al. 2002). These differences in sediment supply could be related to differences in watershed characteristics, including water loss (infiltration) in dryland channels in the increasingly arid climate within the Little Colorado River watershed (Block and Redsteer 2011) and the presence of multiple small dams or impoundments in the Little Colorado River drainage.

3.3.3.2 Ungaged Tributaries

Sediment supplied by the numerous small ungaged tributaries along the Colorado River is much more difficult to estimate because there are no stream gages. Studies have attempted to calculate sediment loads from ungaged tributaries using a number of methods, including mass-balance calculations assuming quasi-equilibrium, regional sediment-yield equations, sediment-rating curves, and peak discharge to total sediment-load relations (Griffiths and Topping 2015). However, there has been some scientific debate over these methods and over the resulting estimates from these various sources (Griffiths and Topping 2015; Schmidt and Grams 2011a). As a result, eight new gages were established in the late 2000s on previously ungaged lesser tributaries in Glen, Marble, and Grand Canyons to better estimate the supply of fine sediment (sand, silt, and clay) from these tributaries to the Colorado River (Griffiths and Topping 2015). Over the 13-year study period, the annual sediment load from the lesser tributaries to the Colorado River in upper Marble Canyon was found to vary two orders of magnitude, from approximately 1,800 to 340,000 metric tons of sand and around 2,900 to 370,000 metric tons of

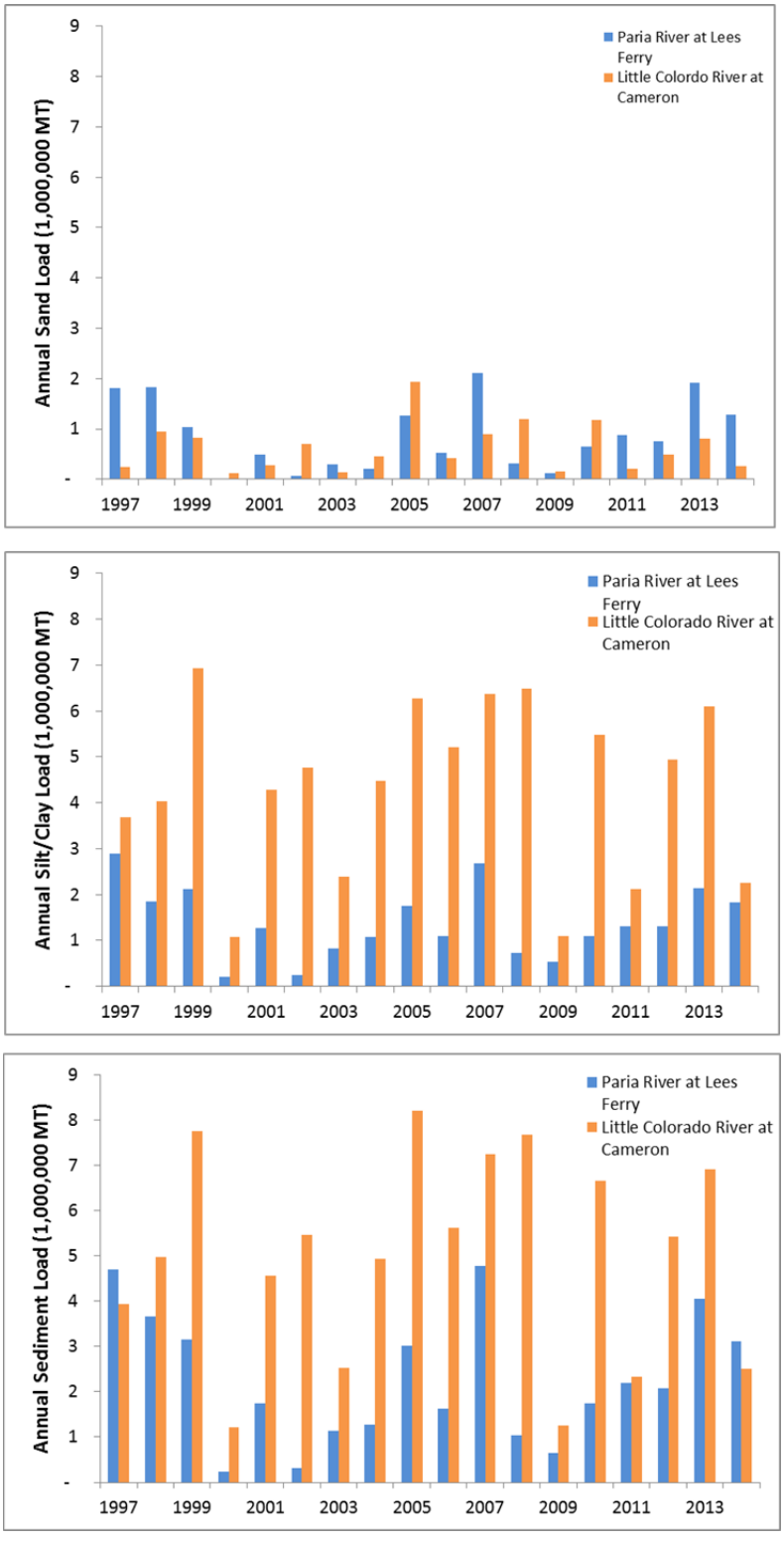

FIGURE 3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers (Source: GCMRC 2015a)

silt and clay. This is equivalent to about 10% of the measured mean annual sand load and about 8% of the measured mean annual silt and clay load in the Paria River. The annual sand load of the lesser tributaries ranged from1.6 to 49% of the annual sand load of the Paria River during individual years. The measured mean-annual silt-and-clay load translates to about 8% of that in the Paria River over the same period (Griffiths and Topping 2015).

Results from the more recent sediment-monitoring network also found that sediment loads do not necessarily correlate with drainage size, and cumulative sediment loads may vary by two orders of magnitude on an annual basis. Thus, previous indirect estimates of annual sediment load from the tributaries were generally too high; this translates to a sediment budget for the Colorado River below Glen Canyon Dam that is in greater deficit than previously concluded by most researchers (Griffiths and Topping 2015).

3.3.4 Sediment Transport and Storage

The operations of Glen Canyon Dam that affect sediment resources can be generally categorized as either operational flows (e.g., daily, monthly, and seasonal) or experimental releases (i.e., HFEs, described in more detail below). Using different flow regimens to manage sediment resources involves establishing a balance between erosional and depositional processes, which is controlled by many factors, including sediment sources and characteristics (described above), as well as physical aspects of sediment transport and storage (described below), that control the sediment balance. However, many uncertainties still remain regarding how these factors influence erosion and depositional processes, which generate the spatial and temporal variations in sandbar and channel-margin deposits throughout the Colorado River (Schmit and Schmidt 2011).

3.3.4.1 Sediment Transport

The term “sediment load” refers to sediment being transported by the river. Sediment load is further categorized as either bedload (i.e., particles moving along the river bottom) or suspended sediments (i.e., particles in the water column). More than 90% of the sand transported through the Colorado River system is considered suspended load (Schmidt and Grams 2011b). Sediment transport is controlled by a balance of forces (shear stress, drag, buoyancy, and gravity) acting on sediment particles, where the force balance is further controlled by properties of the flow, river geomorphology, and the surface area, concentration, density, size, and shape of the sediment particles available for transport.

A mass balance approach is commonly used to quantify sediment transport. Mass balance is calculated as the mass of sediment within a reach of the river relative to the amount of sand transported into and out of the reach. A positive mass balance indicates that more sediment is transported into the reach than out of the reach, and a negative balance indicates that more sediment is transported out of the reach than into the reach. Theoretical and empirical formulations that quantify sediment transport are described in more detail in Appendix E.

3.3.4.2 Sediment Storage

Sediment deposits at rest on the riverbed, within sandbars, and along channel margins represent the sediment storage of a river. Sediment storage is the result of coupled flow, sediment transport, and geomorphological conditions (e.g., low-energy recirculating flow within fan-eddy complexes) that result in deposition of sediments. It is important to note that sediment storage does not necessarily mean that there is no movement; instead, it refers to the net condition (i.e., mass balance) between sediment deposition and erosion at a point of interest over a specified period of time. Thus, sediment storage is a dynamic condition that varies based on the specific spatial and temporal scales considered; it can be increasing (net deposition), decreasing (net erosion), or at equilibrium. For example, the net sediment mass balance for a river reach may be in equilibrium over a year-long period. However, on a finer geographic scale, an individual bar may actually be aggrading or eroding as it exchanges sediment with another location within a reach. On a finer temporal scale, seasonal variation over the year-long period would also become apparent.

It has been estimated that more than 80% of the post-dam fine sediment in the Marble Canyon reach is stored in eddies below the 8,000-cfs stage (Hazel et al. 2006). However, deposition above this stage determines the amount of sand that can be seen and used by visitors to GCNP and how much sand is potentially available for campsites (Schmidt and Grams 2011b). Research has also shown that sand supplied from unregulated tributaries remains in storage for only a few months before most of it is transported downstream, unless flows are below approximately 9,000 cfs (Topping, Rubin, et al. 2000a; Rubin et al. 2002; Schmidt and Grams 2011b).

3.3.4.3 High-Flow Experiments

The Glen Canyon Dam Adaptive Management Program (GCDAMP) has conducted six HFEs (the first was called a Beach Habitat Building Flow), which occurred in 1996,[6] 2004, 2008, 2012, 2013, and 2014, to study the controlling factors that act together to build and maintain sandbars. The primary goal of an HFE is to rework sediments contributed by the Paria River, the Little Colorado River, and ungaged tributaries from the riverbed up to sandbar features that are at elevations above operational flow stages (Schmidt and Grams 2011b; Wright and Kennedy 2011; Reclamation 2011d). The first three HFEs conducted have been extensively studied and reported on (Melis 2011; Melis et al. 2011). Overall, these types of sediment-enriched flows were found to be effective at building sandbars (see Figure 3.3-9 as an example), although post-HFE erosion of sandbars did occur at varying rates depending on flow conditions (Wright and Kennedy 2011). More importantly, the research on these early HFEs highlighted the need to study the cumulative effects of more frequent HFEs and motivated Reclamation to

6 Although the purpose of the 1996 HFE was to control nearshore vegetation and remove nonnative fish downstream of Lees Ferry, the experiment also yielded important information on sediment deposition on sandbars (Schmidt and Grams 2011a). It differed in many significant ways from later HFEs including that it was not sediment-triggered and was much longer in duration.

develop an HFE protocol (Reclamation 2011d) that outlines conditions for implementing HFEs. The protocol also provides a methodology for determining the timing, magnitude, and duration of an experimental HFE (Russell and Huang 2010; Reclamation 2011d). The subsequent 2012, 2013, and 2014 HFEs were a direct result of this protocol.

In general, high flows with low suspended sediment concentrations have greater erosive potential, while high flows with high suspended sediment concentrations generate a greater potential for deposition (Topping et al. 2010). Thus, the primary mechanism for building sandbars seems to involve flood events that can mobilize and rework sediments from the tributary inputs and riverbed and deposit them at a high-flow stage in fan-eddy complexes and channel-margin areas. However, several factors affect both the efficiency with which a flood event can build sandbars and the spatial variability of the sandbar response.

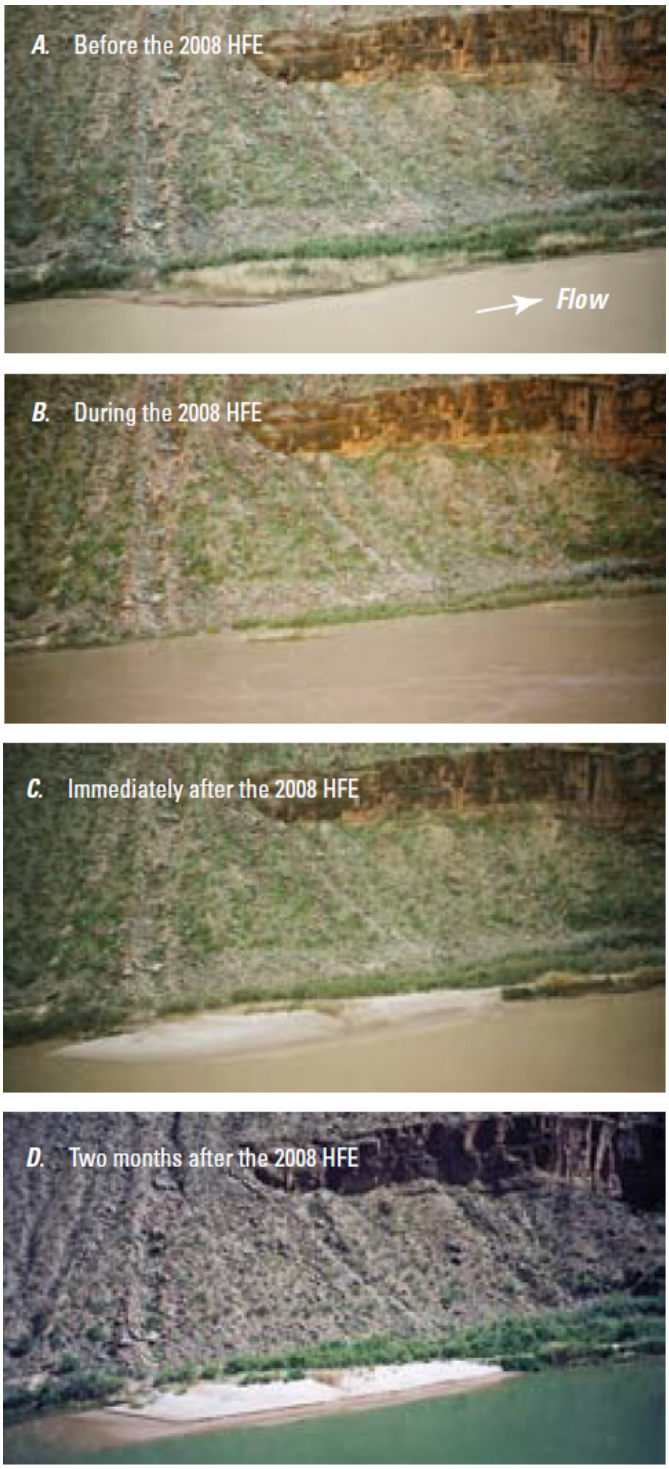

FIGURE 3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE (Source: Schmidt and Grams 2011b)

Preliminary results indicate that sandbar building occurred in Marble and Grand Canyons during each of the fall HFEs conducted from 2012–2014. Sandbars were larger following each HFE at more than half of the 45 long-term monitoring sites (Grams et al. 2015). Immediately following the 2012, 2013, and 2014 HFEs, sandbars were larger at 52%, 52%, and 57% of the monitoring sites, respectively (Grams 2016). Sandbar size did not change substantially at 35% of the monitoring sites following each of the same HFEs. The most recent topographic surveys completed in fall 2015 indicate the total volume of sand with the long-term monitoring sandbars increased during the first 4 years of implementation of the HFE protocol (Grams 2016). Preliminary results also indicate that each of these later HFEs evacuated less sand from upper

Marble Canyon than had been delivered there in the immediately preceding fall accounting season (Schmidt 2015). The net effect of less sand being evacuated by each HFE in relation to each year's sand delivery from tributaries has led to progressive sand accumulation in upper and lower Marble Canyon (Schmidt 2015).

3.3.4.4 Sediment Supply Limitation

In general, flow hydraulics and sediment particle sizes, in addition to the presence of critical geomorphic features (e.g., fan-eddy complexes), appear to be the primary factors controlling sandbar deposition (Topping et al. 2010). Thus, an HFE needs to have high velocities and turbulence, coupled with ample fine sediment supplies in the main channel, to increase suspended sediment concentrations. However, it is difficult to predict the sediment transport and storage in the Colorado River in response to HFEs, primarily because the quantity and particle size distributions of sediment available for transport are not consistent throughout a flood hydrograph, between floods, or over the length of the river (Schmidt and Grams 2011a).

Sediment supply limitations can affect the physical processes that govern sediment deposition during HFEs. It is necessary to have a higher concentration of suspended sediments in the main channel to ensure deposition in the fan-eddy complex (Rubin et al. 1998). Conversely, when suspended sediment concentrations are higher in the fan-eddy complex than in the main channel, there exists the potential to erode sand from the fan-eddy complex. During the early stages of an HFE, the finer-grained components are preferentially entrained from the riverbed and transported; consequently, the early sandbar deposits during a high flow are dominated by finer-grained sand. Once the finer-grained sand is winnowed from the riverbed, the suspended sand concentration decreases and the sand in suspension becomes coarser-grained.

3.3.4.5 Sandbar Deposition and Retention

Sandbars experience cycles of deposition and erosion during normal dam operations. Generally, net erosion is a result of turbulent exchange, decreases with distance downstream of the dam, and increase with daily fluctuations in stage. Sandbar erosion can also result from nearshore currents, waves generated by rapids, seepage erosion caused by dewatering sandbars and groundwater flow, wind, tributary floods, and hillslope runoff (Alvarez and Schmeeckle 2013; Schmidt and Grams 2011a; Melis et al. 1995; Budhu and Gobin 1994; Bauer and Schmidt 1993). Sandbar deposition requires high flows and adequate sediment supply. Without occasional periods of sustained high releases (i.e., above powerplant capacity), sandbars, particularly those at high elevation, will eventually erode and not rebuild (Andrews 1991; Schmidt and Grams 2011a).

Long-term rehabilitation of eddy sandbars can occur only if the increases in sand volume caused by high flows exceed the erosion that occurs during the intervening periods. Alternatively, if there are only small amounts of deposition during high flows and large volumes of erosion during intervening periods, a long-term decrease in sandbar size will result. Figure 3.3-10 presents a conceptual diagram illustrating the dependency of net sandbar size on

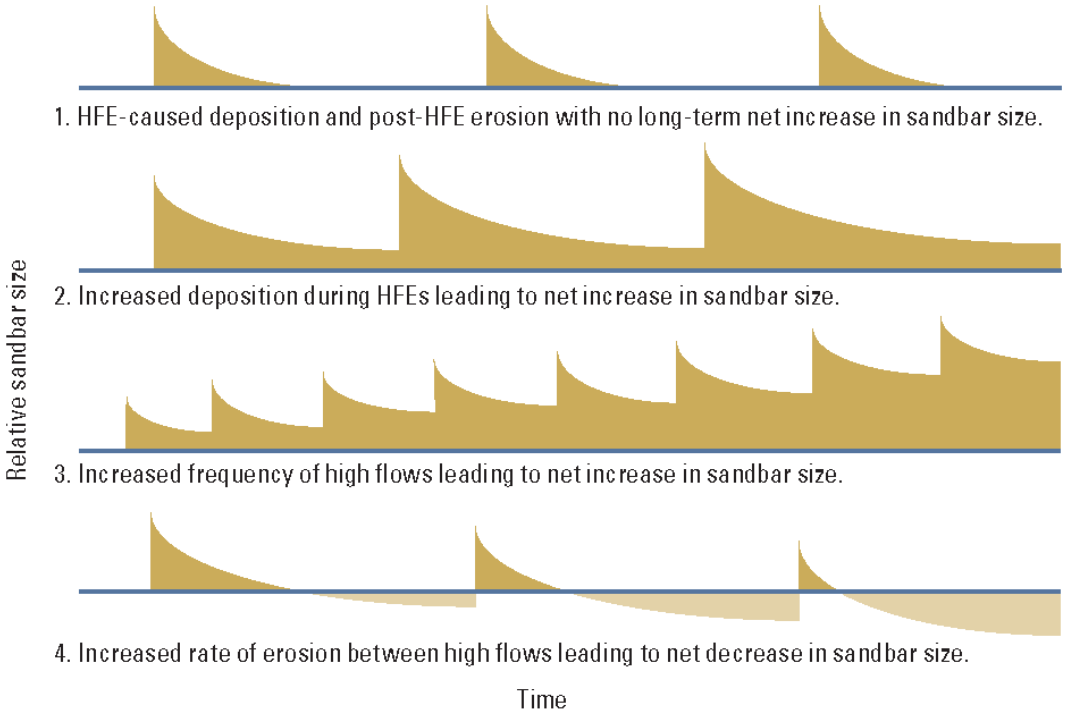

FIGURE 3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates (Source: Schmidt and Grams 2011a)

potential variations during a series of hypothetical HFEs in the amount of deposition, frequency of HFEs, and rate of post-HFE erosion. The first graph shows HFE deposition followed by an equal amount of erosion. The second and third result in net increases in sandbar size by increasing the amount of deposition during HFEs and increasing the frequency of HFEs, respectively; this would require sufficiently great antecedent sand enrichment to support either larger or more frequent HFEs. The last graph depicts a higher rate of erosion following the HFEs, resulting in net decreases in sandbar size (Schmidt and Grams 2011b).

In each of the HFEs,[7] the majority of sandbars exhibited net deposition, as illustrated by the data presented in Figure 3.3-11. The highest level of eddy-sandbar deposition above the reference stage was observed in the parts of Marble and Grand Canyons where the suspended-sand concentration was greatest (Schmidt and Grams 2011b). It is also important to note that, conversely, between 14 and 18% of the monitored sandbars exhibited net erosion (Schmidt and Grams 2011b). Overall, the 1996 HFE (previously referred to as a Beach Habitat Building Flow) resulted in more sandbar erosion than was expected, and antecedent sediment conditions

[7] Summary sandbar results presented are for the 1996, 2004, and 2008 HFEs. The 2012, 2013, and 2014 HFEs post-date the referenced report. Findings from the later HFEs will be released by GCMRC once the research is complete (GCMRC 2014).

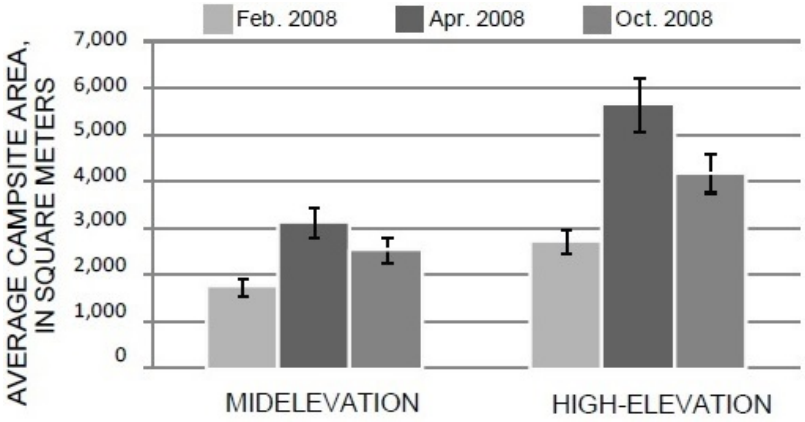

FIGURE 3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE (Source: Hazel et al. 2010)

(pre-HFE tributary inputs and analyses of sediment storage) were determined to be limiting with respect to sediment storage in the system. As a result, subsequent HFEs were all performed under more enriched sediment conditions, because it was assumed that increased sand enrichment volumes would yield increased suspended sediment loads and higher volume deposits. However, analysis of data from the 2004 and 2008 HFEs suggested that this assumption was not necessarily true. Greater levels of sand enrichment will lead to greater reach-averaged bed-sand area, but will not always lead to finer reach-averaged bed-sand grain size. Thus, both grain size and magnitude of sand supply need to be considered in order to maximize sandbar deposition (Topping et al. 2010).

In the period after each of the HFEs, sandbars tended to erode. In general, sandbar erosion rates were especially high immediately following each of the HFEs, then continued at a slower rate (Schmidt and Grams 2011b). The pattern of net erosion after the HFEs mirrors the changes that occurred during flooding. That is, the pattern of high-elevation deposition and low-elevation erosion is dominant during high-flow, high-elevation erosion, and low-elevation deposition is the dominant pattern during intervening low flows (Hazel et al. 2006).

Overall, research suggests that the HFEs are effective at temporarily building the area and volume of sandbars in fan-eddy complexes. However, long-term rehabilitation of sandbars is only possible if the increases in sand volume caused by the HFEs exceed the erosion during intervening operational flow periods (Schmidt and Grams 2011b) (see Figure 3.3-10). Furthermore, net storage gains in the sandbars as a whole cannot occur if sand is simply being transferred from one bar to another during an HFE. The current state of knowledge suggests that modifying the base flow regime alone (flows below 31,500 cfs and without the use of HFEs) cannot increase the area and volume of sandbars over annual or multi-year timescales (Topping et al. 2010). High flows are needed to get the water surface high enough to deposit sand at higher elevations. Therefore, the research suggests that both the number of HFEs and the base flow regime are factors that affect the building and retention of sandbars.

3.3.5 Lake Deltas

Sedimentation rates among reservoirs are highly variable, due mainly to regional climatic and geomorphic differences that affect sediment delivery. In general, the coarser particles (i.e., mostly sand) carried into the reservoirs by tributaries are deposited as deltas in the tributaries arm. The majority of finer particles (i.e., silt and clay) are carried farther downstream into the reservoir, where they settle out as lakebed deposits. Deltas fill the upstream parts of the tributary arms first, building toward the submerged mainstem channel and eventually the dam. Some sediment deposited in upstream parts of the delta may be transported downstream as a result of flood flow when the reservoir is low. The upper surfaces of deltas function as important substrate for vegetation and riparian habitat and can affect recreational navigation and the water quality of the reservoir (Reclamation 1995).

The characteristics of a delta depend on variables such as the quantity and size of inflowing sediment, dam operations, surface water elevation, and hydraulics in the tributary arms. Other factors include erosion and vegetative growth along the margins of the tributary arms and turbulence and density currents in the reservoir. The longitudinal profile of a delta depends primarily on reservoir levels and the slope of the channel through the delta (Strand and Pemberton 1982; Reclamation 1995).

The live storage capacity of Lake Mead is 26.399 maf at an elevation of 1,221.4 ft. All sediment transported into Lake Mead by the Colorado River and its tributaries is trapped in deltas and lakebed deposits. Before closure of Glen Canyon Dam, the total upstream drainage area contributing sediment to Lake Mead was 171, 500 mi^2. Since the dam's closure in 1963, sediment contribution upstream of Lake Powell has been essentially cut off. As a result, the drainage area that could contribute sediment above Lake Mead has been reduced by an estimated 65%, or approximately 59,800 mi^2 (Ferrari 2008). Additional information on the hydrology and water quality of Lake Mead is presented in Sections 3.2.1.3 and 3.2.2.3, along with a map of the reservoir and vicinity (Figure 3.2-2).

Longitudinal profiles of the mainstem Colorado Riverbed elevation upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 are illustrated in Figure 3.3-12. In general, the location along the river where the Colorado River intersects Lake Mead depends greatly on the reservoir's water level elevation, which is primarily controlled by the combination of releases from the Glen Canyon and Hoover Dams. The maximum recorded riverbed elevation was 1,220 ft, which roughly corresponds to the elevation of the riverbed downstream of Bridge Canyon (RM 235) in Lower Granite Gorge. Thus, RM 236 is the approximate upper end of the Colorado River delta, which extends past Pierce basin to about RM 290 (Reclamation 1995).

The shape of the Colorado River delta profile is also affected greatly by reservoir elevation. The delta surface in lower Granite Gorge and upper Lake Mead is relatively flat and composed mainly of sand, which begins to drop out of suspension at the point where the river meets the reservoir (as noted above). Beyond the delta, river and reservoir currents can carry large volumes of finer sediment farther into Lake Mead. Lakebed sediments consist of predominantly fine sediments: 60% clay, 28% silt, and 12% sand. Lakebed deposits extend all the way to Hoover Dam at RM 355, even though the longitudinal profile dips steeply at the delta

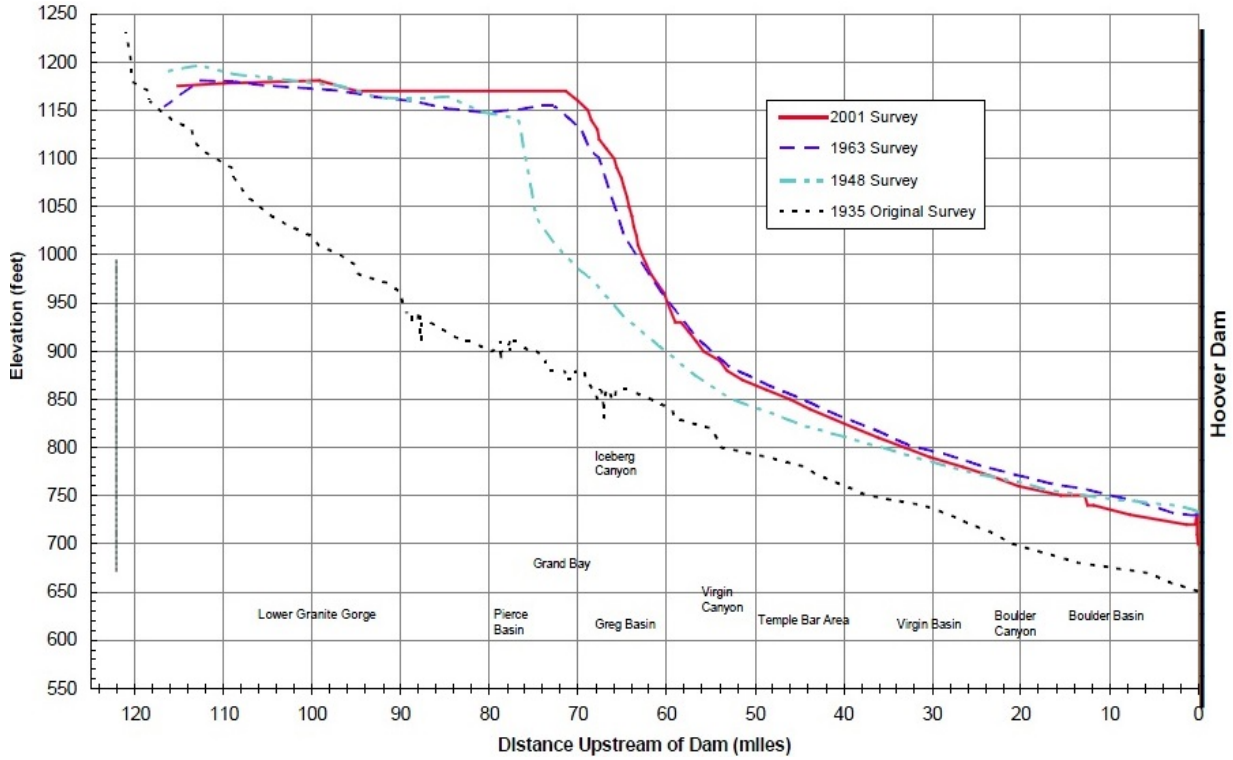

FIGURE 3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 (Source: Ferrari 2008)

crest. The elevation of the delta crest, where the slope changes from relatively flat to relatively steep, has migrated over time (see Figure 3.3-12). According to the 1948–1949 survey of the delta, the delta crest was at RM 278; by the time of the 1963–1964 survey, it had progressed to RM 286 (Reclamation 1995). As of 2001, the delta had progressed another 2 to 3 mi lakeward. The recreational impacts of sediment accumulation in the lower reaches of the western Grand Canyon are described in Sections 3.10.2 and 4.10.2.6.

3.4 NATURAL PROCESSES

The Colorado River Ecosystem is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals and natural ecological processes. NPS management policies state that (1) "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species" and (2) "the Service … will try to maintain all components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006b). For the LTEMP, the

natural processes resource goal is to "restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems." It is not possible to operate Glen Canyon Dam in a manner that could fully restore natural processes and their drivers to those that occurred under unregulated conditions due to, among other things, the existence of the dam and laws governing conveyance of water between the Upper and Lower Colorado River Basins.

Major drivers of natural processes in river ecosystems, including regulated rivers below dams, are river flow, water temperature, sediment transport, and water quality (including nutrients and turbidity) (Poff et al. 1997; Olden and Naiman 2010; Jones 2013a). These drivers directly and/or indirectly determine the abundance, condition, and status of native and nonnative plants and animals and their habitats in the ecosystem below a dam. The primary effects of dam operations on native plant and animal species and their habitats below the dam are a direct function of (1) the physical conditions (e.g., sediment transport, water temperature) that occur below a dam under specific operations; (2) how those conditions affect habitat quality, quantity, and stability; and (3) how aquatic and terrestrial biota will respond to those changes.

The construction and operation of Glen Canyon Dam has altered the ecosystem both above and below the dam (e.g., Turner and Karpiscak 1980; Brown and Johnson 1988; Carothers and Brown 1991; Blinn et al. 1992; Gloss and Coggins 2005; Kennedy and Ralston 2011; Cross et al. 2013). Before the dam, the river was sediment rich, transporting large quantities of sediment during spring and early summer and during flood events. Prior to construction of the dam, there was considerable seasonal and annual variability in flow and water temperature. Annual peak discharge typically reached between 85,000 and 120,000 cfs with records of 300,000 cfs, while flows in late summer, fall, and winter could be less than 3,000 cfs (Wright et al. 2005; Webb et al. 2005; Vernieu et al. 2005). Water temperatures fluctuated seasonally between 0°C (32°F) and 30°C (86°F), with highest water temperatures occurring in summer.

The physical changes that have resulted from dam construction and operation include serving as a barrier to the movement of most aquatic organisms between the Upper and Lower Colorado River Basins, a decrease in mean main channel water temperatures, a reduction in sediment supply and transport, increased bed scouring and incision, a reduction in peak flows with coupled reductions in the height of annual sediment deposition and areas of sediment erosion, increased daily fluctuations in flow and stage, and increased water clarity (Reclamation 1995; Topping et al. 2000a, 2003; Grams et al. 2007). Following completion of the dam, operations resulted in lower maximum annual volumes, lower peak flows, higher base flows, and decreased annual flow variability (Topping et al. 2003). In addition, in order to increase the value of hydropower, daily fluctuations increased, at times varying from 5,000 to 30,000 cfs (Wright et al. 2005). The incoming sediment load is deposited in Lake Powell and water released from the dam is clear. As a consequence, there has been a significant reduction in sediment supply and transport in the main channel below the dam (Topping et al. 2000a; Vernieu et al. 2005; Wright et al. 2005). Because of the location of the penstocks, water released from the dam is cold, averaging between 9 and 12°C (48° and 54° F), with warmest river temperatures occurring in late fall (Vernieu et al. 2005). Downstream water temperatures are

more naturalized and exhibit greater variation, ranging from about 9°C (48°F) to 18°C (64°F) in the western Grand Canyon near Diamond Creek.

The presence of the dam and dam operations has resulted in changes in flow, sediment transport, connectivity, and water temperature. These physical changes, in turn, have resulted in an increase in nonnative riparian vegetation, changes in the distribution and composition of riparian vegetation communities, changes in the aquatic food base, the loss or reduction of native fish, and increases in nonnative fishes (Valdez and Carothers 1998; Gloss and Coggins 2005; Ralston 2005). The physical changes have resulted in a downslope migration of riparian vegetation toward the river's edge (Reclamation 1995; Sankey et al. 2015), the establishment of marshes in the varial zone (Stevens et al. 1995), the development of a cold-water zone that supports rainbow trout (McKinney, Speas et al. 2001; Reclamation 2011e), changes in the composition and productivity of the aquatic food base (Kennedy and Gloss 2005), and a restriction in the distribution, reproduction, and growth of native fish in locations downstream of the dam and tributaries (Gloss and Coggins 2005).

The status of physical conditions in the river is described in Section 3.2 (Water Resources) and Section 3.3 (Sediment Resources). These sections describe the past and current conditions associated with hydrology and flow, water quality (including temperature), and sediment transport and storage. Descriptions of biological resources in the system may be found in Sections 3.5.1 (Aquatic Food Base), 3.5.2 (Native Fish), 3.5.3 (Nonnative Fish), 3.6 (Vegetation), and 3.7 (Wildlife).

3.5 AQUATIC ECOLOGY

This section presents information on the aquatic ecology of the Colorado River between Glen Canyon Dam and the inflow of Lake Mead. Included are discussions of the aquatic food base (i.e., invertebrates, algae, rooted plants, and organic matter that serve as the base of the food web for fish; Section 3.5.1), native fish (including endangered and other special status species; Section 3.5.2), and nonnative fish (including coldwater and warmwater species; Section 3.5.3). For all of these topics, the effects of dam operations and other factors on these resources are discussed.

3.5.1 Aquatic Food Base

Invertebrates (animals without backbones), algae, rooted plants, and organic matter serve as the aquatic food base for fishes in the Colorado River Ecosystem (Gloss et al. 2005). Although most of this food base is produced within the aquatic system, terrestrial inputs to the Colorado River Ecosystem of organic matter (e.g., leaf litter) and invertebrates also contribute. In turn, instream production of both algae and invertebrates helps support terrestrial consumers such as grasshoppers and spiders, insectivorous birds and bats, reptiles, and waterfowl; indirect links include peregrine falcons, belted kingfishers, osprey, great blue herons, and bald eagles, which feed on fishes or waterfowl that consume aquatic food base organisms (Bastow et al. 2002; Baxter et al. 2005; Sabo and Power 2002; Shannon, Kloeppel et al. 2003; Shannon et al. 2004;

Stevens and Waring 1986a; Yard et al. 2004). See Section 3.7 of this EIS for a discussion of riparian and terrestrial wildlife. Flow patterns and temperature (all of which were and continue to be influenced by the presence and changing operations of Glen Canyon Dam) have a major influence on the food base of the Colorado River Ecosystem within the Grand Canyon.

This section presents an overview of the aquatic food base prior to and following the construction and operation of Glen Canyon Dam. Included in the discussion are invasive aquatic species that have affected or may affect food base organisms of the Colorado River downstream of Glen Canyon Dam. The major groups of aquatic food base organisms include (1) periphyton (e.g., algae and cyanobacteria that live attached to rocks and other surfaces) and rooted aquatic plants, (2) plankton (very small plants [phytoplankton] and animals [zooplankton] that occur in the water column), and (3) macroinvertebrates (i.e., invertebrates that are visible to the naked eye).

As summarized by Cross et al. (2013), large dams alter the physical template of rivers by changing flow, temperature, and sediment regimes. Nutrients and sediments are trapped in reservoirs such as Lake Powell rather than being carried downstream (Johnson and Carothers 1987). These changes alter riverine food webs, reduce biodiversity, and often lead to extirpation of native species and facilitation of invasion by nonnative species.

Prior to the construction of Glen Canyon Dam, the productivity of the Colorado River was low due to scouring by annual floods and high turbidity, although there were productive areas in rapids, riffles, whirlpools, and backwaters (Woodbury 1959; Haden et al. 2003). Collections made along the banks of the Colorado River in Glen Canyon and in tributaries or side canyons included 28 species of green algae, 5 species of cyanobacteria, 20 species of diatoms, and 91 species of aquatic insects (e.g., mayflies, dragonflies, true bugs, dobsonflies, caddisflies, aquatic moths, beetles, and true flies). Only 16 insect species were collected from sites along the river in Glen Canyon (including 4 species of mayflies and 3 species of caddisflies), while 77 species were collected from tributaries. Examination of fish stomach contents indicated that organisms derived from tributaries and terrestrial habitats played an important part in the diet of river fishes in Glen Canyon (Woodbury 1959).

The combination of altered flows, reduced organic inputs from areas upstream of the dam, decreased turbidity, and an altered thermal regime has led to a shift in the aquatic food base in the Colorado River below Glen Canyon Dam (Benenati et al. 2002; Blinn et al. 1995; Kennedy and Gloss 2005). In general, aquatic invertebrate diversity has declined, while density and biomass have increased (Kennedy and Gloss 2005). The influence of Glen Canyon Dam, coupled with sediment inputs from tributary streams, has resulted in a stair-step decrease in the food base biomass in the Colorado River. In the post-dam period, the 16-mi reach of Glen Canyon accounted for 69% of the algal and 50% of the macroinvertebrate mass collected throughout the 224-mi section of the Colorado River. Sites within Marble and Grand Canyons contributed 18 and 41% and 13 and 9%, respectively, of algal and macroinvertebrate biomass. Food base reductions in reaches downstream of the Paria River result from elevated sediment inputs from tributary streams. The suspended sediments increase turbidity and the deposited sediments alter substrate characteristics (Shannon et al. 1994, 2001). Thus, the aquatic food base of the tailwater section (between the dam and the Paria River) and the rest of the mainstem

(e.g., between the Paria River and Diamond Creek) are often discussed separately. The Colorado River below the Paria River is seasonally influenced by tributary sediment and organic matter inputs, making them more similar to the pre-dam condition, particularly as distance from the dam increases (Rosi-Marshall et al. 2010).

Glen Canyon Dam operations have played a significant role in the formation of the varial zone (i.e., the portion of the river bottom that is alternately flooded and dewatered during operations, often on a daily basis). Benthic communities subject to periodic stranding, desiccation, ultraviolet radiation, and winter freezing often have depleted species diversity, density, and/or biomass in the varial zone (Fisher and LaVoy 1972; Hardwick et al. 1992; Blinn et al. 1995; Stevens, Shannon, et al. 1997).Recent studies have demonstrated that this varial zone actually constrains the abundance and diversity of aquatic insects in the Colorado River downstream of Glen Canyon Dam (Kennedy et al. 2016), thereby limiting the amount of invertebrate prey that is available to support native and desired nonnative fish populations. Most aquatic insects have complex life cycles with a winged adult stage that is terrestrial, while egg, larval, and pupal stages are aquatic. The majority of adult aquatic insects (~80%; Kennedy et al. 2016) use river edge habitats for egg laying, whereby eggs are cemented onto rocks or vegetation along the river edge and just under the water surface. Brief desiccation of insect eggs (e.g., 1 hour), as is typical of eggs laid in the varial zone, leads to their complete mortality (Kennedy et al. 2016). Evidence for this egg mortality effect can be seen throughout Grand Canyon, with aquatic insects being more abundant in locations where the timing of daily low flows coincides with peak egg laying activity (i.e., late afternoon), because insect eggs laid in these locations are never subjected to desiccation induced mortality. Additional evidence for this egg mortality effect is seen by comparing insect diversity downstream of dams throughout the Western United States, with insect diversity being strongly and negatively related to the degree of hydropower production (Kennedy et al. 2016). Thus, the varial zone downstream of hydropower dams, such as Glen Canyon, greatly reduces the quality and availability of river edge habitats that are used by aquatic insects for their egg laying; this constrains both the diversity and abundance of aquatic insects that are present in these ecosystems.

More detailed information on the effects of dam operations on the aquatic food base is provided in Section 4.5.

3.5.1.1 Periphyton and Rooted Aquatic Plants

Physical factors associated with dam releases that have the greatest influence on tailwater algal communities include (1) daily and seasonal constancy of water temperatures, (2) modifications in nutrient regimes, (3) reduced sediment and increased water clarity, (4) formation of stable armored substrates, (5) fluctuations in water levels that produce daily drying and wetting cycles, and (6) reductions in seasonal flow variability and alterations in the timing or occurrence of extreme flows (Blinn et al. 1998). These conditions allowed ubiquitous *Cladophora glomerata* (a filamentous green algae) to become the dominant algal species below Glen Canyon Dam within 6 years of dam closure in 1963 (Czarnecki et al. 1976; Carothers and Minckley 1981; Blinn et al. 1989, 1998; Stanford and Ward 1991). This species remained dominant until 1995 (Blinn and Cole 1991; Blinn et al. 1995; Benenati et al. 1998). Changes in

flow regimes (e.g., repeated episodes of exposure and desiccation of the varial zone) and diluted nutrient concentrations associated with higher reservoir volumes caused the decrease in dominance of *Cladophora* (Benenati et al. 1998, 2000, 2002). Prior to June 1995, *Cladophora* comprised 92% of the phytobenthic community, but it decreased to <50% after that time (Benenati et al. 2000). The aquatic flora is now dominated by miscellaneous algae, macrophytes, and bryophytes (MAMB) including filamentous green algae (mainly *Ulothrix zonata* and *Spirogyra* spp.), the stonewort *Chara contraria*, the aquatic moss *Fontinalis* spp., and the macrophyte *Potamogeton pectinatus*. *Cladophora* is still present, but in much reduced levels, probably due to changes in reservoir and river chemistry and discharge regimes (Benenati et al. 2000; NPS 2005a; Yard and Blinn 2001).

Cladophora occurs along the entire course of the river; however, its abundance decreases downstream (Blinn and Cole 1991; Shannon et al. 1994; Shaver et al. 1997; Stevens, Shannon et al. 1997). This decrease results from high suspended sediment loads contributed from the major perennial tributaries, particularly the Paria River and Little Colorado River (Blinn et al. 1995). Suspended sediments reduce photosynthetic efficiency and scours *Cladophora* from substrates (Blinn et al. 1995; Hall et al. 2015).

Cladophora is colonized by a wide variety of diatoms (a group of unicellular or colonial algae) and macroinvertebrates because it can offer protection from predators, food, or a substrate that is anchored against flow disturbance (Dodds and Gudder 1992). Diatoms are the dominant food in the tailwaters of Glen Canyon Dam, but become less important downstream, where bacteria play a more important role in the food web (Blinn et al. 1992). *Cladophora* that becomes detached from the substrate in Glen Canyon is exported downstream where it enters the detrital pathways (Angradi and Kubly 1993, 1994).

The cyanobacteria *Oscillatoria* is co-dominant with *Cladophora* in Marble Canyon and dominates farther downstream in the Grand Canyon due to its tolerance of exposure to air and lower light levels compared to *Cladophora* (Blinn et al. 1992; Stevens, Shannon et al. 1997). Fewer diatoms occur on *Oscillatoria* compared to *Cladophora* (Shannon et al. 1994). Closely attached (adnate) diatoms dominate those that do occur on *Oscillatoria*, while upright or stalked diatoms dominate those that occur on *Cladophora*. Macroinvertebrates and fishes more easily consume the upright diatoms. While *Oscillatoria* provides cover for burrowing midges and aquatic worms, it has little food value for macroinvertebrates (Blinn et al. 1992). Energy from macroinvertebrate biomass associated with tufts of *Cladophora* is 10 times higher than for *Oscillatoria*. Therefore, replacement of *Cladophora* by *Oscillatoria* indirectly reduces potential energy flow in the Colorado River food web (Shaver et al. 1997).

Submerged macrophytes collected in the mainstem included horned pondweed (*Zannichellia palustris*), Canadian waterweed (*Elodea canadensis*), Brazilian elodea (*Egeria densa*), pondweed (*Potamogeton* spp.), aquatic moss (*Fontinalis* spp.), and muskgrass (*Chara* spp. [green alga]) (Carothers and Minckley 1981; Valdez and Speas 2007).

The distribution, ecological importance, and favorable temperature range for select primary producer taxa that occur downstream of Glen Canyon Dam are summarized in Table F-5 (Appendix F).

3.5.1.2 Plankton

Plankton occurring in the Colorado River downstream from Glen Canyon Dam includes both phytoplankton and zooplankton. The phytoplankton population in the Colorado River downstream of the dam is diverse, but sparse (numbers never exceeded 3 million organisms/m^3 [3,000 organisms/L]), and decreased with distance downstream of Lees Ferry. A total of 122 species were identified, with diatoms being dominant. In general, the phytoplankton of the Colorado River is considered relatively unproductive due to a combination of high flow rates, low temperatures, elevated turbidity (with increasing distance from the dam), and scouring action by rapids and suspended solids, which limit reproduction and survival (Sommerfeld et al. 1976).

The factors that regulate zooplankton in the Colorado River below Glen Canyon Dam are the distribution and abundance of zooplankton in Lake Powell and operations of the dam (AZGFD 1996; Speas 2000). Low levels of Lake Powell may result in increases in the composition and density of zooplankton downstream as waters are withdrawn from layers closer to the surface (Reclamation 1995). Cole and Kubly (1976) concluded that most zooplankton in the Colorado River originated from Lake Powell or tributaries (primarily Elves Chasm and Tapeats and Diamond Creeks). Mean zooplankton density in the 352 km of the Colorado River downstream of Glen Canyon Dam was 614 organisms/m^3 (0.614 organisms/L) (Benenati et al. 2001).

It has been reported that backwater areas are localities where zooplankton populations can persist (Haury 1986), and that zooplankton densities in backwaters are significantly higher than those from the main channel (AZGFD 1996). Backwaters were thought to support more zooplankton because they are more stable habitats and may retain nutrients that benefit both phytoplankton and zooplankton (AZGFD 1996). Some production of zooplankton occurs in eddies, backwaters, and other low-velocity areas (AZGFD 1996; Stanford and Ward 1986; Blinn and Cole 1991). However, given that even under stable flows waters in backwaters are recycled 1.5 to 3.4 times per day, it seems unlikely that water-column resources such as zooplankton could ever become substantially higher in backwaters than in the mainstem river (Behn et al. 2010).

The temperature requirements for select zooplankton taxa are summarized in Table F-6 (Appendix F).

3.5.1.3 Macroinvertebrates

Temperature and suspended sediment alterations associated with Glen Canyon Dam, and operations of Glen Canyon Dam itself, resulted in a food base with low species diversity. Although productivity of the food base is high in the Glen Canyon reach, food base production in the Grand Canyon is extremely low, falling in the bottom 10% of production values for streams and rivers throughout the world (Cross et al. 2013). Owing to these changes in the physical template of the river, coupled with intentional and accidental introductions of nonnative invertebrates, the food base consists of both native and nonnative species. The abundant aquatic macroinvertebrates within Lees Ferry include *Gammarus lacustris* (an introduced nonnative

amphipod), midges (order Diptera, family Chironomidae), snails (*Physella* sp. and *Fossaria obrussa*), and segmented worms (especially Lumbricidae and Lumbriculidae), which are associated with *Cladophora* beds, as well as ooze- and gravel-dwelling worms (Naididae and Tubificidae), fingernail clams in the family Sphaeriidae (*Pisidium variable* and *P. walkeri*), and the planarian *Dugesia* spp. (Blinn et al. 1992; Stevens, Shannon et al. 1997). Prior to 1995, gastropods (snails) were infrequent but have since increased in abundance due to invasion by the nonnative New Zealand mudsnail (*Potamopyrgus antipodarum*) (Valdez and Speas 2007; Cross et al. 2010). This species is discussed later in this section.

Glen Canyon Dam limits the downstream transport of terrestrial materials such as insects, leaf litter, and woody debris. This reduction of organic input, coupled with low temperature variability and highly variable discharges, can contribute to decreased biodiversity and density of macroinvertebrates (Kennedy et al. 2016), particularly within the Glen Canyon reach. Seasonal turbidity increases, particularly from the confluence of the Paria River to Lake Mead, and reduces overall invertebrate biomass. The decrease in light penetration lowers primary production and favors the growth of the less nutritious cyanobacteria *Oscillatoria* in the lower reaches of the Colorado River (Blinn et al. 1999; Hall et al. 2012).). Macroinvertebrates are not generally associated with *Oscillatoria* because it is very compact, has little surface area for colonization, and largely lacks epiphytic diatoms (Blinn et al. 1995).

In contrast to insects, *Gammarus* and other non-insect aquatic macroinvertebrates can complete their development over a relatively wide temperature range (Vinson 2001), and non-insect aquatic macroinvertebrates lack a terrestrial life stage so their entire life cycle occurs in the river. *Gammarus* is largely replaced by midges and blackflies below the Paria River (Blinn et al. 1992; Seegert 2010; Donner 2011). The decrease in standing stock of *Gammarus* with distance from Glen Canyon Dam (Blinn and Cole 1991; Blinn et al. 1992) corresponds to a decrease in *Cladophora* biomass and associated epiphytic diatoms downriver (Hardwick et al. 1992). Although blackflies and midges are relatively less prevalent in Glen Canyon, they support more than half of the rainbow trout (*Oncorhynchus mykiss*) production in that reach (Cross et al. 2011). The 2008 HFE caused a 60% decline in overall invertebrate production that was driven by a large reduction in the production of nonnative New Zealand mudsnails (Cross et al. 2011). However, the production of midges and blackflies increased by 30 and 200%, respectively, in the year following the HFE, and these insects supported a 200% increase in rainbow trout production (Cross et al. 2011).

The relatively high densities of blackfly larvae in the downstream reaches of the Colorado River suggest the presence of smaller food particles (e.g., bacteria) in these reaches (Blinn et al. 1992; Wellard Kelly et al. 2013). Being filter feeders, blackflies are more common in high-velocity areas with little algal cover, including hard, smooth substrates and driftwood lodged among rocks. Limited data suggest that the blackfly assemblage in the river has changed from at least a five-species assemblage to a near monoculture of *Simulium arcticum* (Blinn et al. 1992).

The Colorado River in Glen and Grand Canyons supports very few mayflies, stoneflies, or caddisflies because of a combination of stressors, including altered temperature regimes and a large varial zone (Stevens, Shannon, et al. 1997; Kennedy et al. 2016). Cold water released from

Glen Canyon Dam can prevent aquatic insect eggs from hatching and may limit successful recruitment of these orders from warmer tributaries (Oberlin et al. 1999), while a large varial zone associated with hydropower production leads to desiccation-induced mortality of insect eggs laid along river edge habitats (Kennedy et al. 2016). The caddisfly *Ceratopsyche oslari* occurs throughout the Colorado River but at a low abundance (Blinn and Ruiter 2009). Haden et al. (1999) believe that interspecific interactions between *Gammarus* and the net-building *C. oslari* may contribute to the caddisfly's limited occurrence in the Colorado River below Glen Canyon Dam. Since 1994, recent colonizers (possibly as a result of reduced discharge variability from Glen Canyon Dam) throughout the river include caddisflies (*Hydroptila arctica*, *Rhyacophila* spp., *C. oslari*, and others), true flies (*Bibiocephala grandis* and *Wiedemannia* spp.), mayflies (*Baetis* spp.), beetles (*Microcylloepus* spp.), planarians, and water mites (Shannon et al. 2001). However, caddisflies and mayflies remain relatively sparse in the Colorado River, especially upstream of the Paria River. Tables F-2 through F-4 (Appendix F) present the biomass, production, and abundance of invertebrates, respectively, over the course of 3 years at various locations in the Colorado River.

Flow fluctuations and repeated inundation and exposure can have a significant impact on food base organisms in the varial zone. Warm air temperatures in summer or subfreezing air temperatures in winter can cause mortality of macroinvertebrates stranded in the varial zone (Gislason 1985). The varial zone probably provides poor habitat for species with multiple life history stages (Jones 2013b). Dewatering within the varial zone may adversely impact areas where adult aquatic insects either emerge or deposit eggs (Vinson 2001; Kennedy et al. 2016).

Drifting macroinvertebrates, particularly blackflies and midges, are an important food resource for rainbow trout (McKinney and Persons 1999) and other fishes. Flow regime, discharge, and distance from the dam influence drift of macroinvertebrates in the Colorado River (Shannon et al. 1996; Stevens et al. 1998; Sublette et al. 1998; Kennedy et al. 2014). In general, a positive correlation exists between invertebrate drift concentrations and flow magnitude; however, reduced flow can increase stream drift through behavioral factors such as crowding and avoidance of desiccation (Blinn et al. 1995; Kennedy et al. 2014). The density of invertebrates on the river bottom is also an important control of invertebrate drift concentrations (Kennedy et al. 2014). Tributary and terrestrial insects compose a small portion of the stream drift in the Colorado River corridor (Shannon et al. 1996). It is possible that terrestrial invertebrate drift is high during and immediately after rainstorms and is therefore a rare but locally important resource for mainstem Colorado River fishes (Shannon et al. 1996).

Table F-7 (Appendix F) summarizes information on the distribution, importance to higher trophic levels, and temperature range for common macroinvertebrates that occur downstream of Glen Canyon Dam.

Tribal Perspectives on Aquatic Food Base

The Zuni believe that macroinvertebrates are underwater species that are not yet ready for this world, and any disturbance to them could have negative consequences. The river's life begins at the headwaters. The river is the umbilical cord to the earth, and through the Zuni

religion, prayers, and songs there is also an invisible cord to the Zuni. This statement about underwater species relates to the Zuni history, as Zunis believe that their most ancient ancestors emerged onto this world only when they were ready for emergence. To force an aquatic species to change is to impede the species' natural development and future progress, a violation of Zuni beliefs about the world's natural order.

3.5.1.4 Nonnative Invasive Species

Some nonnative species have been introduced to supplement the aquatic food base. Because of the low benthic food base noted in the late 1960s, Arizona Game and Fish Department (AZGFD) biologists introduced macroinvertebrates into the Glen Canyon reach, including crayfish, snails, damselflies, caddisflies, crane flies, midges, true bugs, beetles, and leeches (McKinney and Persons 1999). These introductions were not monitored for a sufficient length of time to determine their success; however, most of these taxa did not persist in the river (Carothers and Minckley 1981; Blinn et al. 1992). *Gammarus lacustris* was also introduced into the Glen Canyon reach in 1968 to provide food for native and nonnative fishes (Ayers et al. 1998). *Gammarus* and midges have become important components of the aquatic food base.

Other nonnative invasive species that have potentially detrimental effects on both the food base and fish communities have become established in the Colorado River below Glen Canyon Dam. New Zealand mudsnail was first detected in Glen Canyon in 1995. By 1997, densities on cobble/gravel substrates reached about 3,390/ft^2. Densities averaged 5,567/ft^2 between 1997 and 2006, except for 2000, when densities averaged 20,540/ft^2. High densities that year coincided with experimental steady flows. Although the New Zealand mudsnail can withstand short periods of desiccation, its density is generally higher in systems with constant flows (see Section F.2.1.3 of Appendix F). The New Zealand mudsnail has dispersed downstream through Grand Canyon and was documented in Lake Mead in 2009 (Sorensen 2010). The mudsnail accounted for 20 to 100% of the macroinvertebrate biomass at six cobble bars studied in the Colorado River. The snails probably consume the majority of the available epiphytic diatom assemblage. The New Zealand mudsnail is a trophic dead-end and may adversely affect the food base in the Colorado River (Shannon, Benenati, et al. 2003). Epiphytic diatom biomass estimates at Lees Ferry were an order of magnitude lower in 2002 compared to 1992 (before New Zealand mudsnails were present) (Benenati et al. 1998; Shannon, Benenati et al. 2003). However, the biomass of other dominant aquatic food base taxa has been variable and not apparently influenced by the presence of the snails (Cross et al. 2010). However, at high population levels (e.g., ≥9,300 individuals/ft^2), New Zealand mudsnails can substantially modify lower trophic levels (Hall et al. 2006).

The New Zealand mudsnail can directly affect native species by consuming a large proportion of the primary production (especially periphyton), competing with native snails and other grazing invertebrates, and negatively impacting both invertebrates and vertebrates at higher trophic levels in aquatic food webs that depend on the aquatic invertebrate food base (Riley et al. 2008; Hall et al. 2003, 2006; Vinson and Baker 2008). At high densities, the New Zealand mudsnail may compete with other macroinvertebrates for food (e.g., diatoms) or

space (Kerans et al. 2005). Hall et al. (2006) suggest that the New Zealand mudsnail is sequestering a large fraction of the carbon available for invertebrate production and altering food web function.

The New Zealand mudsnail has a good chance of being transported by either biological or physical vectors because of its small size and locally high population density (Haynes and Taylor 1984). Recreational fishing and fish stocking have been implicated in the spread and introduction of the New Zealand mudsnail (Moffitt and James 2012). The New Zealand mudsnail can also be carried by waterfowl from one system to another and by fish within a system (Haynes et al. 1985).

Vinson and Baker (2008) evaluated the ability of rainbow trout to assimilate New Zealand mudsnails. They found that juvenile rainbow trout will readily ingest the snails but receive little nutritional value because the snails have an operculum that protects them from digestive agents. Also, trout lack pharyngeal teeth that would assist in grinding snail shells. Trout-fed mudsnails lost 0.14 to 0.48%/d of their initial body weight, while those fed amphipods gained 0.64 to 1.34%/d of their initial body weight. Only 15% of New Zealand mudsnails were assumed to have been digested, 32% were dead but present in their shells and assumed to be undigested, and 53% were alive. The results confirm that North American trout fisheries face potential negative impacts from the New Zealand mudsnail invasion (Vinson and Baker 2008). Although the New Zealand mudsnail occurs throughout the river from the Glen Canyon Dam to Lake Mead, its densities tend to be much higher in the upper reaches of the river (Cross et al. 2013). For example, in the Glen Canyon reach, densities of mudsnails were an order of magnitude higher than downstream in Grand Canyon (Cross et al. 2013).

A few nonnative invasive invertebrates are fish parasites that use food base organisms as an intermediate host. For example, the internal parasite *Myxobolus cerebralis*, which causes whirling disease in salmonids, uses the oligochaete worm *Tubifex tubifex* as an intermediate host (see Section 3.5.3.1 for additional information on whirling disease). The parasitic trout nematode (*Truttaedacnitis truttae*) is present in rainbow trout in the Glen Canyon reach. The ecological impact of the infestation is poorly known, but may influence food consumption, impair growth, and reduce reproductive potential and survival of rainbow trout. The nematode may require an intermediate host such as a copepod or other zooplankton taxa (McKinney, Robinson, et al. 2001).

The Asian tapeworm (*Bothriocephalus acheilognathi*) was first introduced into the United States with imported grass carp (*Ctenopharyngodon idella*) and was discovered in the Little Colorado River by 1990. It now parasitizes the humpback chub population from the Colorado and Little Colorado Rivers. The tapeworm could infect all species of native and nonnative fish species in the Little Colorado River (USGS 2004). Cyclopoid copepods are intermediate hosts for the tapeworm; however, fish that prey upon small infected fish can acquire tapeworm infections as well. Thus, large humpback chub that normally consume little zooplankton can become infected by preying upon smaller infected fish (USGS 2004).

Asian tapeworms were recovered in all fish species sampled from the Little Colorado River but were rare in suckers, rainbow trout, and catfish (mean ≤0.08/fish). Their highest

abundance and prevalence were in humpback chub (mean 18.36/fish with 84% of fish infected). The abundance and prevalence of the tapeworm in nonnative cyprinids, such as the fathead minnow (*Pimephales promelas*—mean 0.84/fish, with 23% of fish infected), red shiner (*Notropis lutrensis*—mean 1.2/fish, with 63% of fish infected), and common carp (*Cyprinus carpio*—mean 3.5/fish, with 52% of fish infected), as well as the plains killifish (*Fundulus zebrinus*—mean 1.26/fish, with 15% of fish infected), implicates any of these species as being potential hosts that introduced the tapeworm into the Little Colorado River. It is also possible that bait bucket transfers into the upper reaches of the Little Colorado River or into the Colorado River may have been responsible for the introductions (Choudhury et al. 2004).

Increased body loads of the parasitic copepod known as anchor worm (*Lernaea cyprinacea*) and the Asian tapeworm cause poorer body condition in humpback chub from the Little Colorado River. For fishes collected from 1996 to 1999, prevalence of the anchor worm was found to be 23.9%, and the mean intensity was 1.73/fish in the Little Colorado River compared to 3.2% and 1.0/fish in the Colorado River. The prevalence of Asian tapeworm was 51.0% and 252/fish in the Little Colorado River, but only 15.8% and 12/fish in the Colorado River. Differences in parasite density and abundance between the Little Colorado River and Colorado River are caused by temperature differences. Temperatures in the Colorado River near the Little Colorado River do not reach those necessary for either parasite to complete its life cycle; thus, these parasites were probably contracted while the humpback chub was in the Little Colorado River (Hoffnagle et al. 2006). Table F-8 (Appendix F) presents the temperature requirements for the Asian tapeworm, anchor worm, and the trout nematode.

Table F-8 (Appendix F) summarizes information on the temperature requirements for the Asian tapeworm, anchor worm, and trout nematode. While not included in the table, whirling disease infection prevalence and severity in salmonids is greatest at 10 to 15°C (Steinbach Elwell et al. 2009).

There are concerns about the potential for other nonnative invasive species to become established in the future and further impact the condition of the aquatic food base. The quagga mussel (*Dreissena bugensis*) is one species of particular concern. It can alter food webs by filtering phytoplankton and suspended particulates (Benson et al. 2013). Although there was conflicting information as to the presence of quagga mussels in Lake Powell for a few years prior to 2012, a noticeable population had not yet developed in that year (NPS 2012c). However, as of 2014, thousands of adult quagga mussels have been observed within the reservoir on canyon walls, the Glen Canyon Dam, boats, and other underwater structures (Repanshek 2014). Quagga mussels established in Lake Powell may cause changes in dissolved nutrients, phytoplankton, and zooplankton within the reservoir, which would likely impact food web structure or trophic linkages below Glen Canyon Dam (Nalepa 2010). The quagga mussel was first detected in the Colorado River below Glen Canyon Dam in 2014 after it began to establish in Lake Powell.

As the population of quagga mussels develops in Lake Powell, the potential for mussel larvae to travel though Glen Canyon Dam increases. Those that survive could attach in low flow areas of the Colorado River, but it is not known if they could reach high numbers (NPS 2012c). The risk of the quagga becoming established within the Colorado River Ecosystem is low, except in the Glen Canyon reach, where lower suspended sediment and higher nutrient levels (compared

to downstream reaches) favor its establishment (Kennedy 2007). It is unlikely to establish at high densities within the river or its tributaries because of high suspended sediment, high ratios of suspended inorganic/organic material, and high water velocities, all of which interfere with the ability of the quagga mussel to effectively filter food. High concentrations of sand may cause abrasion and physically damage its feeding structures (Kennedy 2007). In addition, it only takes 5 days for water to travel from Glen Canyon Dam to Diamond Creek (Kennedy 2007), so few quagga mussel larvae exported from Lake Powell will be large enough (i.e., >0.2 mm) to colonize the mainstem before they reach Lake Mead, where there is already an established quagga population. Larval mortality in the rapids of Grand Canyon also is likely to be high (Kennedy 2007). Quagga mussels are being found in the river below the dam in relatively low numbers; one mussel has been reported from as far downstream as River Mile 209.

If the quagga mussel obtained moderate densities in Lees Ferry, estimates of filtration capacity indicate they are unlikely to substantially alter the quality (e.g., nutrient concentrations, suspended organic matter concentrations) of water within or exported from Lees Ferry (Kennedy 2007).

3.5.1.5 Food Web Dynamics

Primary production, specifically diatoms, forms the base of the aquatic food web in Glen Canyon. In contrast, a combination of primary production and terrestrial and tributary inputs of organic matter is the basis of the aquatic food web in Marble and Grand Canyons, but high-quality algal matter supports the food web to an extent that is disproportionate to its availability. Midges and blackflies principally fuel the production of native and nonnative fishes, and fish production throughout the river appears to be limited by the availability of high-quality prey, particularly midges and blackflies, and fish may exert top-down control on their prey (Carlisle et al. 2012).

The food web within Glen Canyon is rather simple. Complexity increases with distance from the dam (Figures G-2 and G-3 in Appendix G) (Cross et al. 2013). The New Zealand mudsnail and nonnative rainbow trout dominate the food web in the Glen Canyon reach of the Colorado River. The simple structure of this food web has a few dominant energy pathways (diatoms to a few invertebrate taxa to rainbow trout) and large energy inefficiencies (i.e., <20% of invertebrate production consumed by fishes). Epiphytic diatoms, *Gammarus*, midges, and blackflies provide the primary food base for rainbow trout (Cross et al. 2013).

Below large tributaries, invertebrate production declines about 18 fold, while fish production remains similar to upstream sites. However, sites below large tributaries have increasingly diverse and detritus-based food webs. Midges and blackflies are the dominant invertebrates consumed in downstream reaches (Cross et al. 2013). Fish populations are food-limited throughout most of the mainstem, and tend to consume all of the available invertebrate production in downstream reaches (Cross et al. 2013).

3.5.2 Native Fish

Human activities have greatly affected the fish fauna of the Colorado River between Glen Canyon Dam and Lake Mead. Warmwater nonnative fish were introduced as early as the late 1880s (Carothers and Brown 1991). Overall, the Colorado River Basin once contained a unique assemblage of 35 native fish species, 74% of which were endemic (Minckley 1991). Relatively little information is available regarding the fish community prior to the construction of Glen Canyon Dam. Limited sampling in Glen Canyon before dam construction (conducted from 1957 to 1959) reported only two species from the mainstem proper: the nonnative channel catfish (*Ictalurus punctatus*; about 90% of the captures) and the native flannelmouth sucker (*Catostomus latipinnis*; about 10% of the catch) (Woodbury et al. 1959; McDonald and Dotson 1960). In contrast, mainstem backwaters and tributaries of the Colorado River within the Glen Canyon reach had a more diverse fish community, with 14 nonnative and 6 native species, dominated by the native flannelmouth sucker and speckled dace (*Rhinichthys osculus*).

Prior to Glen Canyon Dam closure in 1963, the river carried high sediment loads and, depending on season, flows and water temperatures varied widely (see Section 3.3.3). Construction and closure of Glen Canyon Dam permanently altered the river downstream, creating a relatively clear river with nearly constant year-round cold temperatures (<12°C [54°F]) and daily fluctuating but seasonally modulated flows based on tributary inflows and water storage and electrical generation needs (Reclamation 1995; NPS 2013e). As a consequence, the cold water temperatures in many miles of the main channel are below those needed for spawning, egg incubation, and growth of most native fish (Figure 3.5-1), and successful reproduction has been largely supported in tributaries (Reclamation 1995). In recent years, however, there has been some newly documented reproduction of native fish in portions of the lower Grand Canyon; adult and larval razorback suckers have been captured there (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012; Albrecht et al. 2014; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Razorback suckers have also been recently observed in the San Juan River arm of Lake Powell (Francis et al. 2015). Colorado River tributaries continue to exhibit natural flow and temperature regimes conducive to native fish spawning and rearing. Most native fish in the mainstem from the dam to the Little Colorado River are large juveniles and adults, while earlier life stages rely extensively on more protected and warmer near-shore habitats, primarily backwaters (Johnstone and Lauretta 2007; Ackerman 2008). The habitats and reproduction of native species in the system are discussed in more detail in later sections.

In addition to the effects of the altered mainstem physical environment on the reproduction, growth, survival, and distribution of native fishes in the Colorado River below Glen Canyon Dam, past introductions of nonnative fish species, both intentional and accidental, have affected native fish in the Colorado River and its tributaries downstream of Glen Canyon Dam. Coldwater and/or warmwater nonnative fish exist in all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam (see Section 3.4.4). These species can dominate the fish community in some areas and may threaten native species survival. Nevertheless, habitats in the Colorado River and its tributaries in GCNP support the largest remaining endangered humpback chub population, and this population has been growing since the late 1990s (Coggins and Walters 2009) and is now estimated at approximately 11,000 adults (Yackulic et al. 2014). Over

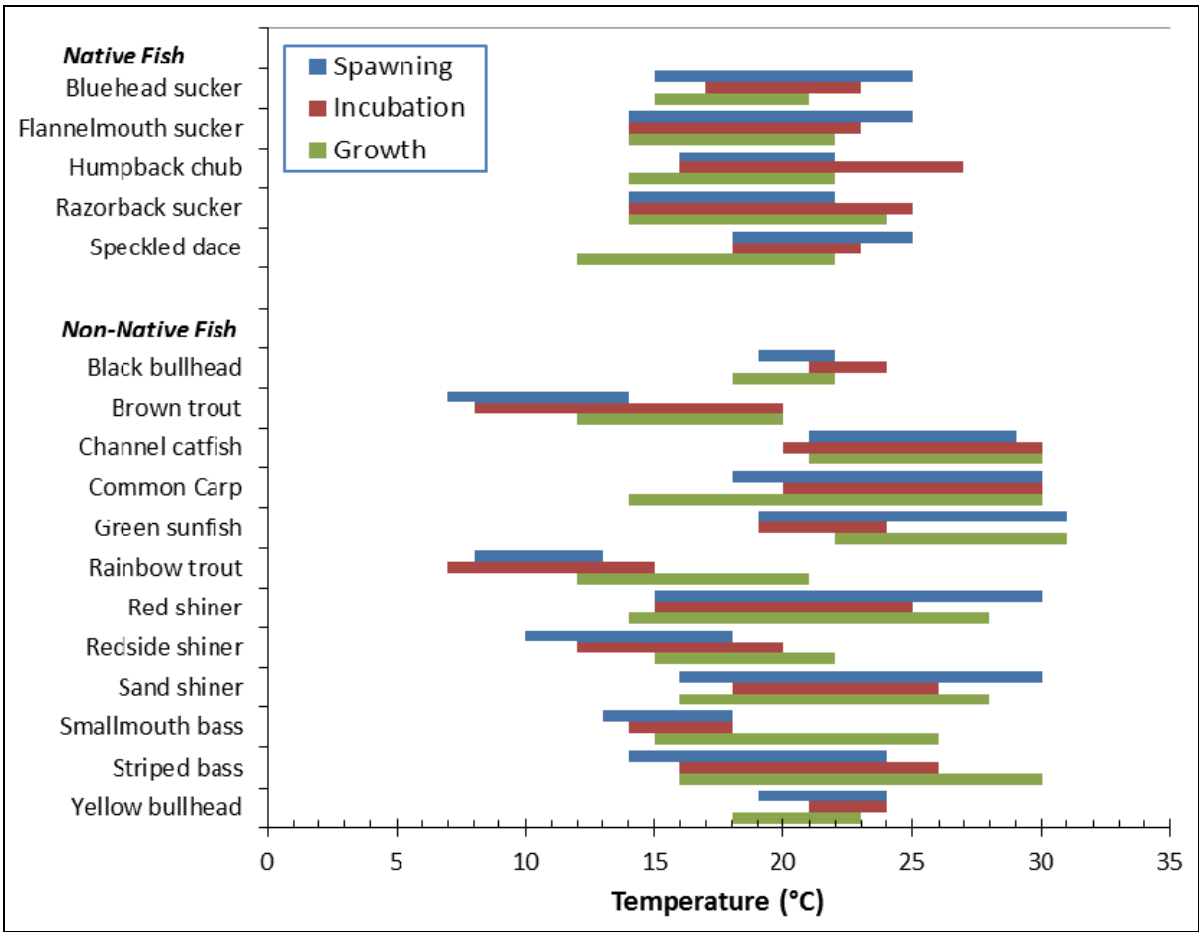

FIGURE 3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam (Source: Valdez and Speas 2007)

this same time period, the Grand Canyon fish community has also shifted toward a more dominant native species component (Lauretta and Serrato 2006; Johnstone and Lauretta 2007; Ackerman 2008; Makinster et al. 2010). It is hypothesized that the recent shift from nonnative to native fish is due in part to warmer than average water temperatures and the decline of coldwater salmonids (Ackerman 2008; Andersen 2009; Reclamation 2011c; Yackulic et al. 2014).

There are 11 species of native fishes that occur, may occur, or historically have occurred within the study area (Table 3.5-1). Among these native species, five species—the humpback chub, razorback sucker (*Xyrauchen texanus*), bluehead sucker (*Catostomus discobolus*), flannelmouth sucker, and speckled dace—occur within the mainstem and its tributaries. Three other species—the Zuni bluehead sucker (*Catostomus discobolus yarrowi*), Little Colorado sucker (*Catostomus latipinnis* sp. 3), and Little Colorado spinedace (*Lepidomeda vittata*)—are endemic to the upper reaches of the Little Colorado River. The remaining three species—the bonytail chub (*G. elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*)—have been extirpated from the mainstem between Glen Canyon Dam

TABLE 3.5-1 Native Fish of the Colorado River through Glen and Grand Canyons

Species	Listing Status[a]	Presence in Project Area[b]
Humpback chub (*Gila cypha*)	ESA-E, CH; AZ-SGCN	Lake Powell, Paria River confluence to Separation Canyon, Little Colorado River, Havasu Creek
Bonytail chub (*Gila elegans*)	ESA-E, CH; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon
Razorback sucker (*Xyrauchen texanus*)	ESA-E, CH; AZ-SGCN	Lake Powell; Lake Mead upstream to Lava Falls
Colorado pikeminnow (*Ptychocheilus lucius)*	ESA-E; AZ-SGCN	Lake Powell; extirpated from the Grand Canyon.
Bluehead sucker (*Catostomus discobolus*)	AZ-SGCN	Paria River to Lake Mead, including tributaries
Flannelmouth sucker (*Catostomus latipinnis*)	NL	Lake Powell to Lake Mead
Speckled dace (*Rhinichthys osculus*)	NL	Glen Canyon Dam to Lake Mead, including tributaries

[a] ESA = Endangered Species Act; E = listed as endangered; CH = federally designated critical habitat in project area; AZ-SGCN = Arizona Species of Greatest Conservation Need; NL = not listed.

[b] Habitat and life history information is presented in species-specific discussions in this section.

Sources: 56 FR 54957; AZGFD (2001a,b; 2002a,b; 2003a); Andersen (2009); Bezzerides and Bestgen (2002); Coggins and Walters (2009); Francis et al. (2015); Makinster et al. (2010); Ptacek et al. (2005); Rees et al. (2005); Rinne and Magana (2002); FWS (2002a); Ward and Persons (2006); Woodbury et al. (1959); Gloss and Coggins (2005); GCMRC (2014); Albrecht et al. (2014).

and Hoover Dam. The extirpated species and those found only in the upper reaches of the Little Colorado River are considered outside the affected area considered in this EIS. Currently, five species of native fish are known to exist in the Colorado River between Glen Canyon Dam and Lake Mead; these are discussed in detail in the following sections.

3.5.2.1 Special Status Fish Species

Two species of native fish that are listed under the Endangered Species Act of 1973 (ESA) (16 USC 1531, as amended)—the humpback chub and the razorback sucker—occur in the potentially affected portions of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead. These two species are also designated as Arizona Species of Greatest Conservation Need (AZ-SGCN). In addition, two other native fish, the flannelmouth

sucker and bluehead sucker, are included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a).

Humpback Chub

The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family may attain a length of 20 in., weigh 2 lb or more, and live as long as 40 years (Andersen 2009).

Distribution and Abundance. The humpback chub was federally listed as endangered in 1967. Historically, this species occurred throughout much of the Colorado River and its larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming (AZGFD 2001a). Currently, the humpback chub is restricted to six population centers, five in the upper Colorado River basin and one in the lower basin (FWS 2011a). The upper basin populations occur in (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River in Desolation and Gray Canyons, Utah; and (5) the Yampa River in Yampa Canyon, Colorado. The only population in the lower basin occurs in the Colorado River in Marble Canyon, the Grand Canyon, and Little Colorado River (FWS 2011a).

The Colorado River/Little Colorado River population is the largest of the six population centers of the humpback chub. Within the Grand Canyon, this species is most abundant in the vicinity of the confluence of the Colorado River and Little Colorado River (Paukert et al. 2006). In addition, eight other areas (aggregation areas) where humpback chub are, or have been, regularly collected have been identified; these aggregation areas are located at 30-Mile, Lava Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 3.5-2; Valdez and Ryel 1995). In addition, since 2009, translocations of humpback chub have been made by the U.S. Fish and Wildlife Service (FWS) to introduce juvenile fish upstream of Chute Falls in the Little Colorado River, and by NPS to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of establishing additional spawning populations within the Grand Canyon (NPS 2012b, 2013g). Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have successfuly spawned in Havasu Creek (NPS 2013g). Sampling conducted between October 2013 and September 2014 in the western Grand Canyon between Lava Falls (RM 180) and Pearce Ferry (RM 280) collected 144 juvenile humpback chub during sampling of the small-bodied fish community, and 209 larval and juvenile humpback chub during sampling of the larval fish community (Albrecht et al. 2014). These results suggest that young humpback chub are using nursery and rearing habitats between RM 180 and RM 280 in the western Grand Canyon that are not clearly associated with any of the aggregation areas identified above.

Monitoring data show that from 1989 through 2001, there was a steady decline of adult humpback chub within the Little Colorado River aggregation in the Grand Canyon; estimated numbers declined from approximately 11,000 adults (age 4+) in 1989 to about 5,000 adults in 2001 (Coggins et al. 2006; Coggins and Walters 2009) (Figure 3.5-3). However, since about 2001, the downward population trend reversed, with the estimated number of adult fish

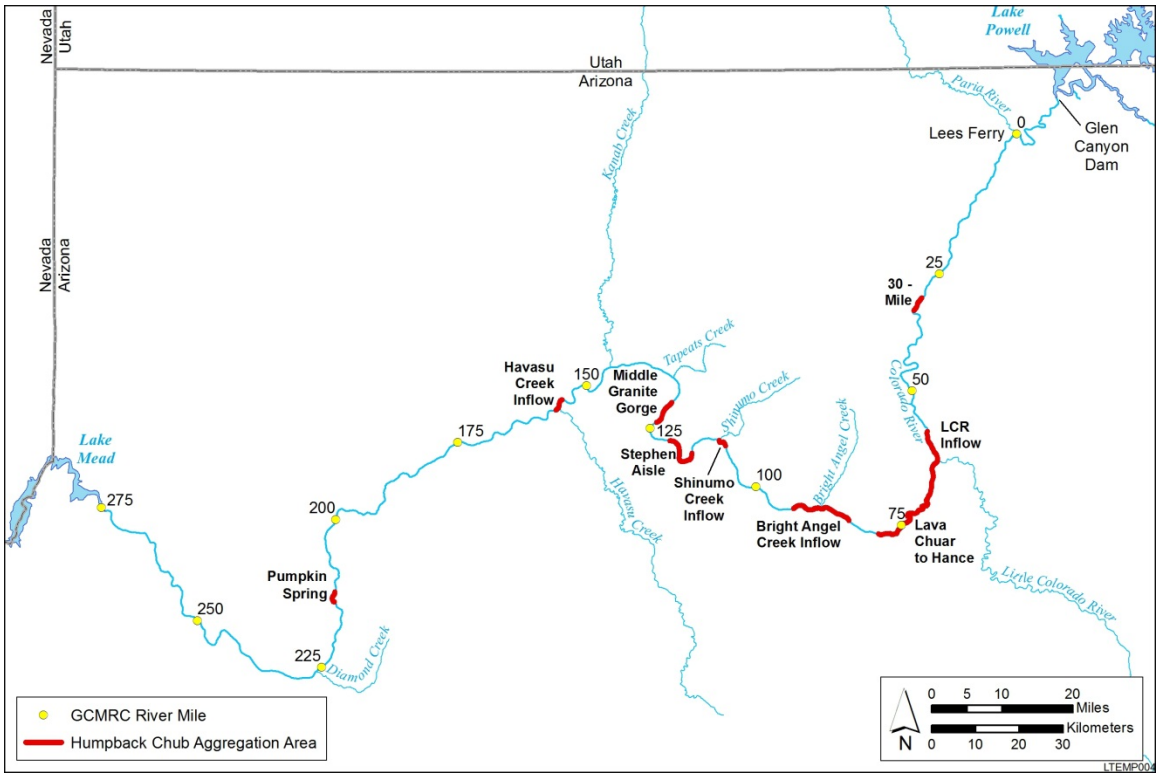

FIGURE 3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead (Sources: VanderKooi 2011; NPS 2013b)

increasing to approximately 8,000 fish by 2008 (Figure 3.5-3) (Coggins and Walters 2009). More recently, abundance estimates for 2009 to 2012 suggest the population has continued to increase to approximately 11,000 adults (Figure 3.5-4) (Yackulic et al. 2014). Factors suggested as being responsible for this estimated increase are discussed later in this section. In addition, recent preliminary population estimates for humpback chub aggregations suggest that humpback chub in several aggregations may have increased as a result of (1) translocations to Shinumo and Havasu Creeks; (2) good production in the Little Colorado River; (3) water temperatures that were about 1°C (1.8°F) warmer since the early 2000s (including significantly warmer than normal water temperatures in 2004, 2005, and 2011); and (4) declines in trout abundance at the Little Colorado River inflow due to implementation of trout control measures, a system-wide decline in trout abundance, or both (NPS 2013e; Yackulic et al. 2014).

Habitat. Throughout the humpback chub's current range, adults are found in turbulent, high-gradient canyon-bound reaches of large rivers (AZGFD 2001a) as well as in deep pools separated by turbulent rapids. Within the Grand Canyon, the humpback chub occurs primarily in the vicinity of the Little Colorado River (RM 30-110; Figure 3.5-2), with adults being associated with large eddy complexes. Converse et al. (1998) found that densities of subadult humpback chub in the mainstem Colorado River downstream of the Little Colorado River were greater along shoreline areas with vegetation, talus, and debris fans than in areas with bedrock, cobble,

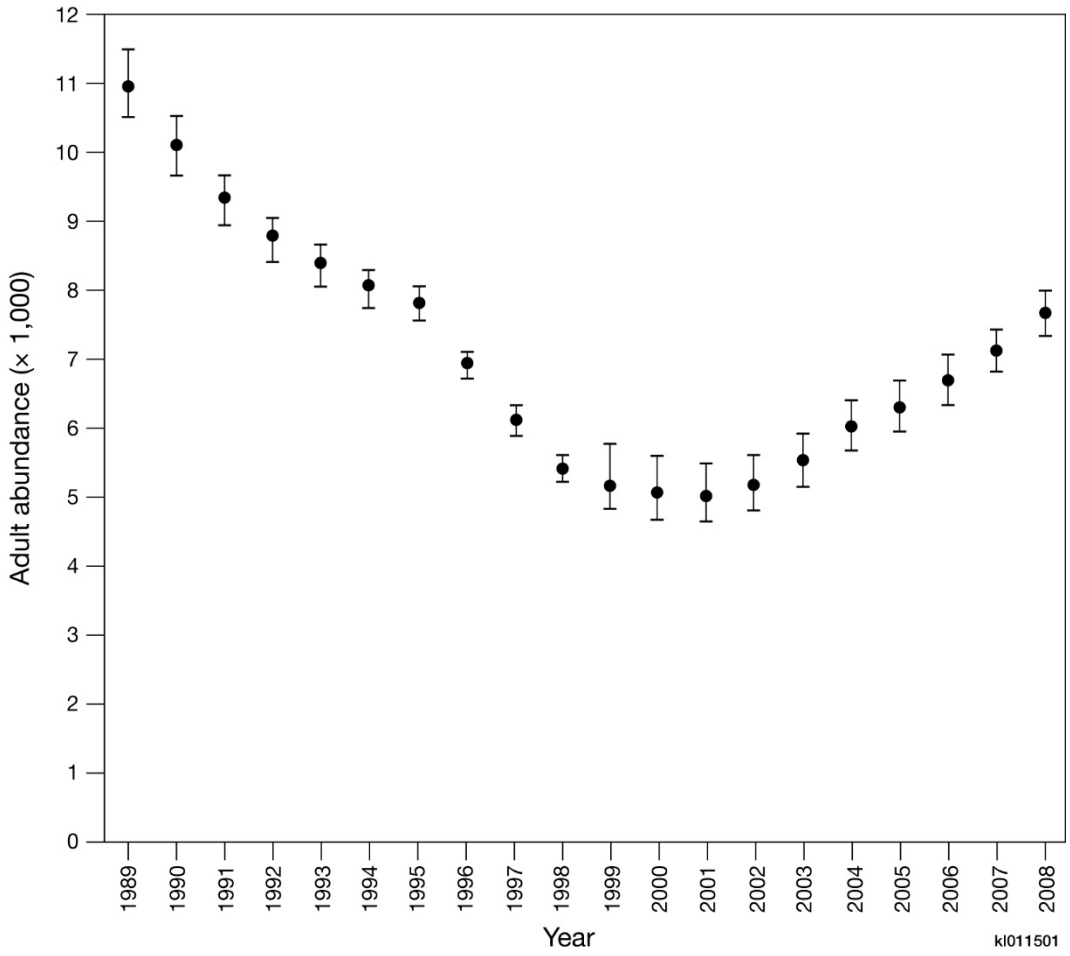

FIGURE 3.5-3 Estimated Adult Humpback Chub Abundance (Age 4+) from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age (Error bars represent minimum 95% confidence intervals and do not consider uncertainty in growth or mortality.) (Source: Coggins and Walters 2009)

and sand substrates. One recent mark-recapture study reported that approximately 87% of recaptured fish were collected in the same mainstem river reach or tributary where they were originally tagged, with 99% of all recaptures occurring in and around the Little Colorado River (Paukert et al. 2006). However, some of the marked fish were determined to have moved as much as 96 mi throughout the Grand Canyon. In the Little Colorado River, adults inhabit a variety of habitats, including pools and areas below travertine dams (AZGFD 2001a). More recently, a study conducted in 2010 examined the movement of 30 radio-tagged adult humpback chub in the Colorado River during 2 months of fluctuating flow followed by 2 months of steady flow (Gerig et al. 2014). The radio-tagged fish were found to use eddies extensively while avoiding runs. During both flow treatments, the tagged fish exhibited only small daily movements of about 33 ft/day, and no effect of flow was observed on either habitat selection or movement.

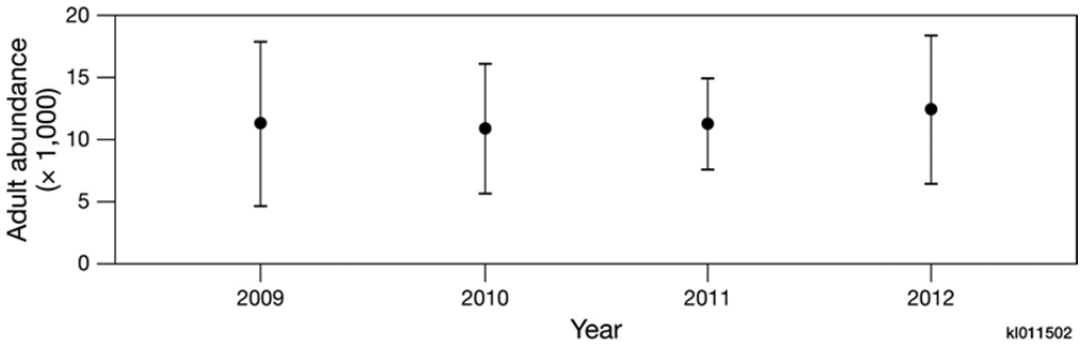

FIGURE 3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 (Error bars represent the 95% confidence intervals.) (Source: Yackulic et al. 2014)

The main spawning area for the humpback chub within the Grand Canyon is the Little Colorado River, which provides warm temperatures suitable for spawning and shallow low-velocity pools for larvae (Gorman 1994). Many of the larval fish remain in the Little Colorado River for one or more years, and growth rates and survival are relatively high compared to estimates for the colder waters of the mainstem Colorado River (Dzul et al. 2014). Spring abundance estimates for age-1 humpback chub within the Little Colorado River from 2009 to 2012 ranged from approximately 1,000 to more than 9,000 individuals (Dzul et al. 2014). Within the Little Colorado River, young humpback chub prefer shallow, low-velocity near-shore pools and backwaters; they move to deeper and faster areas with increasing size and age (AZGFD 2001a). In the mainstem of the Colorado River, young-of-the-year (YOY) fish may be found in backwater and other near-shore, slow-velocity areas that serve as nursery habitats (Valdez and Ryel 1995; Robinson et al. 1998; AZGFD 2001a; Stone and Gorman 2006). Juvenile humpback chub (<3 years old) have been collected in all types of near-shore habitats by the Humpback Chub Near-shore Ecology Study, with the highest numbers collected from talus slopes (Dodrill et al. 2015).

These near-shore habitats may be beneficial to the humpback chub (and other native fishes) as they provide shallow, productive, warm refugia for juvenile and adult fish (Reclamation 1995; Hoffnagle 1996). Temperature differences between main channel and near-shore habitats can be pronounced in backwaters and other low-velocity areas. The extent of warming is variable and depends on the timing of the daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation (Korman et al. 2006). For example, summertime water temperatures in backwaters have been reported to be as high as 25°C (77°F) while main channel temperatures are near 10°C (50°F) (Maddux et al. 1987). The amount of warming that occurs in backwaters is affected by daily fluctuations, which drain and fill backwater habitats with cold main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During the low steady summer flow experiment conducted in 2000, temperatures in one backwater were as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the

day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer under steady flows than under fluctuating flows (Hoffnagle 1996; Trammell et al. 2002; Korman et al. 2006; Anderson and Wright 2007). In general, the levels of warming observed in nearshore areas and backwaters during the low summer steady flows in 2000 persisted only for short periods of time and were smaller than seasonal changes in water temperatures (Vernieu and Anderson 2013). Consequently, temperature effects on native fishes were probably small.

Although the use of thermal refugia such as backwaters has been documented in a variety of systems (e.g., Tyus and Haines 1991; Bodensteiner and Lewis 1992; Torgersen et al. 1999; Ebersole et al. 2001; Westhoff et al. 2014), the overall importance of backwater habitats in the Colorado River relative to humpback chub survival and recruitment is uncertain (Reclamation 2011c). While juvenile humpback chub have been reported to show positive selection for backwater habitats, the spatial extent of such habitats in the Colorado River is small compared to other nearshore habitats such as talus slopes (Dodrill et al. 2015). Dodrill et al. (2015) reported that the total abundance of juvenile humpback chub was much higher in talus than in backwater habitats, and that when relative densities were extrapolated using estimates of backwater prevalence after an HFE, the majority of juvenile humpback chub were still found outside of backwaters. This suggests that the role of HFEs in influencing native fish population trends in the Colorado River may be limited.

Life History. The humpback chub is primarily an insectivore, with larvae, juveniles, and adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily chironomids and simulids), Thysanoptera (thrips), Hymenoptera (ants, wasps, bees), and amphipods (such as *Gammarus lacustris*) (Kaeding and Zimmerman 1983; AZGFD 2001a; Cross et al. 2013). Feeding by all life stages may occur throughout the water column as well as at the water surface and on the river bottom.

The Grand Canyon humpback chub population reproduces primarily in the lower 8 mi of the Little Colorado River, although occasional spawning is suspected in other areas of the Colorado River as well (Valdez and Masslich 1999; Anderson et al. 2010; AZGFD 2001a). Adults move into the Little Colorado River from the Colorado River to spawn from March to May (Kaeding and Zimmerman 1983; Gorman and Stone 1999; FWS 2008). Relatively little spawning and juvenile rearing occur in the mainstem of the Colorado River, primarily because of the cold mainstem water temperatures (Andersen 2009). Mainstem spawning is suspected near 30-mile spring, or in other areas in the western Grand Canyon following the detection of larval humpback chub in recent years (Albrecht et al. 2014, Kegerries et al. 2015), although studies have not been completed to identify spawning areas or habitat in the Colorado River in the Grand Canyon. This species requires a minimum temperature of 16°C (61°F) to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C (45 to 54°F) because of water releases from Glen Canyon Dam (Andersen 2009). Drought-induced warming has resulted in mainstem water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and fall months. Although some increases in spawning may have played a role in the estimated increase in the humpback chub population in the system since that time, it is likely that the

increased temperatures resulted in higher survival of juveniles in the mainstem (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Following spawning, larvae have been reported to drift in the Little Colorado River from April through June, and many drift out into near-shore habitats of the Colorado River (FWS 2008). Robinson et al. (1998) estimated about 38,000 larval humpback chub drifted from the Little Colorado River into the mainstem in May and June 1993. Juveniles generally have lower monthly rates of movement than adults, with the exception of a high probability of juveniles being transported from the Little Colorado River to the Colorado River during high flows of the monsoon season, when numbers of juvenile humpback chub in the mainstem have been documented to increase by as much as 4,000 fish (Yackulic et al. 2014).

Although survival of larval and juvenile fish in the mainstem was once thought to be very rare because of seasonally constant, low water temperatures (Clarkson and Childs 2000), more recent information suggests that juveniles can successfully rear to adulthood in the Colorado River mainstem, at least under recent environmental conditions that include warmer water (Yackulic et al. 2014). Increasing water temperatures have been shown in the laboratory to increase hatching success, larval survival, larval and juvenile growth, and improve swimming ability and reduce predation vulnerability (Hamman 1982; Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) postulated that, with warmer water, growth and survival of juveniles in the mainstem will be greater and result in increased mainstem recruitment, and thus contribute to the overall adult population. Increased water temperatures may also affect predation of YOY humpback chub by rainbow and brown trout (*Salmo trutta*) (Ward 2011; Ward and Morton-Starner 2015; Yard et al. 2011). Ward and Morton-Starner (2015) conducted laboratory studies that indicated predation success of rainbow trout on YOY humpback chub decreased from approximately 95 to 79% as water temperature increased from 10°C to 20°C (50°F to 68°F); predation success by brown trout was about 98% and did not change significantly over the same temperature range. Yard et al. (2011) examined the effects of temperature on trout piscivory in the Colorado River and reported no relationship between water temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation was found between water temperature and the incidence of piscivory for the brown trout.

Factors Affecting Distribution and Abundance in the Grand Canyon. These factors include habitat alterations associated with dams and reservoirs and the introduction of nonnative fishes, which act as competitors and/or predators of the humpback chub (see Section 3.5.3.3) (AZGFD 2001a; Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). The abundance and distribution of nonnative fishes are discussed in Section 3.5.3. In addition, the Colorado River now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may infect some humpback chub and affect survival (Clarkson et al. 1997; Andersen 2009). While coldwater releases from Glen Canyon Dam have limited reproduction and recruitment of humpback chub (and other native fishes) in the mainstem Colorado River, warmer water temperatures in the mainstem over the last decade have been sufficiently high to allow for modest growth, survival, and recruitment of humpback chub, contributing to the improving status of this species in the Grand Canyon (Reclamation 2011a; Yackulic et al. 2014).

Population estimates indicate that the number of adult humpback chub in the Grand Canyon increased from about 2001 to 2008 (Figures 3.5-3) and has been stable in recent years (Figure 3.5-4). A number of factors have been suggested as being responsible for the observed increases, including experimental water releases, trout removal, declines in trout abundance due to low DO levels during 2006, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). Some experimental releases, such as the November HFE in 2004, may have adversely affected rainbow trout and improved humpback chub habitat along the main channel (Korman et al. 2010). However, the March 2008 HFE may have improved rainbow trout spawning habitat quality and age-0 survival rates (Korman et al. 2011) in the Glen Canyon reach. Following this, the abundance of rainbow trout (using catch-per-unit-effort as a surrogate for abundance) in this reach was reported to be about 300% larger in 2009 than in 2007 (about 3.9 fish per minute vs. 1.3 fish per minute, respectively) (Makinster et al. 2011), and a similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little Colorado River confluence (RM 56–69) (Kennedy and Ralston 2011). The effects of HFEs on trout abundance are discussed in more detail in Section 3.5.3.4.

Predation by rainbow and brown trout at the Little Colorado River confluence has been identified as an additional mortality source affecting humpback chub survival, reproduction, and recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). Predation by channel catfish and black bullhead (*Ictalurus melas*) are also thought to threaten humpback chub in the Grand Canyon, particularly if warmer water conditions occur (NPS 2013e). Because of their size, adult humpback chub are less likely to be preyed on by trout; however, emergent fry, YOY, and juvenile humpback chub are susceptible to predation in the mainstem Colorado River in the vicinity of the Little Colorado River (Yard et al. 2011).

Experimental removal of nonnative brown and rainbow trout was conducted in the Colorado River in the Grand Canyon between 2003 and 2006 (see Section 3.5.3.4). Twenty-three trips to remove trout from the vicinity of the confluence of the Little Colorado River (RM 56–RM 66) resulted in the removal of more than 23,000 nonnative fish (mostly rainbow trout). During this time, the rainbow trout population in the Colorado River in the vicinity of the Little Colorado River was decreased by more than 80% (Andersen 2009). Although the estimated humpback chub abundance increased during this time (Figure 3.5-3), the relationship between trout removal at the Little Colorado River, decreases in trout abundance, and increases in humpback chub abundance are not clear; trout abundance declined throughout the mainstem Colorado River downstream of Glen Canyon Dam during the same general time frame (Coggins et al. 2011). Increased numbers of humpback chub may also be attributable to a variety of other factors, including warmer water temperatures that occurred during this time, the HFE experimental flows, or a general decrease in rainbow trout abundance throughout the Grand Canyon ecosystem (Andersen 2009; Coggins et al. 2011; also see Section 3.5.3.4).

To aid in the mechanical trout removal effort, an experimental nonnative fish suppression flow regime from Glen Canyon Dam was implemented between January and March in 2003, 2004, and 2005 (Reclamation 2011c). These flows were intended to reduce rainbow trout abundance in the Glen Canyon reach by increasing mortality of incubating life stages. While the experimental flows were successful in reducing hatching and survival of young trout, density-dependent factors compensated with higher survival and growth of the remaining fish

(Korman et al. 2005), and thus the flows were not effective in limiting trout recruitment. However, those flows differ from the trout management flows being proposed under many alternatives in this EIS. See Section 3.5.3.4 for more detailed discussions on both the nonnative fish suppression flows and mechanical trout removal.

As previously discussed, the cold water temperatures in the main channel are below the temperature needed for spawning, egg incubation, and growth of the humpback chub (as well as for most native fish) (Figure 3.5-1). Survival of humpback chub young in the mainstem is thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval and juvenile growth (Coggins and Pine 2010), reduce swimming ability, and increase predation vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstem Colorado River have generally been elevated over the last decade (Figure 3.5-5). These temperatures are not optimal for humpback chub spawning and growth. However, juveniles can now successfully rear to adulthood in the Colorado River mainstem, and mainstem recruitment is likely contributing to the overall adult population that now appears to be stable or increasing (Yackulic et al. 2014; Figure 3.5-4).

Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of drought conditions that lowered the level of Lake Powell and resulted in the release of warmer water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009, and 2011. In 2005, maximum mainstem water temperature exceeded 15°C (59°F) at Lees Ferry and approached 18°C (64°F) in the vicinity of the Little Colorado River (RM 61), the warmest temperature at those locations since the reservoir was filled in 1980 (Figure 3.5-5). Maximum water temperature in the mainstem at Lees Ferry reached about 14°C (57°F) in 2008 (USGS 2014b), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstem water temperatures at Lees Ferry and the Little Colorado River confluence (RM 61) reached about 15°C (59°F) and 16°C (61°F), respectively (Figure 3.5-5). This warmer water appears to have benefitted the humpback chub and other native fish, but they may also have benefitted nonnative warmwater species (e.g., channel catfish, striped bass) that are more abundant farther downstream in the Grand Canyon (Andersen 2009; Coggins and Walters 2009; Kennedy and Ralston 2011).

Tribal Perspectives on Humpback Chub. The Navajo people revere all creatures within the Grand Canyon and its tributaries as sacred and unique in maintaining the balance of the natural order and natural laws. But here it is important to note that the humpback chub is one of the utmost sacred beings that dwell within the Grand Canyon (more specifically the Little Colorado River). It is mentioned extensively within oral history when the Navajo Na adin Tahi of the waterway ceremony (voyager) took his journey through the canyon on a hallowed log with the turkey that ran alongside him. It is said that the voyager encountered many dangers and monsters that attempted to stop him in his journey. The humpback chub is a product of the one Teehooltsodii (Water Monster), as they are her children, and she negotiated with Haashch cheii

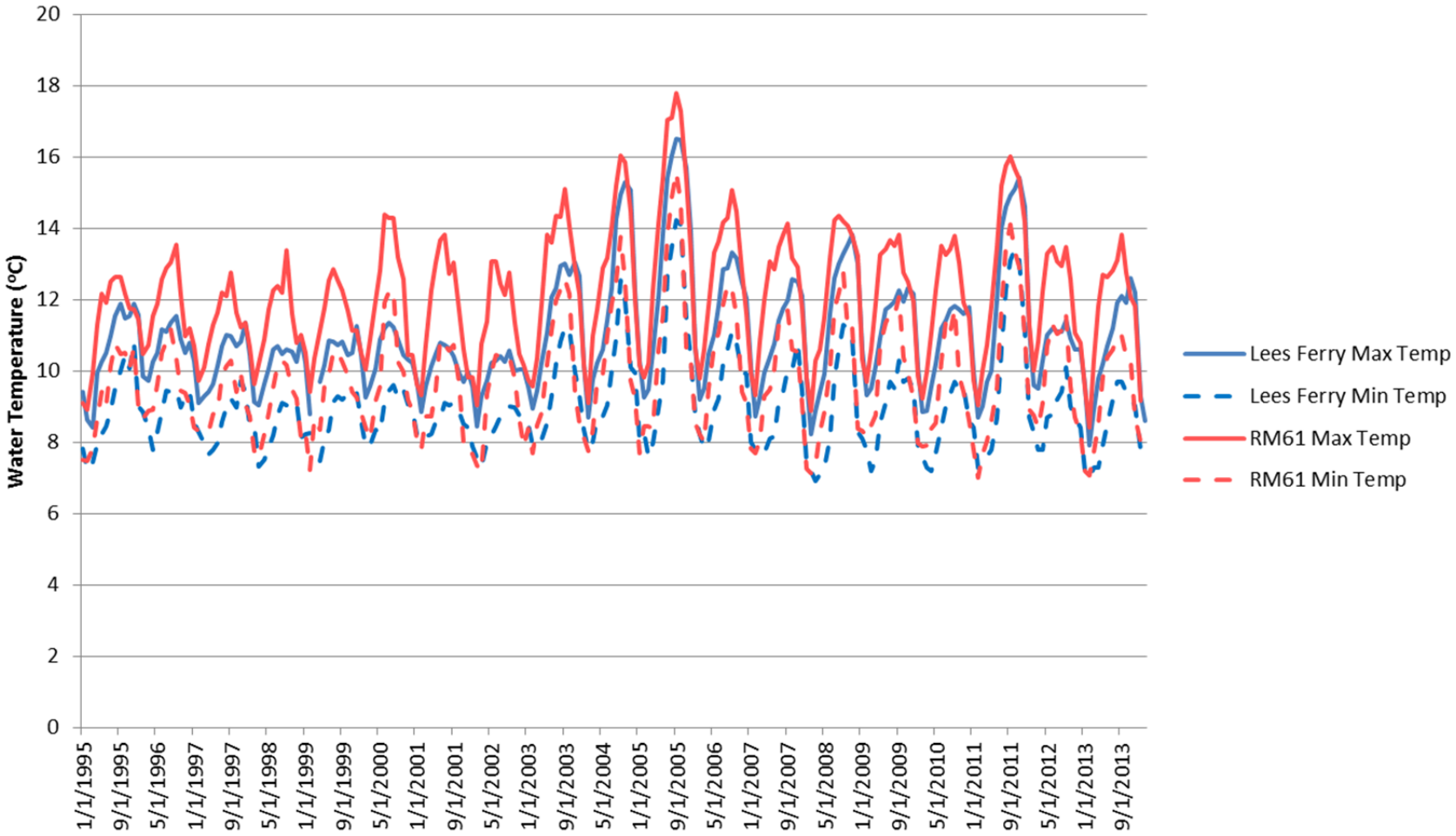

FIGURE 3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence (RM 61), 1995 to Present (Source: USGS 2014b)

yaal tii (Talking God) that they would be able to stay within the Little Colorado River or Little Colorado River Confluence after she was cast out for stealing Talking God's grandchild.

Razorback Sucker

The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado River system. It is a large fish, with adults reaching lengths up to 3 ft and weighing as much as 13 lb (FWS 2002a), and may live 40 years or more (AZGFD 2002a).

Distribution and Abundance. The razorback sucker was listed as endangered in 1991 (56 FR 54957). The species is endemic to large rivers of the Colorado River Basin from Wyoming to Mexico. Currently, it occurs in the Green River, upper Colorado River, and San Juan River subbasins; the lower Colorado River between Lake Havasu and Davis Dam; Lake Mead and Lake Mohave; and tributaries of the Gila River subbasin (FWS 2002a), and Lake Powell (Francis et al. 2015). The largest remaining wild-spawned population was in Lake Mohave (Marsh et al. 2003); however, the wild fish have died from old age and the population is being supported by rearing of wild-spawned larvae in hatcheries and release of those fish to the reservoir. Within the Grand Canyon, this species historically occurred in the Colorado River from Lake Mead into Maxson Canyon (RM 252.5), with several documented captures at the Little Colorado River inflow in 1989 and 1990, and from the Paria River mouth (in 1963 and 1978, as reported in NPS 2013e). The population in Lake Mead is believed to be self-sustaining, and in 2002 was estimated to consist of about 400 adults (FWS 2002a). More recently (2009–2011), the lakewide population in Lake Mead was estimated to range from 733 to 982 fish (Shattuck et al. 2011).

Until recently, the last razorback sucker collected from the Grand Canyon (RM 39.3) was caught in 1993, and the species was considered extirpated from the Grand Canyon. However, razorback suckers and flannelmouth-razorback sucker hybrids have recently been captured from the western Grand Canyon (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012; Rogowski and Wolters 2014; Rogowski, Wolters, et al. 2015). Four fish that were sonic-tagged in Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to Quartermaster Canyon (RM 260) (Kegerries and Albrecht 2012, as cited in NPS 2013e). An additional untagged adult razorback sucker was captured in GCNP near Spencer Creek (RM 246) in October 2012 (Bunch, Osterhoudt, et al. 2012), and another adult was collected in late 2013 (GCMRC 2014). Recent sampling of channel margin habitats has also documented razorback sucker larvae as far upstream as RM 179 (just upstream of Lava Falls), indicating that spawning is occurring in the mainstem river in the western Grand Canyon (Albrecht et al. 2014 [462 larvae]; Kegerries et al. 2015 [81 larvae]). Adult razorback suckers have also recently been located as far upstream as RM 184.4 near Lava Falls, and numerous adults have been documented in the western Grand Canyon, indicating that the species utilizes the Colorado River above the Lake Mead inflow area more than previously thought (Albrecht et al. 2014).

Habitat. The razorback sucker uses a variety of habitats, ranging from mainstream channels to slow backwaters of medium and large streams and rivers (AZGFD 2002a). In rivers, habitat requirements of adults in spring include deep runs, eddies, backwaters, and flooded off-channel areas; in summer, runs and pools, often in shallow water associated with submerged sandbars; and in winter, low-velocity runs, pools, and eddies (FWS 2002a). In reservoirs, adults prefer areas with water depths of 3 ft or more over sand, mud, or gravel substrates. Young require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). Recent captures of larval razorback sucker in the western Grand Canyon found the highest density of larvae in isolated pools, which composed less than 2% of all habitat sampled (Albrecht et al. 2014). Similar results were found in 2015, when the highest catch of larval razorback sucker was found in isolated pools, followed by backwaters, which composed 2.1% and 9.1% of habitats sampled, respectively (Kegerries et al. 2015). Critical habitat was designated for this species in 1994, and includes the Colorado River and its 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam (a distance of about 500 mi), including Lake Mead to full pool elevation (59 FR 13374).

Life History. Both adults and immature fish are omnivorous, feeding on algae, zooplankton, and aquatic insect larvae. In Lake Mohave, their diet has been reported to be dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987).

Razorback suckers exhibit relatively fast growth the first 5 to 7 years of life, after which growth slows and possibly stops (AZGFD 2002a). Both sexes are sexually mature by age 4. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and at water temperatures typically greater than 14°C (57°F) (FWS 2002a). In reservoirs, spawning occurs over rocky shoals and shorelines. Temperatures for spawning, egg incubation, and growth of this species range from 14 to 25°C (57 to 77°F) (Figure 3.5-1). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (50°F); optimum temperatures for adults are around 22–25°C (72–77°F) (AZGFD 2002a). Based on back-calculation from the dates of larval collection, Kegerries et al. (2015) estimated that the onset of spawning in the Grand Canyon was in mid-February when average daily water temperatures were between 10 and 12°C (50 and 54°F). Spawning appeared to peak toward the end of March when water temperatures ranged from 12–14°C (54–57°F), although the entire spawning period was estimated to range from mid-February to July (Kegerries et al. 2015).

Historically, this species exhibited upstream migrations in spring for spawning, although current populations include groups that are sedentary and others that move extensively (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much as 62 mi to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have been reported to move 12 to 19 mi between spring spawning and summer use areas (Mueller et al. 2000). Kegerries et al. (2015) reported that sonic-tagged razorback sucker either stayed near spawning areas or moved up to 361 km (224 mi) within the western Grand Canyon, the Colorado River inflow to Lake Mead, and throughout Lake Mead.

Factors Affecting Distribution and Abundance in the Grand Canyon. The decline of the razorback sucker throughout its range has been attributed primarily to habitat loss due to dam construction, loss of spawning and nursery habitats as a result of diking and dam operations, and alteration of flow hydrology (AZGFD 2002a). For example, the 80% reduction in the historical distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River (Valdez et al. 2012). In addition, competition with and predation by nonnative fishes have also been identified as important factors in the decline of this species (Minckley et al. 1991; FWS 2002a). In the Grand Canyon, the decline of native fish, including razorback sucker, has been attributed in large part to an increased diversity and abundance of nonnative fishes along with the effects of Glen Canyon Dam on water temperatures, flow, and sediment (Gloss and Coggins 2005).

As described above, recent efforts to better understand the use of the western Grand Canyon by razorback sucker has revealed that the species is more widespread there than previously thought, occupies and spawns in the river from at least Lava Falls to throughout Lake Mead, and maintains a reproducing population in the project area (Albrecht et al. 2014; Kegerries et al. 2015). Currently, there is little information on the habitat use and life history needs for the species in the Grand Canyon and Lake Mead. Additional research and monitoring are needed to better understand the management implications for recovery of razorback sucker in this reach of its range (Albrecht et al. 2014).

Bluehead Sucker

The bluehead sucker is a member of the Catostomidae family. Adults may reach 12 to 18 in. in total length in large rivers but may be smaller in smaller tributaries; they may live from 6 to 8 years to as many as 20 years (Sigler and Sigler 1987; Bezzerides and Bestgen 2002; AZGFD 2003a). This species has been reported to be as large as 20 in. long in the mainstem Colorado River in Grand Canyon, with tributary fish being smaller (AZGFD 2003a). A related subspecies, the Zuni bluehead sucker, occurs in the headwaters of the Little Colorado River along with bluehead suckers that are the same subspecies as those that occur in the mainstem Colorado River (AZGFD 2002b).

Distribution and Abundance. Bluehead sucker populations are declining throughout the species' historic range, and the species has been identified as an AZ-SGCN (AZGFD 2012). The bluehead sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). In the Colorado River Basin, this species is found in the Colorado River and its tributaries from Lake Mead upstream into Arizona, Colorado, New Mexico, Utah, and Wyoming. This species is also found in the Snake River (Idaho and Wyoming), the Bear River (Idaho and Utah), and Weber River (Utah and Wyoming) drainages (Bezzerides and Bestgen 2002; AZGFD 2003a).

Within the Grand Canyon, the bluehead sucker occurs in the Colorado River mainstem and its tributaries, including the Little Colorado River, Clear Creek, Bright Angel Creek, Kanab

Creek, and Havasu Creek (Rinne and Magana 2002; AZGFD 2003a; Ptacek et al. 2005; NPS 2013e), and prior to 2014, in Shinumo Creek (Healy et al. 2014). Annual fish monitoring conducted between 2000 and 2009 in the Colorado River between Glen Canyon Dam and the inflow to Lake Mead show the bluehead sucker to be present in all reaches of the river (Makinster et al. 2010). This species is very rare in the upper sections of GCNP and increases in number near the Little Colorado River inflow and downstream (Bunch, Makinster et al. 2012; Bunch, Osterhoudt et al. 2012).

Abundance estimates using monitoring data and Age-Structured Mark-Recapture (ASMR) models show the abundance of age-1 (juvenile) bluehead suckers in the Grand Canyon declined from 1990 to 1995, increased from 1995 to 2003, and then declined through 2009 (Walters et al. 2012). Similar estimates for age-4 (adult) fish show abundance began increasing from the late 1990s until 2005 or 2006, after which abundance also declined. The estimated abundance of age-1 bluehead sucker has ranged from 1,000 or less to as many as 60,000 fish between 2000 and 2009 (Walters et al. 2012). Estimated abundance of age-4+ adults during this same period ranged from about 5,000 to as many as 75,000 fish. Although the bluehead sucker was likely extirpated from Shinumo Creek following fires and flooding in 2014 (Healy et al. 2014), relatively high numbers of individuals remain in the lower Colorado River between Lava Falls Rapid (RM 179) and Lake Mead (Bunch, Makinster, et al. 2012; Bunch, Osterhoudt et al. 2012). Recent sampling of the larval fish community in the western Grand Canyon between Lava Falls and Pearce Ferry collected bluehead sucker larvae throughout the study area (Albrecht et al. 2014). In this study area, the bluehead sucker was the most abundant species in the larval fish community, composing almost 40% of the total catch.

Habitat. The bluehead sucker typically inhabits large streams and may also occur in smaller streams and creeks (Sigler and Sigler 1987; AZGFD 2003a). Riverine habitats may range from cold (12°C [54°F]), clear streams to warm (28°C [82°F]), very turbid rivers. Large adults live in deep water (6 to 10 ft), while juveniles use shallower, lower velocity habitats (Bezzerides and Bestgen 2002). In clear streams, the bluehead sucker stays in deep pools and eddies during the day and moves to shallower habitats (e.g., riffles, tributary mouths) to feed at night, while in turbid waters they may use shallow areas throughout the day (Beyers et al. 2001; AZGFD 2003a). In the Grand Canyon, larval and young bluehead suckers inhabit backwater areas and other near-shore low-velocity habitats such as eddies, embayments, and isolated pools (Childs et al. 1998; AZGFD 2003a; Albrecht et al. 2014).

Life History. The bluehead sucker is an omnivorous benthic forager. It feeds by scraping algae, invertebrates, and other organic and inorganic materials off rocks and other hard surfaces (Ptacek et al. 2005). Larvae drift to backwaters and other areas of low current where they feed on diatoms, zooplankton, and dipteran larvae.

In the lower Colorado River, this species spawns in spring and summer after water temperatures exceed 16°C (61°F). Spawning in Grand Canyon tributaries occurs mid-March through June in water depths ranging from a few inches to more than 3 ft and at temperatures of 16 to 20°C (61 to 68°F) over gravel-sand and gravel-cobble substrates (AZGFD 2003a;

NPS 2013e). In Kanab Creek, spawning has been reported to occur at temperatures of 18.2–24.6°C (64.8–76.3°F) (Maddux and Kepner 1988). Smaller tributaries may provide nursery grounds for populations of large adjacent rivers (Rinne and Magana 2002).

Factors Affecting Distribution and Abundance in the Grand Canyon. As with the humpback chub, decreases in distribution and abundance of the bluehead sucker throughout its range, as well as in portions of the Colorado River and its tributaries below Glen Canyon Dam, have been attributed to two main factors: (1) habitat degradation through loss, modification, and/or fragmentation and (2) interactions with nonnative species (Gloss and Coggins 2005; Ptacek et al. 2005). Disturbance related to fire and flooding may also influence bluehead sucker distribution in tributaries. The construction and operation of Glen Canyon Dam has altered downstream temperature and flow regimes. Cold tailwaters below dams are below temperatures needed for spawning and recruitment (Rinne and Magana 2002; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012).

The introduction of nonnative fish has increased competition with and predation on bluehead sucker (AZGFD 2003a; Ptacek et al. 2005). Large nonnative predators such as channel catfish and trout, mid-sized fish like sunfishes, and even smaller nonnative minnows may all prey on one or more life stages of the bluehead sucker (Rinne and Magana 2002; Ptacek et al. 2005; Yard et al. 2011).

3.5.2.2 Other Native Species

Two other native fish species occur in the affected area of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead—flannelmouth sucker and speckled dace (Table 3.5-1). Both speckled dace and flannelmouth sucker are identified as AZ-SGCN (AZGFD 2012). In addition, the flannelmouth sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006a). The flannelmouth sucker and speckled dace are discussed below.

Flannelmouth Sucker

The flannelmouth sucker is member of the sucker family (Catostomidae). It is a relatively large fish, with a maximum total length of greater than 2 ft and a maximum weight exceeding 3 lb (AZGFD 2001b; Rees et al. 2005). It is a long-lived species, living as long as 30 years (AZGFD 2001b).

Distribution and Abundance. Historically, the flannelmouth sucker ranged throughout the Colorado River Basin, in moderate to large rivers in Arizona, California, Colorado, Nevada,

New Mexico, Utah, and Wyoming (Bezzerides and Bestgen 2002; Rees et al. 2005). Within the Grand Canyon, this species may be found in the mainstem Colorado River and its tributaries including the Little Colorado and Paria Rivers and Shinumo, Bright Angel, Kanab, and Havasu Creeks (Douglas and Marsh 1998; Weiss 1993; AZGFD 2001b; Bezzerides and Bestgen 2002). In contrast to bluehead sucker, flannelmouth sucker are only found below the barrier falls in Shinumo and Havasu Creeks. Annual monitoring conducted between 2000 and 2009 found the flannelmouth sucker to be present in all reaches of the river between Lees Ferry and the inflow to Lake Mead (Makinster et al. 2010). Abundance, across all reaches and measured as catch-per-unit-effort, has been increasing since 2000, especially since about 2004 (Makinster et al. 2010). However, abundance has been decreasing within individual reaches between RM 0 and RM 179 since about 2005, but increasing downstream of RM 179. Recent surveys of the small-bodied and larval fish communities in the western Grand Canyon (Lava Falls to Pearce Ferry) found flannelmouth sucker to be present throughout the reach, accounting for over 38% of the total larval catch in this area (Albrecht et al. 2014).

Abundance estimates using monitoring data and ASMR models show an increase in the abundance of age-1 (juvenile) and age-4 (adult) flannelmouth suckers in the Grand Canyon between 2000 and 2008 (Walters et al. 2012). Abundance of age-1 flannelmouth sucker increased from about 2,500 in 2000 to about 10,000 in 2008, while abundance of age 4+ adults increased from about 10,000 to about 25,000 for this same period (Walters et al. 2012). Other abundance estimates based on electrofishing catch-per-unit-effort for this same time period showed an increase in abundance from less than 1,000 in 2000 to about 12,000 in 2009, while the estimated abundance of age-4+ adults increased from about 2,500 in 2001 to about 31,000 in 2009 (Walters et al. 2012).

Habitat. This species prefers large to moderately large rivers. Adults may prefer deep water when not feeding (Rinne and Minckley 1991), while larvae and young are often associated with shallow, slow-moving near-shore areas such as backwaters and shoreline areas of slow runs or pools (AZGFD 2001b; Rees et al. 2005). Although it is a riverine species, in the upper Colorado River Basin the flannelmouth sucker has been collected from Flaming Gorge and Fontenelle Reservoirs. In the Colorado River in the Grand Canyon, subadults are found in eddies and runs over sand bottoms. In the Little Colorado River, adult and juvenile flannelmouth suckers use low-velocity, near-shore habitats with large amounts of cover during the daylight, and their use of faster, more exposed mid-channel habitats increases at night (Gorman 1994). Juveniles and adults may be considered habitat generalists and can be found using pool, run, and eddy habitats. Recent surveys of larval flannelmouth sucker in the western Grand Canyon (Lava Falls to Pearce Ferry) found the highest abundance of larvae in embayments, isolated pools, backwaters, and other low-velocity habitats (Albrecht et al. 2014).

Life History. The flannelmouth sucker is an omnivorous benthic feeder, foraging on invertebrates, algae, plant seeds, and organic and inorganic debris (Bezzerides and Bestgen 2002; Rees et al. 2005; Seegert et al. 2014). Larvae feed primarily on aquatic invertebrates, crustaceans, and organic debris (Childs et al. 1998). As they become juveniles and adults, their

diet shifts and becomes primarily composed of benthic matter including organic debris, algae, and aquatic invertebrates (Rees et al. 2005; Seegert et al. 2014).

This species has been reported to prefer water temperatures ranging from 10 to 27°C (50 to 81°F), and is most common at about 26°C (79°F) (Sublette et al. 1990). Water temperatures reported during spawning activity range from 6 to 18.5°C (43 to 65°F), but are usually above 14°C (57.2°F) (Bezzerides and Bestgen 2002). In the lower Colorado River Basin, flannelmouth sucker spawning typically occurs in March and April (Bezzerides and Bestgen 2002). Water temperature has been suggested as a primary cue for spawning in other parts of this species range, but it does not appear to provide a spawning cue in the Grand Canyon where relatively synchronized spawning has been reported among sucker stocks from creeks with different temperature and flow regimes (Weiss 1993; Weiss et al. 1998). In the Paria River, the timing of spawning has been correlated with the receding limb of the hydrograph (Weiss 1993).

In the Grand Canyon, flannelmouth suckers apparently spawn at only a limited number of tributaries, and fish may move considerable distances to reach spawning sites (Douglas and Marsh 1998; Weiss et al. 1998; Douglas and Douglas 2000). Tributary spawning in the Grand Canyon may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstem Colorado River (Bezzerides and Bestgen 2002).

Body condition of flannelmouth sucker is variable throughout the Grand Canyon, but is greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased number of warmwater tributaries in this reach (Paukert and Rogers 2004). Mean condition peaks during the prespawn and spawning periods and is lowest in summer and fall (McKinney et al. 1999; Paukert and Rogers 2004). Sucker condition in September was positively correlated with Glen Canyon discharge during summer (June–August), possibly due to an increased euphotic zone and greater macroinvertebrate abundance observed during higher water flows (Paukert and Rogers 2004).

Factors Affecting Distribution and Abundance in the Grand Canyon. Flannelmouth sucker populations have declined throughout the species' historic range; in the lower Colorado River, this decline has been attributed primarily to flow manipulation and water development projects (Rees et al. 2005). Coldwater releases from Glen Canyon Dam have altered the thermal regime of the main channel of the Colorado River, which for larvae may result in slow growth, delayed transition to the juvenile stage, and possibly higher mortality (Rees et al. 2005).

In the cold tailwaters below Glen Canyon Dam, water temperatures (8 to 12°C [46 to 54°F]) are at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers; even though water temperatures do warm downstream, the cold summer water temperatures have been suggested as a major factor limiting survival of YOY, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates were for 2003 and 2004, when there was a sudden increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). Paukert and Rogers (2004) reported post-spawn condition of

flannelmouth sucker below Glen Canyon Dam to be variable, but were typically greatest in the vicinity of warmwater tributaries such as the Paria River, the Little Colorado River, and Bright Angel Creek.

The flannelmouth sucker in the Grand Canyon may also be experiencing competition with and predation by nonnative species that are in the system (Rees et al. 2005). Potential competitors include species such as the channel catfish and the common carp. Potential predators include rainbow and brown trout and red shiner. Rainbow and brown trout diet sampling found enough juvenile flannelmouth suckers in trout stomachs to account for as much as 50% of the estimated annual mortality rates of juveniles (Yard et al. 2011; Walters et al. 2012). The ability of flannelmouth sucker to escape trout predation is also inhibited by colder water temperatures (Ward and Bonar 2003).

Speckled Dace

The speckled dace is native to the western United States and is one of eight species in the genus *Rhinichthys*. It is a small fish, typically less than 76 mm in length, and has a relatively short lifespan of about 3 years (Sigler and Sigler 1987).

Distribution and Abundance. This species is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow, and it was captured most commonly in the western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010).

Habitat. The speckled dace may be found in a variety of habitats, ranging from cold, fast-flowing mountain streams to warm, intermittent desert streams and springs. Where found, it occurs in rocky runs, riffles, and pools of headwater streams, creeks, and small to medium rivers, typically in waters with depths less than 1.6 ft (AZGFD 2002c); it rarely occurs in lakes (Page and Burr 1991).

Life History. The speckled dace is an omnivorous bottom feeder, feeding primarily on insect larvae and other invertebrates, as well as algae and fish eggs (Seegert et al. 2014). Its young are mid-water plankton feeders (Sigler and Sigler 1987). This dace spawns twice, once in spring and again in late summer (AZGFD 2002c). Spawning occurs over gravel in areas prepared by the male.

Factors Affecting Distribution and Abundance in the Grand Canyon. The speckled dace is a widespread and abundant species in western North America (AZGFD 2002c). Although this species is the most widely distributed and abundant native fish species in the Grand Canyon ecosystem, its abundance and distribution could be affected by many of the same factors that affect the abundance and distribution of the other native fish in the ecosystem, namely altered temperature, flow, and sediment regimes and predation by nonnative fish (AZGFD 2002c; Gloss and Coggins 2005).

3.5.3 Nonnative Fish

As many as 25 nonnative species of fish have been reported with some regularity from Lakes Powell and Mead and the Colorado River and its tributaries between these reservoirs (Valdez and Speas 2007; Coggins et al. 2011; Reclamation 2011e; Table 3.5-2). Most of these introduced species are native to other basins in North America but not the Colorado River Basin, and a few are species from outside North America. These fish occur in the Grand Canyon as a result of intentional and unintentional introductions, especially into Lakes Powell and Mead. A number of species were stocked as game fish and others as forage fish for the stocked game fish. Among these nonnative species, three are largely restricted to Lake Powell and/or Lake Mead, and occur in the Colorado River and its tributaries below Glen Canyon Dam only occasionally; these species are black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and gizzard shad (*Dorosoma cepedianum*) (Table 3.5-2). Another four species—northern pike (*Esox lucius*), threadfin shad (*Dorosoma petenense*), rock bass (*Ambloplites rupestris*), and yellow perch (*Perca flavescens*)—are largely restricted to the upper Little Colorado River watershed (Ward and Persons 2006; Valdez and Speas 2007). The remaining 18 species have been reported from the mainstem Colorado River and/or its tributaries between Glen Canyon Dam and the inflow to Lake Mead. New introductions of nonnative fish species continue to be documented throughout the Colorado River Basin, and new introductions are likely to occur (Martinez et al. 2014).

Common nonnative fish species in Lake Powell include striped bass, smallmouth and largemouth bass, walleye (*Sander vitreus*), bluegill, green sunfish (*Lepomis cyanellus*), common carp, and channel catfish. Species that occur in the reservoir, but that are mainly associated with tributaries and inflow areas, include fathead minnow, mosquitofish (*Gambusia affinis*), red shiner, and plains killifish (NPS 1996; Reclamation 2007a). Largemouth bass (*Micropterus salmoides*) and black crappie populations were stocked initially and, following successful establishment, these were the principal target species in the sport fisheries for many years. Both species have declined in recent years due to a lack of habitat structure for young fish. Filling and fluctuation of the reservoir resulted in changing habitat that eliminated most of the vegetation favored by many species (Reclamation 2007a). Smallmouth bass (*Micropterus dolomieu*) and striped bass (*Morone saxatilis*) were introduced following these changes in habitat structure and are presently the dominant predators in the reservoir (Reclamation 2007a). Threadfin shad were introduced to provide an additional forage base and quickly became the predominant prey species (NPS 1996). Gizzard shad were accidentally introduced into Morgan Reservoir in the San Juan River drainage in 1996 and subsequently proliferated in Lake Powell (Mueller and Brooks 2004; Vatland and Budy 2007).

TABLE 3.5-2 Nonnative Fish Found in the Colorado River through Glen and Grand Canyons

Species	Native Origin	Occurrence in Project Area
Coldwater Species		
Rainbow trout (*Oncorhynchus mykiss*)	North America	Colorado River from Glen Canyon Dam to Havasu Creek; abundant from Glen Canyon Dam to Lees Ferry; abundance decreases through Marble Canyon to the confluence with the Little Colorado River, although substantial numbers may still be present in some locations in some years; locally abundant at the Little Colorado River confluence and some locations through Grand Canyon in some years.
Brown trout (*Salmo trutta*)	Europe	Colorado River from Glen Canyon Dam to Kanab Creek; locally abundant near confluence with Bright Angel Creek, the Little Colorado River, and some other tributaries.
Warmwater Species		
Black bullhead (*Ictalurus melas*)	North America	Lake Powell, Lake Mead; Colorado River at the Little Colorado River; Colorado River downstream of Diamond Creek; generally absent from Glen Canyon, rare in Marble Canyon, and locally common in some areas of the Grand Canyon.
Yellow bullhead (*Ameiurus natalis*)	North America	Colorado River downstream of the Little Colorado River to Lake Mead; Little Colorado River, abundance presumed similar to that of black bullhead.
Channel catfish (*Ictalurus punctatus*)	North America	Lake Powell, Lake Mead, Colorado River from Marble Canyon to Lake Mead; generally absent from Glen Canyon, rare in Marble Canyon, and numerous in the Grand Canyon.
Green sunfish (*Lepomis cyanellus*)	North America	Lake Powell; Lake Mead; Kanab Creek; discovered in abundance in a slough located just downstream of Glen Canyon Dam in 2015 (eradication efforts conducted); generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Bluegill (*Lepomis macrochirus*)	North America	Lake Powell, Lake Mead; abundance presumed similar to that identified for green sunfish.
Largemouth bass (*Micropterus salmoides*)	North America	Lake Powell; Kanab Creek; Lake Mead to Maxson Canyon; generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon.
Smallmouth bass (*Micropterus dolomieu*)	North America	Lake Powell; Colorado River at the Little Colorado River, below Glen Canyon Dam; rare from Glen Canyon through the Grand Canyon.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Rock bass (*Ambloplites rupestris*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Black crappie (*Pomoxis nigromaculatus*)	North America	Lake Powell; Lake Mead; generally absent from Glen Canyon, Marble Canyon, and Grand Canyon.
Fathead minnow (*Pimephales promelas*)	North America	Colorado River from the Paria River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Golden shiner (*Notemigonus crysoleucus*)	North America	Colorado River from Glen Canyon to Separation Canyon; Kanab Creek; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Redside shiner (*Richardsonius balteatus*)	North America	Lake Powell; Colorado River at the Little Colorado River; generally rare throughout Glen Canyon, Marble Canyon, and Grand Canyon.
Red shiner (*Cyprinella lutrensis*)	North America	Colorado River at the Little Colorado River; Colorado River from Bridge Canyon to Lake Mead.
Common carp (*Cyprinus carpio*)	Eurasia	Lake Powell, Lake Mead, Colorado River from Glen Canyon Dam to Lake Mead.
Goldfish (*Carassius auratus*)	Eurasia	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Plains killifish (*Fundulus zebrinus*)	North America	Little Colorado River; Colorado River from Little Colorado River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Mosquitofish (*Gambusia affinis*)	North America	Lake Powell; Colorado River from Separation Canyon to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon.
Walleye (*Stizostedion vitreum*)	North America	Lake Powell; Colorado River from Lava Falls to Lake Mead; generally rare throughout Glen Canyon (but consistently observed during electrofishing surveys), Marble Canyon, and the Grand Canyon.
Yellow perch (*Perca flavesens*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.

TABLE 3.5-2 (Cont.)

Species	Native Origin	Occurrence in Project Area
Warmwater Species (Cont.)		
Striped bass (*Morone saxatilis*)	North America	Lake Powell; Colorado River from Havasu Creek to Lake Mead; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon.
Northern pike (*Esox lucius*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed.
Gizzard shad (*Dorosoma cepedianum*)	North America	Lake Powell; generally absent from Glen Canyon, Marble Canyon, and the Grand Canyon.
Threadfin shad (*Dorosoma petenense*)	North America	Lake Powell; Lake Mead; Colorado River from Glen Canyon to Separation Canyon; Upper Little Colorado River watershed; generally rare in Glen Canyon, Marble Canyon, and the Grand Canyon.

Sources: Holden and Stalnaker (1975); Gloss and Coggins (2005); Valdez and Speas (2007); Coggins et al. (2011); Reclamation (2011e).

Common nonnative fish species present in Lake Mead include striped bass, largemouth bass, red shiner, common carp, threadfin shad, and mosquitofish. The sport fishery in Lake Mead is primarily for striped bass and largemouth bass, although catfish species and hatchery-reared rainbow trout are also targeted by some anglers (Reclamation 2007a). As with Lake Powell, nonnative fish species present in Lake Mead were established through intentional and unintentional introductions.

The coldwater releases from Glen Canyon Dam result in river temperatures that are substantially cooler in summer and fall than those that occurred prior to construction of the dam. During periods of the year with warmer air temperatures, water temperatures gradually warm with downstream distance from the dam. These low water temperatures generally do not support native fish reproduction in the mainstem, and largely restrict native fish spawning to warmwater tributaries (Vernieu et al. 2005; Kennedy and Ralston 2011). Cold water similarly limits growth rates and reproduction for many of the warmwater nonnative fishes present in the mainstem (Clarkson and Childs 2000). However, low reservoir elevations since 2003 have resulted in release temperatures as high as 16°C (61°F) in some years. Table 3.5-3 presents average recorded water temperatures for various locations downstream of Glen Canyon Dam from 2006 to 2009.

The nonnative fish community changes in response to temperature and turbidity gradients in the mainstem (Makinster et al. 2010). In general, the reaches of the river just downstream of Glen Canyon Dam are dominated by coldwater nonnative species while downstream reaches through the Grand Canyon are currently dominated by native species, although substantial

TABLE 3.5-3 Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009

Mainstem River Location	Mean Water Temperature (°C±SD [°F±SD])	Turbidity (NTU)[a]
Lees Ferry, RM 0	10.4 ±1.5 (50.7 ±2.7)	2 ±10.5
Fence Fault, RM 30	10.7 ±1.5 (51.3 ±2.7)	50 ±347
Upstream Little Colorado River Confluence, RM 61	11.3 ±1.7 (52.3 ±3.0)	71 ±478
Phantom Ranch, RM 88	12.0 ±2 (53.5 ±3.6)	225 ±672
Diamond Creek Vicinity, RM 225	13.8 ±3.1 (56.9 ±5.5)	347 ±1,070

[a] NTU = nephelometric turbidity units. As NTU increases, water clarity decreases.

Source: Kennedy and Ralston (2011).

numbers of warmwater nonnative species are also present (Makinster et al. 2010). The water temperatures in the Glen Canyon reach are suitable (although colder than optimal) for rainbow trout spawning and growth (McKinney, Speas, et al. 2001). In the reach of cool, clear water between the dam and the Little Colorado River, the productivity of the aquatic food web (Section 3.5.1) is driven by microscopic algae (Angradi 1994; Shannon et al. 1994), invertebrate biomass is higher than in reaches farther downstream (Stevens, Shannon, et al. 1997), and rainbow trout (a visual sight feeder) is the dominant fish species (Makinster et al. 2010). As water temperature and turbidity increase downstream of the Little Colorado River confluence, nonnative warmwater fish species such as the common carp, red shiner, and several species of catfish increase in number (Makinster et al. 2010). The warmer water temperatures provide suitable conditions for spawning and growth for many of the warmwater nonnative species, many of which are benthic feeders adapted to foraging in turbid conditions (Gloss and Coggins 2005).

In addition, the annual distribution of nonnative fishes in the lower portions of the Grand Canyon may also be influenced by the elevation of Lake Mead. As the elevation of Lake Mead rises, lake-like conditions suitable for many of the warmwater nonnative fishes will temporarily extend farther upstream into the lower portion of the Grand Canyon.

More detailed information on coldwater and warmwater nonnative fish species is provided in the next two sections.

3.5.3.1 Coldwater Nonnative Species

Brown and rainbow trout make up the coldwater nonnative fish community of the Colorado River between Glen Canyon Dam and the inflow to Lake Mead (Figure 3.5-1). The rainbow trout is common in the Glen Canyon reach and in the mainstem Colorado River between the confluence with the Paria River and the confluence with the Little Colorado River

(Makinster et al. 2010; Reclamation 2011e). Smaller numbers are found associated with tributaries, including Bright Angel Creek, Shinumo Creek, Deer Creek, Tapeats Creek, Kanab Creek, and Havasu Creek (Reclamation 2011e). Brown trout are found primarily in and near Bright Angel Creek, which supports a spawning population (Reclamation 2011e), but they are also found throughout the upper reaches of the river corridor, including in Glen Canyon.

Rainbow Trout

The rainbow trout is very common in the reach of the mainstem Colorado from Glen Canyon Dam to the Paria River, and this population serves as the principal basis for the trout fishery. This species is also found in relatively high abundance in Marble Canyon between the Paria River and the confluence of the Colorado River with the Little Colorado River (Makinster et al. 2010; Reclamation 2011e). Downstream of the Little Colorado River confluence, smaller numbers of rainbow trout are found in localized aggregations associated with some tributaries.

Rainbow trout were initially introduced in the Grand Canyon region through stocking of tributaries such as Bright Angel Creek during the 1920s. Additional introductions of rainbow trout were made downstream of Glen Canyon Dam in 1964 following completion of dam construction. Prior to 1991, the population was maintained through annual stocking, and stocking continued through 1998 (Makinster et al. 2011). Since that time, the Glen Canyon rainbow trout fishery has been maintained through natural reproduction of rainbow trout rather than through stocking, and, with the exception of localized spawning in some downstream tributaries, most of the rainbow trout production in the Colorado River downstream of Glen Canyon Dam occurs within the Glen Canyon reach. Collections of YOY rainbow trout during recent surveys in the vicinity of the Little Colorado River suggest that some successful spawning may be occurring in or near the Little Colorado River. Standardized annual monitoring of the population of rainbow trout in the 15-mi reach of the Colorado River between Glen Canyon Dam and Lees Ferry began in 1991. Based on catches of rainbow trout during annual monitoring surveys, the abundance of rainbow trout in Glen Canyon generally increased over the period from 1991 to 1997, remained at high levels until approximately 2001, and then declined to low levels by 2007 (Figure 3.5-6). From 2008 through 2010, the relative abundance of rainbow trout in the Glen Canyon reach again increased to near historic high levels. Relative abundance reached all-time high levels in water years 2011 and 2012, followed by a decline in water year 2013 consistent with previous high abundance estimates (AZGFD data as reported in GCMRC 2014; Figure 3.5-6).

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas, et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Kormon et al. 2012). McKinney et al. (1999) attributed the increase in abundance from 1991 to 1997 to increased minimum flows and reduced fluctuations in daily discharges resulting from implementation of interim flows between 1991 and 1996 and adoption of the current modified low fluctuating flow regime in 1996. The decline in abundance from 2001 to 2007 has been attributed to the combined influence of increased trout metabolic demands

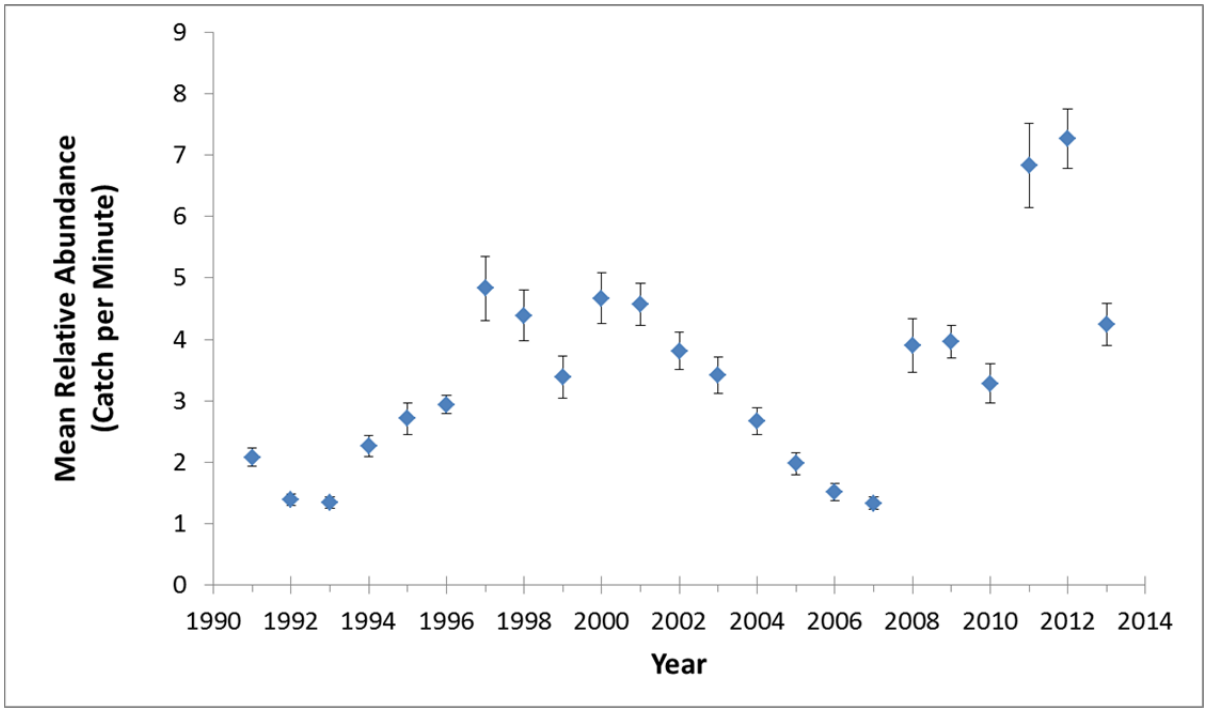

FIGURE 3.5-6 Mean (±2 SE) Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 (Source: Persons 2014)

due to warmer water releases from Glen Canyon Dam during that period, together with a static or declining food base, periodic DO deficiencies, and high numbers of the invasive New Zealand mudsnail, which serves as a poor food source (Cross et al. 2011). A similar decline in rainbow trout abundance below the Paria River was observed during the 2001 to 2007 time period (Makinster et al. 2010). Increases in recruitment levels and the levels of trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for YOY rainbow trout resulting from the HFE that occurred in March of 2008 (Makinster et al. 2011). Korman et al. (2012) also found that recruitment of rainbow trout in Glen Canyon was positively and strongly correlated with annual flow volume and reduced hourly flow variation, and also that recruitment increased after two of three high-flow releases related to the implementation of equalization flows. The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or "plumpness") of rainbow trout in the population, with the condition generally being inversely related to the relative abundance of rainbow trout within the reach (Makinster et al. 2011). Thus, it has generally been observed that as the relative abundance of trout within the reach increases, the condition of trout within the reach declines; as condition falls lower, it is anticipated that survival and recruitment to the population would be affected.

Rainbow trout in Glen, Marble, and Grand Canyons are considered exposed to whirling disease. Whirling disease infects only salmon and trout species, and is caused by *Myxobolus cerebralis*, a myxozoan parasite introduced to North America from Europe in the 1950s. Whirling disease was initially detected in Glen Canyon in 2007 (Makinster 2007). Twenty-two

percent of rainbow trout samples collected from Glen Canyon in 2011 were found to be infected with whirling disease. The presence of whirling disease has raised concerns regarding the potential to spread whirling disease to unaffected waters and watersheds through live removal and relocation of rainbow trout associated with the Nonnative Fish Control Environmental Assessment (EA) (Reclamation 2011e). It is anticipated that there is a low risk of spreading whirling disease as a consequence of conducting experimental floods as part of the High-Flow Experiment EA (Reclamation 2011d; VanderKooi 2012). The parasite is already present downstream from Glen Canyon Dam, and no barriers exist to prevent infected rainbow trout from moving into Marble and Grand Canyons. It is likely that HFEs will result in a decrease in the prevalence and severity of infections through reductions in the abundance of the intermediate host, the oligochaete worm *Tubifex tubifex*, and its preferred habitat of fine sediment and organic matter (VanderKooi 2012).

Because of the potential for trout to compete with and prey on native fish (Gloss and Coggins 2005; Yard et al. 2011; Whiting et al. 2014), the numbers of trout that leave the Glen Canyon reach and move to downstream locations is of potential concern. In particular, there is interest in limiting the numbers of trout that would enter the reach of the Colorado River in the vicinity of the confluence with the Little Colorado River because of the potential for negative effects on the endangered humpback chub population (Gloss and Coggins 2005; Yard et al. 2011). Data suggest that the numbers of trout that emigrate downstream from the Glen Canyon reach may largely be driven by the abundance of trout within the Glen Canyon reach. An increase in rainbow trout in the Little Colorado River reach after 2006 has been attributed to the increased survival and growth of young trout in the Glen Canyon reach following the March 2008 HFE (Wright and Kennedy 2011). The largest increases in trout abundance in both the Glen Canyon reach and the vicinity of the confluence with the Little Colorado River were seen after the 2011 equalization flows (Figure 3.5-6). It has been suggested that the 2008 HFE may have improved conditions for spawning and egg incubation of rainbow trout in the Glen Canyon reach by flushing fine sediment from spawning gravels and may have improved the survival of young trout by increasing the production and availability of invertebrates that serve as food for trout (Korman et al. 2010; Rosi-Marshall et al. 2010; see Section 3.5.1 for background information on the aquatic food base). Modeling conducted by Korman et al. (2012) suggests that 70% or more of the variation in the rates of rainbow trout emigration from the Glen Canyon reach could be explained by variation in recruitment levels in the Glen Canyon reach. Regardless, higher recruitment does not necessarily result in greater levels of emigration and there are years in which recruitment levels in the Glen Canyon reach were relatively high but emigration into Marble Canyon was not (e.g., following the HFE in 2012; Korman et al. 2012). In addition to emigration of trout to the Little Colorado River reach, recent captures of YOY trout upstream of the Little Colorado River confluence suggest that there may be some limited amount of spawning in lower Marble Canyon. Efforts to control nonnative fish in the Little Colorado River reach using flow manipulation to limit recruitment in Glen Canyon and mechanical removal in the Little Colorado River reach itself are described in Section 3.5.3.4.

Brown Trout

As with rainbow trout, brown trout are not native to the Colorado River and were stocked in Grand Canyon in the first half of the 1900s. Brown trout are no longer stocked in the Colorado River downstream of Glen Canyon Dam and are now found primarily in and near Bright Angel Creek, which supports a naturally spawning population (Reclamation 2011e). Unlike rainbow trout, brown trout are not susceptible to infestations of whirling disease. A trout control project, using a combination of a fish weir trap and electrofishing to benefit native species in Bright Angel Creek and endangered humpback chub in the Colorado River, was implemented by the NPS during winters 2006–2007, 2010–2011, 2011–2012, 2012–2013, 2013–2014, and 2014–2015 under the 2006 and 2013 EAs and a Finding of No Significant Impact (FONSI; NPS 2006c, 2013d).

Overall, the abundance (based on electrofishing surveys) of brown trout in the Colorado River between Lees Ferry and Lake Mead declined from 2000 to 2006; abundance may have increased somewhat between 2007 and 2009 (Figure 3.5-7; Makinster et al. 2010). Because spawning by brown trout in the Grand Canyon occurs primarily in tributaries (e.g., Bright Angel Creek and Shinumo Creek), recruitment rates may be less affected by conditions in the mainstem than recruitment rates of rainbow trout. However, recent increases in brown trout recruitment in 2014–2015 have occurred in the Lees Ferry reach of the Colorado River in Glen Canyon (Stewart 2016). Brown trout were observed to be spawning near the 4-mi bar in Glen Canyon during the fall of 2014, and an increase in age-1 brown trout, likely as a result of spawning and recruitment in 2014, was observed in 2015 (Korman et al. 2015). Spawning of brown trout was also observed during October and November of 2015 near the 4-mi bar in Glen Canyon (Korman et al. 2015). It is unclear if flow operations, including recent fall HFEs, caused an increase in brown trout in recent years.

Some brown trout captured in Bright Angel Creek were originally tagged in other parts of the Colorado River, as much as 25 mi from Bright Angel Creek (Reclamation 2011e). Small numbers of brown trout are also found in other locations within the Grand Canyon, including in the vicinity of the Little Colorado River confluence and in Glen Canyon. An indication of the relative abundance of brown and rainbow trout in the vicinity of the Little Colorado River is provided by the numbers captured using electrofishing during trout removal efforts. Of 23,000 nonnative fish captured as part of removal efforts from 2003 to 2006, 19,020 were rainbow trout and 470 were brown trout (Reclamation 2011e). All brown trout captured during these efforts were removed from the river.

Although the number of brown trout is small relative to rainbow trout, Yard et al. (2011) found that on an individual basis, the brown trout is a more active predator on native fish in the Colorado River than rainbow trout (see Section 3.5.3.3). Yard et al. (2011) also found a significant positive correlation between temperature and the levels of piscivory by brown trout. Other studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout in different ways. For example, while the incidence of predation attempts increased, the success of predation of rainbow trout on YOY humpback chub decreased as temperatures increased from 10°C to 20°C (50°F to 68°F)

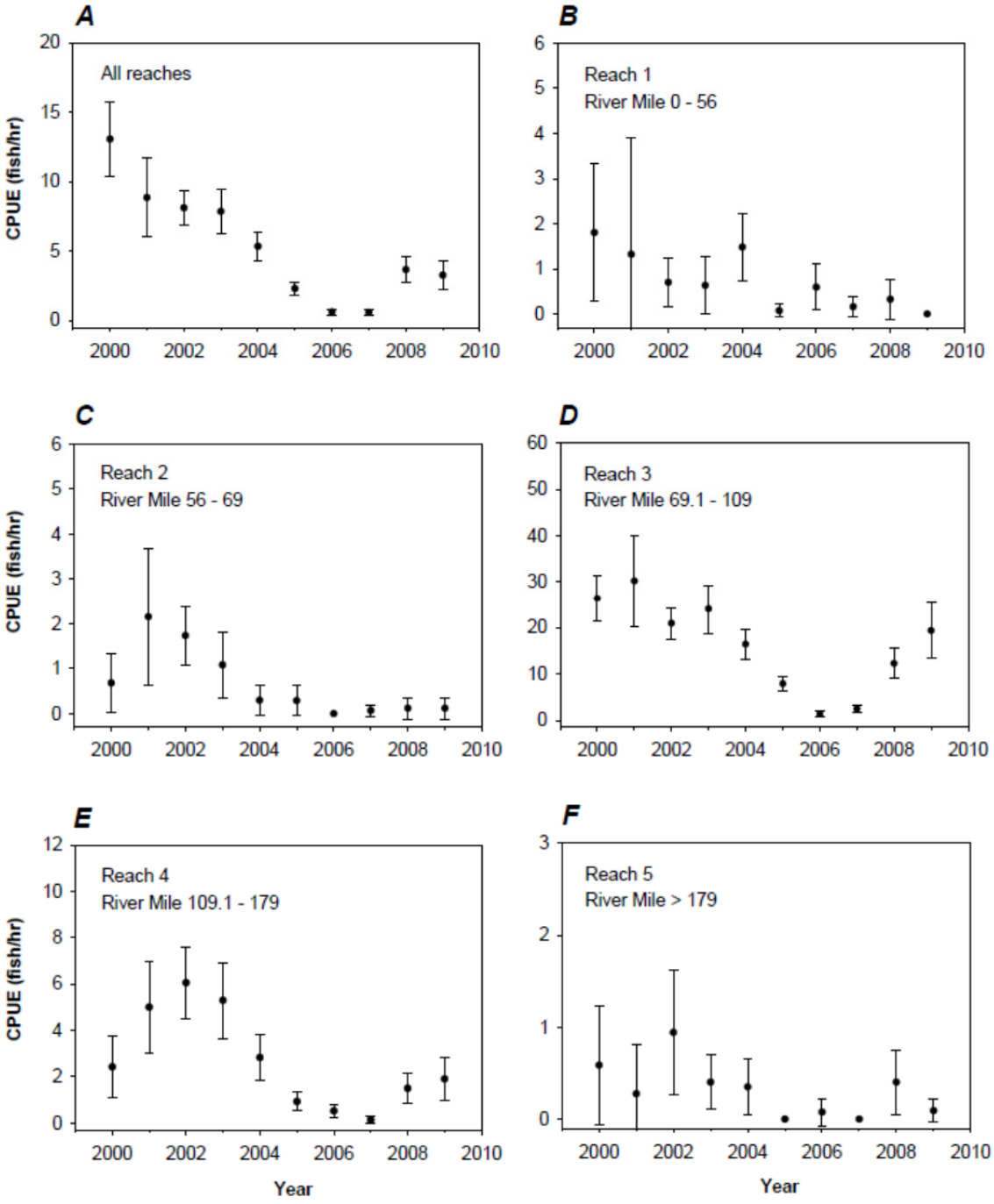

FIGURE 3.5-7 Mean (±2 SE) Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 (Note differences in scale among graphs A–F.) (Source: Makinster et al. 2010)

(Ward 2011). In contrast, the success of predation by brown trout did not change significantly over the same temperature range (Ward 2011).

3.5.3.2 Warmwater Nonnative Species

Surveys of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead, as well as experimental fish removal studies, indicate the presence of 17 nonnative warmwater fish species (Trammell and Valdez 2003; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011; Albrecht et al. 2014) (Table 3.5-2). Among the species collected, the common carp, fathead minnow, and red shiner are generally the most common warmwater species in the mainstem and tributaries (Rogers and Makinster 2006; Ward and Rogers 2006; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011). Smaller warmwater nonnative species, such as fathead minnow, red shiner, plains killifish, and bullhead, are primarily found in tributaries, especially in the Little Colorado River, but may also be found in the mainstem below the Little Colorado River confluence (Johnstone and Lauretta 2007).

Warmwater nonnative species have been collected in low numbers and only sporadically in the Glen Canyon reach; species collected include the common carp, channel catfish, and fathead minnow (Johnstone and Lauretta 2007; Ackerman 2008). Other species collected from this reach include green sunfish, smallmouth bass, striped bass, redside shiner, golden shiner, and walleye (FWS 2008). During July 2015, a large, reproducing population of green sunfish was discovered in a slough at RM 12, approximately 3 mi downstream of Glen Canyon Dam. Neither the source nor mechanism of introduction for some of these species (e.g., green sunfish, smallmouth bass) into the Glen Canyon reach is known with certainty; however, the nearest source for a number of these species is Lake Powell.

Warmwater nonnative species collected from the mainstem Colorado River in the vicinity of the Little Colorado River confluence include smallmouth and striped bass, green sunfish, black and yellow bullhead, red shiner, and plains killifish (Trammell and Valdez 2003; Johnstone and Lauretta 2007; FWS 2008).

Based on surveys conducted below Diamond Creek (RM 226–276.5) in 2005, the most abundant nonnative fish species included red shiner, mosquitofish, channel catfish, and common carp (Ackerman et al. 2006). Albrecht et al. (2014) reported that native fishes composed approximately 98% of the total age-0 catch during 2014 surveys and dominated the total number of small-bodied fish captured during 2013–2014 surveys in the lower Grand Canyon (Lava Falls to Pearce Ferry); bluehead sucker, flannelmouth sucker, and speckled dace were the most common native species collected. Eight nonnative species were captured during 2013–2014 surveys, including brown trout, rainbow trout, common carp, channel catfish, fathead minnow, plains killifish, western mosquitofish, and red shiner (Albrecht et al. 2014). Bridge Canyon Rapid (RM 235.1) may provide a natural impediment to the upstream movement of many of the nonnative fish except striped bass, walleye, and channel catfish (Valdez and Leibfried 1999; Reclamation 2011a).

The Little Colorado River may represent a source for some nonnative fishes found in the mainstem Colorado River (Stone et al. 2007). As many as 20 species of warmwater nonnative fishes have been reported from the Little Colorado River watershed (Table 3.5-4). Warmwater species collected from the Little Colorado River below Chute Falls include common carp, red shiner, fathead minnow, plains killifish, black bullhead, and channel catfish (Table 3.5-3) (Ward and Persons 2006; FWS 2008). Standardized monitoring from 1987 to 2005 found that nonnative warmwater fish generally compose only a small percentage of the fish collected from the Little Colorado River, typically accounting for less than 10% of the total fish catch in any single year (Ward and Persons 2006). Six species of warmwater nonnative fish (common carp, fathead minnow, red shiner, channel catfish, yellow bullhead, and plains killifish) are known to reproduce in the Little Colorado River (Choudhury et al. 2004).

Climatologists predict that the Southwest will experience extended drought due to global climate change, and lower Lake Powell Reservoir elevations and warmer release temperatures are predicted (Seager et al. 2007; CCSP 2008a,b). Warmer water conditions could benefit warmwater nonnative fishes, result in invasions of new species, and cause greater proliferation of existing nonnative fish species (Rahel and Olden 2008).

3.5.3.3 Interactions with Native Species

Nonnative fish in the Colorado River are considered to adversely affect native fish in the system through predation and/or competition, and by serving as hosts for parasites (Minckley 1991; Coggins et al. 2002, 2011; Gloss and Coggins 2005; Olden and Poff 2005).

Predation and Competition. Piscivory by rainbow and brown trout has been suggested as a large source of mortality for native fish in the Colorado River and its tributaries below Glen Canyon Dam (Blinn et al. 1993; Marsh and Douglas 1997; Yard et al. 2011; Whiting et al. 2014). Near the confluence of the Little Colorado River, Yard et al. (2011) found that 90% of the vertebrate prey consumed by rainbow and brown trout were fish and estimated that rainbow and brown trout consumed over 30,000 fish in the vicinity of the Little Colorado River during a 2-year study period. The incidence of piscivory (proportion of individuals feeding on fish) by species was 70% for brown trout and only up to 3.3% for rainbow trout. However, rainbow trout were approximately 50 times more abundant during the study period, and it was estimated that they accounted for more than half of the total number of fish consumed in the study area (Yard et al. 2011). Overall, trout ate 85% more native fish than nonnative fish, even though native fish composed less than 30% of the small fish available as prey in the study area. Of ingested fish that were identifiable, 56% was composed of native fish, while another 28.8% was composed of unidentified suckers (presumably native flannelmouth and bluehead suckers). Of the identified native fish consumed by the trout, about 27% were humpback chub, 15% were speckled dace, 11% were flannelmouth sucker, and 3% bluehead sucker (Yard et al. 2011). Because the majority of humpback chub consumed by trout during the study were YOY and subadults (<3 years), predation on such fish could affect recruitment to the humpback chub population in the Grand Canyon (Coggins and Walters 2009; Yard et al. 2011). Because of differences in the levels of piscivory exhibited by brown and rainbow trout, current decisions to

TABLE 3.5-4 Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed[a,b]

Species	Below Chute Falls	Above Chute Falls
Black bullhead	X	X
Yellow bullhead	X	X
Common carp	X	X
Channel catfish	X	X
Green sunfish	X	X
Fathead minnow	X	X
Plains killifish	X	X
Red shiner	X	X
Threadfin shad	–	X
Goldfish	–	X
Golden shiner	–	X
Northern pike	–	X
Mosquitofish	–	X
Rock bass	–	X
Bluegill	–	X
Smallmouth bass	–	X
Largemouth bass	–	X
Black crappie	–	X
Yellow perch	–	X
Walleye	–	X

[a] X = present; – = absent.

[b] Fish reported from below and above Chute Falls within the 21-mi perennially flowing portion of the Little Colorado River corridor.

Sources: Ward and Persons (2006); Stone et al. (2007).

implement removal actions at the Little Colorado River to benefit humpback chub are triggered by levels of both brown trout and rainbow trout present in the reach, as well as consideration of the status (estimated size) of the humpback chub population.

In the Grand Canyon, brown trout, rainbow trout, channel catfish, and black bullhead are considered the primary predators of humpback chub, while common carp are a major humpback chub egg predator in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Fathead minnow, red shiner, and plains killifish may be important predators and competitors of young humpback chub, especially in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; FWS 2008). Marsh and Douglas (1997) examined predation of native fish by nonnative fish in the Little Colorado River and found rainbow and brown trout, channel catfish, and black and yellow bullhead to be predators of native fish. In

stomachs from these species that contained food, native fish composed about 14% of the ingested materials, and ingested species included humpback chub, speckled dace, and bluehead and flannelmouth suckers. Whiting et al. (2014) evaluated diets of rainbow and brown trout from Bright Angel Creek, another tributary of the Colorado River in the Grand Canyon, and found that native fish (primarily speckled dace) composed approximately 4% of the diet for larger rainbow trout and 19% of the diet for larger brown trout.

While trout predation on humpback chub has been demonstrated, it is uncertain whether or not trout piscivory has had (or has) a population-level effect on the humpback chub (Yard et al. 2011). Although survival and recruitment of humpback chub have increased following trout removal in 2003 and 2006, it is not known if this increase is due to trout removal or other environmental factors, and further experimentation would be needed to tease apart other system-level dynamics that could have contributed to adult humpback chub population increases observed since 2000. For example, the temperature of water released from Glen Canyon Dam increased during the trout removal study period to temperatures that may have improved humpback chub growth and survival (Coggins et al. 2011). Ongoing studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout (e.g., Ward 2011; Ward and Morton-Starner 2015; see Section 3.5.3.1).

In addition to predation, nonnative fish may affect native fish through competition for resources that may be limited, such as food or appropriate habitat. Many of the small-bodied fish (including juveniles of larger species) in the Colorado River downstream of Glen Canyon Dam share similar habitats and food items, thereby increasing the potential for resource competition (Seegert et al. 2014). For example, nonnative fathead minnows are likely to compete with juvenile bluehead and flannelmouth suckers for resources, since they occupy the same habitat types and also have a high degree of overlap in the types of food items eaten (Seegert et al.2014. Diet evaluations and stable isotope analyses for fish from Bright Angel Creek found that the diets of rainbow trout and small (<150 mm total length) brown trout overlap with native fishes, suggesting competition for food resources (Whiting et al. 2014). Although the magnitude of species-level effects among the various native and nonnative species is poorly understood in most cases, it is likely that such competition has an effect on the abundance and survival of native species.

Research on the food web dynamics of the Grand Canyon provides further evidence that competition between native fish and nonnative fishes is likely occurring. Invertebrates, primarily blackflies and midges, are important food items for both humpback chub and nonnative fishes, particularly rainbow trout. Throughout Marble and Grand Canyons, invertebrate production is low, and fishes consume most of this production. Cross et al. (2013) hypothesized that an influx of rainbow trout from upstream, coupled with this limited resource base, may lead to strong competition among fishes in the Grand Canyon, and that dam operations that alter fish populations such as HFEs may exacerbate this effect.

Parasites and Diseases. The introduction and establishment of nonnative fish in the Colorado River below Glen Canyon Dam has also resulted in the introduction of several species of fish parasites that have the potential to adversely affect native fishes in the system

(Clarkson et al. 1997; Choudhury et al. 2004). Whirling disease, which affects rainbow trout but not the other native or nonnative species in the Colorado River below Glen Canyon Dam, was discussed above. The Asian tapeworm and the anchor worm have been found in native and nonnative warmwater fish in the Colorado River and its tributaries below Glen Canyon Dam, and the prevalence of these parasites is especially high in the Little Colorado River (Clarkson et al. 1997; Choudhury et al. 2004). For example, since first being identified from humpback chub in the Little Colorado River in 1990, reported infestation rates of the Asian tapeworm in native fish in the Little Colorado River were over 50% in some life stages of the humpback chub and as much as 60% in juvenile speckled dace (Clarkson et al. 1997). A 2-year seasonal study of fish parasites in the Little Colorado River reported 17 species of parasites from 4 native and 7 nonnative fish (Choudhury et al. 2004).

The effects of parasite infestation may be serious. For example, pathological effects of the Asian tapeworm have been reported to include intestinal abrasion and disintegration, as well as blockage and perforation of the gastrointestinal tract; chronic effects may include reduced growth and reproductive capacity, depressed swimming ability, and secondary bacterial infections (Clarkson et al. 1997). Fish larvae infested with the anchor worm may be killed, if vital organs are penetrated by the anchors, and secondary infections are possible at attachment points (Berry et al. 1991).

The effects of many of the parasites that have been reported for other fish species suggest that these parasites have the potential to adversely affect native fishes in the Colorado River below Glen Canyon Dam. The high prevalence of parasites in native and nonnative fish in the Little Colorado River may be especially of concern, given the importance of the Little Colorado River in the reproduction of the humpback chub and maintenance of the humpback chub population in the Colorado River below Glen Canyon Dam.

The potential for expansions and infestations of nonnative parasites may also be influenced by water temperatures. Rahel and Olden (2008) suggested that climate change could facilitate expansion of nonnative parasites. This may be an important threat to humpback chub. Optimal Asian tapeworm development occurs at 25–30°C (77–86°F) (Granath and Esch 1983), and optimal anchorworm temperatures are 23–30°C (73–86°F) (Bulow et al. 1979). Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have likely prevented these parasites from completing their life cycles and limited their distribution. Warmer climate trends or operational alternatives could result in warmer overall water temperatures, thereby increasing the prevalence of these parasites, which can weaken humpback chub and increase mortality rates.

3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions

A number of management activities have been designed and implemented to test their efficacy for controlling and reducing the abundance and distribution of nonnative fishes in the Colorado River and its tributaries below Glen Canyon Dam. These control activities included (1) flow releases from Glen Canyon Dam designed to reduce trout recruitment, and (2) mechanical removal of trout and warmwater nonnative fish in the vicinity of the Colorado

River–Little Colorado River confluence (Reclamation 2011e). A series of HFEs was conducted in 1996, 2004, 2008, 2012, 2013, and 2014 to benefit sandbar resources, improve camping beaches, and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Dodrill et al. (2015) reported that although experimental floods increased the prevalence and extent of backwaters, the effects were modest and would be expected to dissipate quickly. There was a large increase in rainbow trout early life stage survival rates and in the abundance of rainbow trout following the 2008 spring HFE; whether such increases would be supported by future spring HFEs is unclear, and the effects of fall HFEs on rainbow trout are less clear; however, preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015). The potential effects of HFEs on trout are described below, as are the possible effects of equalization flows on trout.

Nonnative Fish Suppression Flows

Flows designed to reduce trout recruitment in Lees Ferry were tested in 2003–2005. These flows, conducted from January through March, were intended to dewater and expose rainbow trout redds in the Glen Canyon reach to lethal air temperatures for part of the day, thereby reducing the survival of trout eggs in the exposed redds (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). The flow regimes tested during this period consisted of increasing the extent of daily flow variation during winter and early spring from the normal range of 10,000–18,000 cfs in January and 7,000–13,000 cfs in February–March to a range of 5,000–20,000 cfs in January–March; these operations also resulted in longer periods of dewatering for redds at lower elevations than would occur under normal operations. The fluctuating flows were determined to have resulted in increasing the incubation mortality rate from 5–11% under normal flow conditions to 23–49% under fluctuating flows (Korman et al. 2005; Korman, Kaplinski, et al. 2011; Korman and Melis 2011). However, no measurable reduction in age-0 abundance was observed, presumably due to increased survival of those rainbow trout that survived. These results suggest that the increased level of incubation mortality did not exceed compensatory survival responses (Korman, Kaplinski, et al. 2011). Because of these results, it has been suggested (Korman, Kaplinski, et al. 2011; Korman and Melis 2011) that a more limited fluctuating flow regime may be effective, targeting juvenile trout after the majority of density-dependent responses to egg incubation and hatching success have been realized, but before age-0 trout leave habitats that are potentially more sensitive to flow fluctuations. Testing flow regimes under which flow variation is increased during late spring and summer months when small age-0 trout are utilizing potentially flow-sensitive, low-angle habitat has been suggested (Korman et al. 2005; Korman and Melis 2011).

Nonnative Fish Removal

The removal of predatory nonnative fish has been conducted in various locations in the upper and lower basins of the Colorado River since the mid-1990s with varying degrees of success (Mueller 2005). Removal of nonnative fish in the Colorado River near the Little Colorado River confluence was conducted from 2003 to 2006, and in 2009 (Korman et al. 2005;

Makinster et al. 2009; Coggins et al. 2011). Fish removal activities in 2003–2006 captured more than 36,000 fish, of which 23,266 were nonnative species (including 19,020 rainbow trout) (Korman et al. 2005; Coggins et al. 2011). The removal of trout was estimated to have reduced rainbow trout abundance in this reach from about 6,500 in January 2003 to about 620 in February 2006. Immigration and recruitment account for the difference between the number of trout removed and the abundance estimates. During the 2003–2006 removal activities, large increases in the abundance of fathead minnow and black bullhead were reported beginning in September 2005, suggesting increases in immigration, survival, or both. The observed increase may have been due to increased emigration from the Little Colorado River where these species spawn, or because the combination of reduced rainbow trout numbers and increasing water temperatures may have caused these species to be more abundant and susceptible to capture (Coggins et al. 2011).

Coincident with the 2003–2006 removal activities, the humpback chub population stabilized and increased, suggesting that the nonnative fish removal (especially the removal of rainbow trout) may have allowed higher survival and recruitment by humpback chub (Coggins and Walters 2009; Coggins et al. 2011). However, the relationship between trout removal and survival of humpback chub is not clear because there was a system-wide decrease in rainbow trout abundance and drought-induced increases in river water temperatures during the time of the removal activities that could also have led to increased survival and recruitment of juvenile native fish (Coggins et al. 2011). As indicated in Figure 3.5-3, stabilization and increases in the adult humpback chub population may have begun as early as 2002, prior to the nonnative fish removal actions. Because changes in the adult humpback chub population rely, in part, on survival and recruitment of juvenile humpback chub, increases in survival rates may have occurred for several years prior to the fish removal activities. Further, even though the abundance of trout appeared to return to pre-removal levels by 2009, the estimated adult abundance of humpback chub continued to increase (Figure 3.5-3)

Nonnative fish removal was also conducted in 2009, the results of which indicated that rainbow trout abundance in the vicinity of the Little Colorado River had rebounded from the declines observed in 2006–2007 (Coggins et al. 2011; Reclamation 2011a). The number of rainbow trout in the vicinity of the Little Colorado River prior to the 2009 removal activities was estimated to be similar to the high densities estimated in 2002 (prior to the 2003 fish removal activities) (Wright and Kennedy 2011).

Nonnative fish removal is also being conducted in Shinumo and Bright Angel Creeks to restore and enhance the native fish communities and to reduce predation and competition on endangered humpback chub from nonnative fish. These removals are being conducted to implement conservation measures identified in the 2008 Biological Opinion, the 2009 Supplement, and the 2011 Biological Opinion on the operation of Glen Canyon Dam (FWS 2008, 2009; Reclamation 2011a). Nonnative fish (primarily rainbow trout) are being removed from Shinumo Creek to minimize predation upon newly translocated humpback chub and to reduce competition. From 2009 through 2014, 5,569 rainbow trout were removed from Shinumo Creek using netting, angling, and electrofishing. Brown trout do not occur in Shinumo Creek above a waterfall barrier near the mouth, but a few brown trout were removed below the waterfall. Rainbow trout densities were reduced between summer 2011 and winter 2012, but

rebounded with a strong cohort in June 2012 (likely a "compensatory response"). Abundance of bluehead sucker increased in the lower reaches downstream of translocation areas and speckled dace increased throughout Shinumo Creek as rainbow trout densities were reduced. A sequence of headwater fires and floods occurred in the summer of 2014 that almost eliminated all nonnative and native fish from Shinumo Creek. NPS plans to remove the remaining nonnative trout and monitor the native fish. Nonnative fish, primarily rainbow trout, occur in small numbers in Havasu Creek and are also removed when encountered (Healy et al. 2014).

From 2010 to 2012, trout reduction efforts in Bright Angel Creek included the installation and operation of a fish weir trap and backpack electrofishing in the lower portion of the creek, including the confluence of Bright Angel Creek to Phantom Creek. From 2012 to 2015, removals were expanded to encompass the entire length of Bright Angel Creek (approximately 16 km) and Roaring Springs (approximately 3 km). The operation of the weir was also extended from October through February to capture greater temporal variability in the trout spawning migration. From 2010 to December 2014, about 28,000 brown trout and 4,800 rainbow trout were removed from Bright Angel Creek from both the weir and by electrofishing. Data on early 2015 removals and native fish response are still being analyzed, but trout abundance appears to have been reduced and native fish distribution has expanded upstream. These data are preliminary and may change slightly with further analysis (Healy et al. 2014; Nelson et al. 2012, 2015). As determined through consultation with Traditionally Associated Tribes and others, and consistent with the Memorandum of Agreement between the NPS and the Arizona State Historic Preservation Office, trout removed from the creeks were preserved and distributed for beneficial use through human consumption, or for use by the Tribes for other purposes.

In July of 2015, AZGFD biologists discovered an unusually large, reproducing population of green sunfish in a backwater slough connected to the mainstem Colorado River approximately 3 mi downstream of Glen Canyon Dam. Although the downstream end of the slough is connected to the main channel under the typical range of releases from Glen Canyon Dam, the upstream end of the slough is isolated from the main channel except during high flows. Green sunfish are known to be prolific, with a single female capable of producing up to 10,000 eggs. Green sunfish are considered likely predators of small-bodied native fish and native fish eggs. Biologists with the AZGFD, NPS, USGS, FWS, and Reclamation have determined that green sunfish pose a threat to native fish, including the humpback chub. Two removal efforts using electrofishing, seine netting, and trapping were conducted in August of 2015, but failed to deplete the population despite removing more than 3,000 fish. Biologists from the NPS and AZGFD constructed and installed a large block net at the downstream end of the main slough to minimize the escapement of green sunfish. After analyzing alternative methods for control, the agencies authorized a short-term targeted treatment of the slough with the fish toxin rotenone. Information available as of mid-November 2015 indicates that the eradication efforts appear to have been successful at controlling this population.

In August of 2016, NPS biologists discovered an additional small number of green sunfish in the slough. At the time of preparation of this EIS, mechanical removal efforts with beneficial use were being conducted.

Tribal Perspectives on Nonnative Fish Removal

Both the Hopi Tribe and the Pueblo of Zuni have expressed concerns to the U.S. Department of the Interior (DOI) regarding management actions described above involving fish suppression flows and mechanical removal of nonnative fish. The Hopi have expressed concern regarding the mechanical removal of large numbers of trout and trout management flows, while also expressing an understanding of the need to effectively manage nonnative populations if necessary to prevent the extinction of humpback chub. The Hopi stated their concern of conflicting management objectives to maintain a trout fishery while also minimizing threats to humpback chub. The Pueblo of Zuni consider these actions to be the taking of life without a beneficial use.

During the important Zuni migrations in Grand Canyon many culturally and historically important events occurred. One such specific event occurred in Zuni history which defines the Zuni's familial relationship to aquatic life and provides the fundamental basis for the Zuni objection to the mechanical removal of fish from the confluence of the Colorado and the Little Colorado rivers. In the late nineteenth century, Frank Hamilton Cushing recorded this historical event as it was narrated to him by the Zuni. Cushing labeled the event as the "Abode of the Souls" and the following is a condensed version of that event:

Shortly after Emergence, men of the Bear, Crane, and Seed clans strode into the red waters of the Colorado River and waded across. The men of the clans all crossed successfully. The women travelling with the men carried their children on their backs and they waded into the water. Their children, who were unfinished and immature (because this occurred shortly after Emergence), changed in their terror. Their skins turned cold and scaly and they grew tails. Their hands and feet became webbed and clawed for swimming. The children fell into the swift, red waters. Some of the children became lizards, others turned into frogs, turtles, newts and fish. The children of these clans were lost to the water. The mothers were able to make it to the other side of the river, where they wailed and cried for their children. The Twins heard them, returned, and advised the mothers to cherish their children through all dangers. After listening to the Twins, those people who had yet to pass through the river took heart and clutched their children to them and safely proceeded to the opposite shore. The people who successfully made it out of the river rested, calmed the remaining children, and then arose and continued their journey to the plain east of the two mountains with great water between. Thence, they turned northward to camp on the sunrise slopes of the uppermost mountains.

High-Flow Experiments

A number of HFEs have been conducted in the Colorado River below Glen Canyon Dam (1996, 2004, 2008, 2012, 2013, and 2014) to improve camping beaches and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Rainbow trout abundance was found to increase following the spring HFEs in 1996 and 2008 (Makinster et al. 2011; Kennedy and Ralston 2011). In particular, the 2008 cohort was the largest on record up to that date, while the 2009 cohort was very strong compared to other years (Korman, Kaplinski, et al. 2011; Korman and Melis 2011). While fish hatched before and up to

1 month after the HFE showed lower early survival rates, fish hatched more than 1 month after the HFE showed a large increase in their early survival rate, with age-0 fish abundance being four times higher than expected (Melis et al. 2010; Korman and Melis 2011).

It is thought that cohorts produced after the HFE were not exposed to high flows and emerged into better quality habitat with better food availability (Rosi-Marshall et al. 2010). Concentrations of invertebrate prey in the drift following the spring 2008 HFE showed some prey items such as midge and blackflies (primary preferred food of rainbow trout) to have increased as much as 400% to 800%, and elevated levels in the drift continued for as much as 15 months following the HFE (Melis 2011). The observed changes in rainbow trout abundance following these two HFEs suggest that spring HFEs may benefit rainbow trout populations (Kennedy and Ralston 2011).

In contrast to the increased abundance of rainbow trout following the spring HFEs in 1996 and 2008, trout abundance was reduced following the fall (November) HFE in 2004 (Kennedy and Ralston 2011). However, rainbow trout in the Glen Canyon reach were showing a general population decline that started 2 years prior to the 2004 HFE, and, therefore, results in uncertainty regarding the inferences about the influence of the fall 2004 HFE on rainbow trout abundance and whether the response to fall HFEs is different from those associated with spring HFEs. Preliminary analyses indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012 and 2013 (VanderKooi 2015; Gimbel 2015). In addition, the relative overall abundance of rainbow trout in the Glen Canyon reach declined from 2012 to 2013 (Figure 3.5-6) due to declines in abundance of fish in smaller size classes.

Equalization Flows

There is also a potential for the abundance of YOY rainbow trout to be affected by the high, steady, and sustained flows that result from equalization flows as required by the 1968 Colorado River Basin Project Act. A substantial increase in numbers of age-0 trout was observed in 2011 following a period of sustained high flows required for equalization (Korman, Persons, et al. 2011). It has been hypothesized that the high, steady flows associated with equalization operations could benefit age-0 rainbow trout by inundating additional habitat for spawning, incubation of eggs, and production of food resources, and that these factors resulted in the observed increase in the numbers of age-0 trout.. Implementation of equalization flows is separate and distinct from LTEMP and would not be affected by LTEMP.

3.6 VEGETATION

Terrestrial plant communities along the Colorado River from Glen Canyon Dam to Lake Mead are highly diverse due to great variations in landforms, geologic features, and physical characteristics such as topography, elevation, and aspect. Plant communities along the Colorado River are greatly influenced by flow characteristics.

3.6.1 Historic and Remnant Riparian Plant Communities

A natural riverine environment existed along the Colorado River corridor prior to the modifications in flow regime and sediment transport that resulted from the construction of Glen Canyon Dam (Turner and Karpiscak 1980). Conditions within riparian habitats were constantly changing and highly unstable, with wide variations in annual flood flows as well as annual periods of low flow (Clover and Jotter 1944; Turner and Karpiscak 1980). Seasonal floods, averaging about 86,000 cfs, but frequently exceeding 100,000 cfs (Johnson 1991), resulted from snowmelt and spring rains; while sporadic floods from tributaries resulted from local storms, particularly during the summer monsoon season. Flood flows provided soil moisture which created opportunities for the establishment of species adapted to wet or moist soils near the river across a highly variable range of stage elevation (Clover and Jotter 1944). Floods were also sources of disturbance, removing plants by drowning or scouring across that elevation range (Clover and Jotter 1944). While well-established willows in some locations of the lower Grand Canyon could reach a height of 30 to 40 ft, these willows could be partially or completely removed by floods (Clover and Jotter 1944). Vegetation was typically sparse in areas that were frequently flooded; however, when a number of years passed between flood events, denser growth could develop. In broader reaches of the canyon, scouring was somewhat diminished, allowing some perennial plants to become established in sediment deposits near the river (Turner and Karpiscak 1980).

A zone of riparian vegetation, referred to as the Old High Water Zone, was well established just above the pre-dam scour zone (at and just above the approximately 100,000-cfs stage elevation) (Carothers and Brown 1991). Following dam construction, annual high flows have been limited to approximately 45,000 cfs or lower, except for four higher flow years (1983–1986) since 1965. These relatively low annual high flows have permitted riparian vegetation to develop below the Old High Water Zone in what has become known as the New High Water Zone. Before the dam, annual high flows carried large sediment loads through Glen and Grand Canyons, scouring nearly all vegetation below the Old High Water Zone (Carothers and Brown 1991; Kearsley and Ayers 1999; Ralston 2005).

The principal species[8] of the Old High Water Zone in Glen Canyon included New Mexico olive (*Forestiera pubescens*), Apache plume (*Fallugia paradoxa*), and netleaf hackberry (*Celtis reticulata*), and in Glen and upper Marble Canyons included apache plume, netleaf hackberry, western redbud (*Cercis occidentalis*), live oak (*Quercus turbinella*), and New Mexico olive. The Grand Canyon lacks the latter two species in the river corridor, and catclaw acacia (*Acacia greggii*) and mesquite (*Prosopis glandulosa*) are dominant, with desert broom (*Baccharis sarothroides*) becoming important downstream from RM 127 (Spence 2006; Carothers and Brown 1991; NPS 2005a). Pre-dam sediment terraces occupy the upper levels of the Old High Water Zone and support species adapted to dry soil conditions. High terraces in Glen Canyon support dense stands of four-wing saltbush (*Atriplex canescens*); however, in the Grand Canyon, catclaw acacia, brittlebush (*Encelia* spp.), barrel cactus

8 Plant names in this section use the Flora of North America (FNA 2014) and TROPICOS (Tropicos 2014) nomenclatures.

(*Ferocactus cylindraceus*), bursage (*Ambrosia dumosa*), creosote (*Larrea divaricata*), ocotillo (*Fouquieria splendens*), and other Mojave-Sonoran desert species also occur (Spence 2006).

Surfaces that were subject to frequent floods prior to dam construction ranged from barren to sparsely vegetated (Turner and Karpiscak 1980). Some of the species that occurred prior to the dam in this sparsely vegetated zone included tamarisk, also known as salt cedar (*Tamarix* spp.); seepwillow (*Baccharis* spp.); arrowweed (*Pluchea sericea*); and coyote willow (*Salix exigua*). Tamarisk, a species of Eurasian origin, was described in the 1930s as occurring along the river in "thickets near the eastern end of the park," "fringing the river near the mouth of Bright Angel Creek" (Dodge 1936), and "along the river from Nankoweap Creek to the base of Tanner Trail" (GCNHA 1936). Historic photos from Lees Ferry show tamarisk had established by 1923 (Graf 1978). Clover and Jotter (1944) noted tamarisk occurred in scattered locations (in moist sand near the river's edge) along the length of the river except for a large section of Marble Canyon; it was observed at and above Lees Ferry, below Vasey's Paradise, at the mouth of Saddle Canyon, Lava Pinnacle, and at Separation Rapids. Based on analyses of pre-dam photographs, tamarisk probably occurred as widespread isolated individuals (Turner and Karpiscak 1980).

3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam

The response of riparian vegetation to the operation of Glen Canyon Dam has been well studied, as summarized by Ralston (2012) and Sankey, Ralston, et al. (2015). Most evidence indicates that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing dam operations. "Riparian vegetation" includes all plants found within the Fluctuating, New High Water, Old High Water, and Pre-Dam Flood Terrace hydrologic zones of the mainstem Colorado River downstream from Glen Canyon Dam, as described below.

Following construction of Glen Canyon Dam and the regulation of flows, including the reduction in annual flood peaks and increased year-round water availability at lower stage elevations, riparian vegetation expanded into the newly stable habitat and increased substantially (Ralston 2010; Kennedy and Ralston 2011; Webb et al. 2011; Sankey, Ralston, et al. 2015; Turner and Karpiscak 1980). The overall trend since completion of the dam has been the encroachment of New High Water Zone vegetation onto sandy beaches (Kearsley et al. 1994; Webb et al. 2002). At the same time, water availability decreased or was eliminated at higher elevations above the average annual daily maximum flows. The overall trend in the Old High Water Zone has been increased mortality of species such as mesquite and hackberry (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Plant communities present along the river have developed through associations of species with similar responses to moisture gradients, tolerance to water stress, and modes of reproduction (Kearsley et al. 2006; Stevens et al. 1995; Ralston et al. 2014; Ralston 2012). Such species associations occur on geomorphic surfaces of debris fan-eddy complexes, such as reattachment bars and separation bars, as well as on channel margins between these complexes, and respond dynamically to changes in flow characteristics. Geomorphic setting, substrate type/texture, hydrology, and species life history characteristics affect the temporal and spatial

occurrence of plant communities (Ralston et al. 2014; Merritt et al. 2010). Because of historical patterns of dam releases, communities below the 25,000-cfs elevation on these surfaces differ somewhat from those above that level. Seven plant community types have been identified as occurring on these geomorphic surfaces (Ralston et al. 2014) and are given in Table 3.6-1.

Vegetation zones along the river reflect the frequency of inundation and disturbance (Ralston 2010, 2012; Kennedy and Ralston 2011). The Fluctuating Zone (Figure 3.6-1) supports flood-tolerant marsh species such as sedges, rushes, cattail, horsetail, and common reed. These species occupy return current channels and successional backwaters that are inundated daily for at least part of the year (i.e., up to the elevation of the average annual daily maximum discharge of about 20,000 cfs). The New High Water Zone lies within the influence of dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations but above daily fluctuation levels (Carothers and Brown 1991). Vegetation in the Fluctuating and New High Water Zones are greatly influenced by river flow and dam operations. (Stevens et al. 1995; Porter 2002; Kearsley and Ayers 1999; Kearsley et al. 2006; Ralston 2005, 2012).

The New High Water Zone, inundated by flows up to 45,000 cfs, supports woody riparian species, many herbaceous obligate riparian species (e.g., *Carex* spp., *Juncus* spp., *Equisetum* spp., *Phragmites australis*, and *Typha* spp.) with bunchgrasses such as sand dropseed and shrubs such as spiny aster at upper elevations. The dominant woody species of the Glen Canyon and Grand Canyon New High Water Zone scrub communities include tamarisk, coyote willow, arrowweed, and seepwillow (*Baccharis* spp.), along with desert broom downstream from RM 162 (Spence 2006). Wide, alluvial reaches have greater vegetation cover than narrow, confined reaches (Kennedy and Ralston 2011).

The Old High Water Zone, above 60,000 cfs to approximately 200,000 cfs, supports pre-dam drought-tolerant riparian species found in riparian and upland habitats, such as honey mesquite, catclaw acacia, netleaf hackberry, Apache plume, New Mexico olive, and mountain pepperweed (*Lepidium montanum*), along with desert species such as Mormon tea (*Ephedra* spp.), prickly pear (*Opuntia* spp.), creosote, ocotillo, and brittlebush. Mortality of Old High Water Zone plants is occurring, and some species such as mesquite and hackberry are no longer recruiting in this zone because of the lack of sufficiently high flows and nutrient-rich sediment inputs; however, mesquite and catclaw acacia are now recruiting in the New High Water Zone (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011; Ralston 2005). Because flows do not exceed 45,000 cfs with normal dam operations, the upper margins of this zone are moving downslope, resulting in a narrowing of the zone. Desert species occupy pre-dam flood terraces and windblown sand deposits above the Old High Water Zone.

Vegetation on the geomorphic surfaces along the river (below about the 45,000-cfs stage elevation) has changed since construction of the dam as a function of river flows and climate (precipitation), as well as a result of factors such as increased soil salinity and increased sand coarseness (Carothers and Aitchison 1976; Kearsley et al. 2006; Sankey, Ralston, et al. 2015). Return channel-eddy complexes support many of the largest and better developed riparian patches (Spence 2006). Fluvial marsh wetlands were scarce prior to the construction of the dam and were associated only with perennial tributaries and springs (Webb et al. 2002); however,

TABLE 3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins

Plant Community	Dominant Species	Geomorphic Surfaces
Common reed temperate herbaceous vegetation	Common reed (*Phragmites australis*), cattail (*T. latifolia, T. domingensis*), common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower reattachment bar
Coyote willow-Emory seep willow shrubland/horsetail herbaceous vegetation	Coyote willow, Emory seepwillow (*Baccharis emoryi*), horsetail (*Equisetum laevigatum*), common three-square (*Schoenoplectus pungens*), common spike-rush (*Eleocharis palustris*), alkali muhly (*Muhlenbergia asperifolia*)	Lower channel margin, lower reattachment bar
Tamarisk temporarily flooded shrubland	Tamarisk; in Glen Canyon also desert broom	All surfaces
Cottonwood/coyote willow forest	Coyote willow, cottonwood (*Populus fremontii*), Goodding's willow (*Salix gooddingii*), seepwillow (*Baccharis salicifolia*), salt grass (*Distichlis spicata*), alkali muhly, common reed, horsetail (*Equisetum* spp.), rush (*Juncus* spp.), sedge (*Carex* spp.), Russian olive (*Elaeagnus angustifolia*), tamarisk, creepingbent grass (*Agrostis stolonifera*), sweet clover (*Melilotus* spp.)	Lower separation bar, lower channel margin
Arrowweed seasonally flooded shrubland	Arrowweed (*Pluchea sericea*) in pure stands, or with seepwillow (*Baccharis* spp.), mesquite, or coyote willow	Lower reattachment bar, upper separation bar, upper channel margin, upper reattachment bar
Mesquite shrubland	Mesquite (*Prosopis glandulosa* var. *torreyana*), with seepwillow (*Baccharis* spp.), arrowweed	Lower channel margin, upper separation bar, upper channel margin, upper reattachment bar
Bare sand	Less than 1% vegetation cover	All surfaces

Source: Ralston et al. (2014).

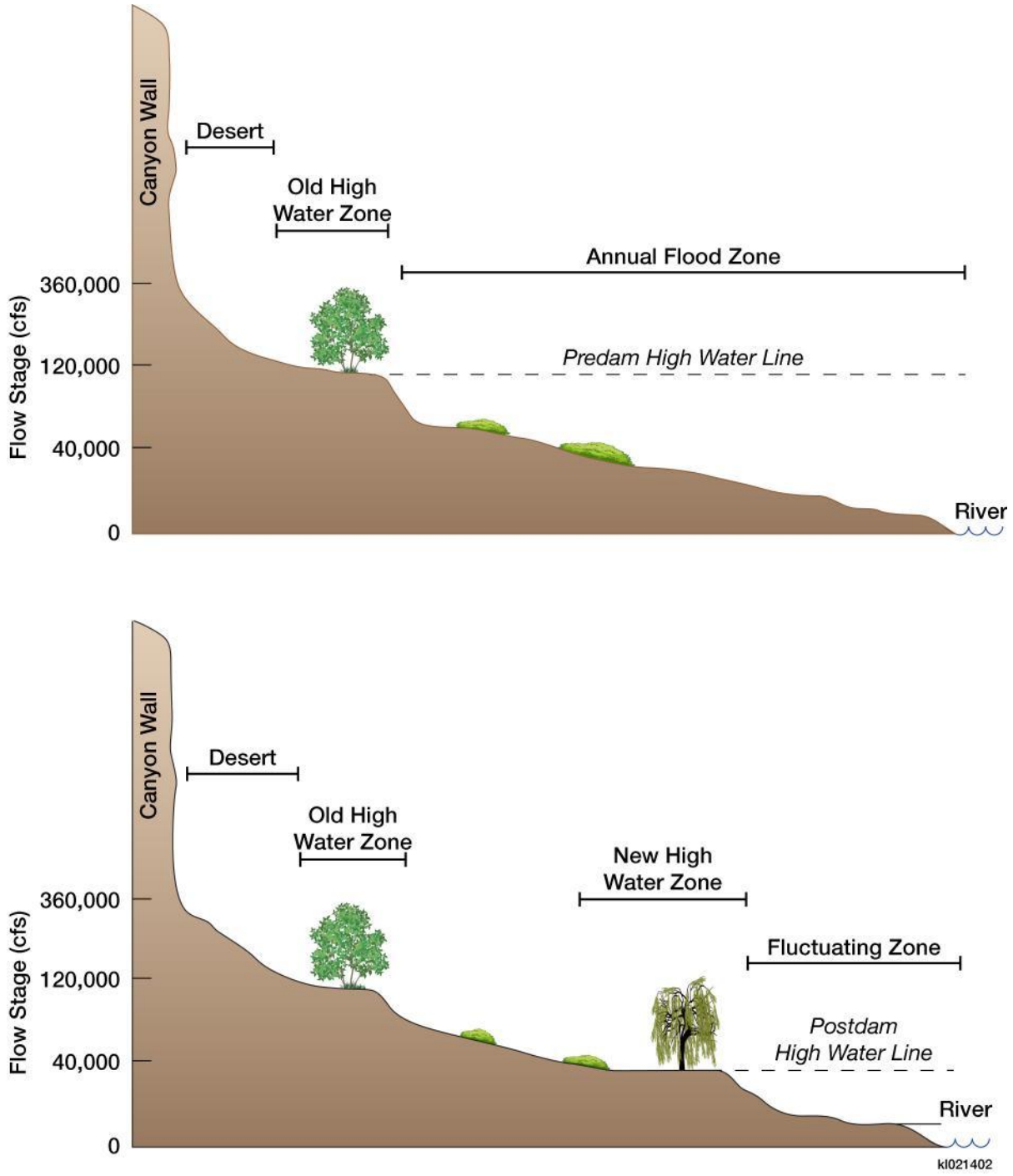

FIGURE 3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam (adapted from Reclamation 1995)

widespread marsh development occurred following the reductions of spring floods, with the number increasing downstream (Stevens et al. 1995). Of the 1,625 ac of riparian vegetation mapped in the New High Water Zone, approximately 5 ac represent marshes, or about 0.3% (because of the typically small size of fluvial marshes, they are underrepresented in the current map, which has a minimum mapping unit of 0.5 ha). Areas mapped as wetland vegetation, including cattails and common reed, in 2002 totaled roughly 10 ac (Ralston 2012; Kennedy and Ralston 2012). Marsh communities are generally dominated by a few species, varying by soil texture and drainage. Wet marsh communities occur on fine-grained silty loams on lower areas of eddy complex sandbars that are frequently inundated and are dominated by cattail and common reed. Loamy sands support an association of horseweed (*Conyza canadensis*), knotweed (*Polygonum aviculare*), and Bermuda grass (*Cynodon dactylon*) (Carothers and Aitchison 1976; Kearsley et al. 2006). Shrub wetland communities (with coyote willow, Emory seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000-cfs stage, that are less frequently inundated. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover after burial following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). On areas of higher stage elevations, short-lived plant species such as longleaf brickellbush, brownplume wirelettuce (*Stephanomeria pauciflora*), broom snakeweed (*Gutierrezia microcephala*), brittlebush, and Emory seepwillow colonize recently disturbed surfaces (Bowers et al. 1997; Webb and Melis 1996). While longer-lived species, such as Mormon tea, cactus (*Opuntia* spp.), and catclaw acacia (*Acacia greggii*), are not as quick to colonize disturbed areas, they are expected to continue to expand into lower stage elevations in the absence of disturbance. These species are found on surfaces that have not been disturbed for 7 to 28 years.

The population of Goodding's willow along the river below Glen Canyon Dam appears to have been affected by the reduction in flood flows on upper riparian terraces, has been in decline, and either no longer occurs at or does not reproduce at two-thirds of the sites where it previously existed (GCWC 2011; Mortenson et al. 2008). Along with the coarsening of substrates, the lack of springtime recruitment floods threatens remaining stands; however, high flows during the mid-1980s resulted in some establishment of Goodding's willow in the Grand Canyon (Mortenson et al. 2012; Ralston 2012). Restoration of Goodding's willow and several other native species has been a focus of NPS revegetation efforts.

Beavers (*Castor canadensis*) have reduced Goodding's willow within the canyon and may influence the invasion of resultant open areas (as well as areas of coyote willow herbivory) by tamarisk (Mortenson et al. 2008). Beavers may be more common along the river now due to the increase in post-dam availability of woody plants (Turner and Karpiscak 1980). In addition, Fremont cottonwood (*Populus fremontii*) recruitment along the river is nearly eliminated each year by beaver foraging on cottonwood seedlings, and very few Fremont cottonwood occur along the river below the dam (GCWC 2011).

Arrowweed, a dominant native woody species of both the Old and New High Water Zones, is adapted to burial by sediments deposited by floods (Ralston 2012). This drought-tolerant clonal species responds to burial by resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth (Ralston 2012). Arrowweed has characteristics of a primary colonizer and quickly occupies open sandbar areas. It spreads laterally by underground rhizomes

and is commonly found in dense monotypic stands with few individuals of other species intermixed (Ralston et al. 2014), thereby reducing species diversity in areas occupied. Because arrowweed interferes with meeting a management objective of open sand beaches in some areas, the NPS has removed it from targeted campsites.

A number of nonnative plant species, many of which are invasive species, occur throughout the riparian zone; among the most common species are tamarisk, camelthorn (*Alhagi maurorum*), Russian thistle (*Salsola tragus*), ripgut brome (*Bromus diandrus*), red or foxtail brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), yellow sweetclover (*Melilotus officinalis*), spiny sow thistle (*Sonchus asper*), Ravenna grass (*Saccharum ravennae*), perennial peppergrass (*Lepidium latifolium*), and Bermuda grass (Reclamation 2011d; NPS 2005a). Ralston concludes that operations since the 1996 ROD; Reclamation 1996) have facilitated the recruitment, establishment, and expansion of both native and exotic plant species (e.g., tamarisk) throughout the river corridor. Furthermore, a recent analysis of vegetation data collected by NPS staff from 2007 to 2010 demonstrated an overall increase in exotic plant cover, particularly in the New High Water Zone (Zachmann et al. 2013).

Tamarisk, a shrub or small tree usually less than 20 ft in height, has long been the most prominent of these invasive species. As noted above, tamarisk was present along the river long before construction of Glen Canyon Dam. Tamarisk along the Colorado River is a hybrid of at least two distinct species (including *T. ramosissima* and *T. chinensis*) (Ralston 2010). It has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where salinities are elevated or where water tables are lowered (Reclamation 2011b). Tamarisk plants accumulate salt on their leaf surfaces, which then accumulates in the surface layer of soil from dropped leaves (Ladenburger et al. 2006). The germination and establishment of native species can be adversely affected as surface soils increase in salinity, which can occur particularly in the absence of annual flooding and scouring, such as along regulated rivers.

High annual floods during the mid-1980s resulted in high tamarisk mortality, with surviving tamarisk located on upper riparian zone terraces; however, those floods also resulted in high levels of tamarisk establishment on elevations well above current river levels (Mortenson et al. 2012). Tamarisk establishment can increase when flood flows coincide with seed releases during spring and early summer (peaking in late May and early June); floods outside of that period result in little tamarisk recruitment (Mortenson et al. 2012; Stevens and Siemion 2012). Seedling survival is greatest when establishment is above the elevation of subsequent floods (Mortenson et al. 2012).

The tamarisk leaf beetle (*Diorhabda* spp.) has had a marked impact on the ecology of riparian zones in the Grand, Marble, and Glen Canyons in recent years. The beetle was discovered in 2009 near Navajo Bridge and at RM 12 and several locations, including Lees Ferry, in 2010; by 2011, it had become established along the Colorado River, occurring discontinuously from Glen Canyon Dam to RM 213, but primarily upstream of RM 27 and from RM 127 to RM 180, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Permanent monitoring plots established in 2010 near Lees Ferry show evidence of mortality in smaller individuals, plus defoliation rates of 75 to 100%. By late 2012, the tamarisk leaf beetle

was widely distributed in the Grand Canyon; as of 2015, there were reports of the beetle downstream past Diamond Creek. The splendid tamarisk weevil (*Coniatus* spp.) also occurs in the Grand Canyon), but much less is known about its abundance, distribution, and impacts. The beetle causes early and repeated defoliation of tamarisk during the summer months (Snyder et al. 2010; Hultine et al. 2010), which may eventually result in mortality after several successive years of defoliation. The long-term effects of the tamarisk leaf beetle and splendid tamarisk weevil on tamarisk abundance and distribution in Glen and Grand Canyons are currently not known; however, plant communities in which tamarisk is currently a dominant species will likely undergo compositional change (Shafroth et al. 2005). The extent of mortality within a tamarisk stand varies by site and may not be extensive; tamarisk may persist despite annual defoliation and may fluctuate with beetle populations (Nagler et al. 2012; Nagler and Glenn 2013). Both native and nonnative plant species may become established on sites of tamarisk mortality, although native species establishment may be slow, and future community composition and habitat characteristics would depend on a variety of site-specific factors, including site hydrology and microclimate, changes in nutrient dynamics, available seed sources, and active restoration efforts (Belote et al. 2010; Hultine et al. 2010; Shafroth, Merritt et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013).

Past flow regimes and past flow experiments provide evidence for the types and scale of potential impacts on vegetation from dam operations. The dynamics of large daily fluctuations on vegetation are known from dam operations prior to 1991. Large daily fluctuations increase the wetted area and thus the sandbar area available for colonization by wetland species; however, erosion exacerbated by fluctuations may limit the available bar area (Stevens et al. 1995). Increases in mean daily flow and daily inundation may remove low stage elevation vegetation and coarsen soil texture. Daily fluctuations also flatten vegetation within the range of fluctuating flows, export leaf litter, and coat leaf surfaces with silt (Stevens et al. 1995).

As a result of interim flows and MLFF, riparian vegetation moved into newly exposed areas and a shift to more upland species in most New High Water Zone vegetation patches was observed in Marble Canyon and Grand Canyon (Kearsley and Ayers 1996). The reduction of daily inundation frequency may increase colonization of wet marsh species at low stage elevations and promote the transition of higher elevation cattail/reed marshes to tamarisk/arrowweed vegetation (Stevens et al. 1995).

As noted above, riparian vegetation communities can be affected by dam operations through scouring and erosion during high flows, drowning, burial by new sediments, and reductions in soil moisture levels; consistent availability of water at low elevations (e.g., below 25,000 cfs) from elevated base flows can promote vegetation growth. Responses of riparian vegetation are affected by the timing, frequency, duration, and magnitude of the river's hydrology, as well as the variability between years and sequencing of flows (Ralston et al. 2014; Merritt et al. 2010). Additional factors related to flow that influence riparian vegetation include characteristics of deposited sediments (such as water-holding capacity, aeration, and nutrient levels), depth to groundwater, and anoxia in the root zone (Merritt et al. 2010). Flood flows during the mid-1980s resulted in a reduction of more than 50% in woody riparian vegetated area below the 60,000-cfs stage elevation due to scouring and drowning, with shallow-rooted species,

such as coyote willow, Emory seepwillow, and longleaf brickellia, experiencing the highest mortality (Ralston 2012). The export of sediments (particularly silts and clays and organic matter) coarsened substrates, affected nutrient concentrations, and reduced opportunities for subsequent recruitment of tamarisk and native shrubs, such as coyote willow and Emory seepwillow (Ralston 2012).

HFEs up to 45,000 cfs rework and rebuild riparian vegetation substrates on sandbars, rocky slopes, debris fans, and return-current channels (Kennedy and Ralston 2011). HFEs also make alluvial groundwater more available to plants growing near and above the 45,000-cfs stage elevation (see Section 4.6.2.1). Seed germination is generally maximized with damp-soil or shallow-water conditions. Floods enhance species diversity, reset successional stages, and prevent monocultures in marsh and wetland habitats, and periodic flooding and drying in wetlands is beneficial to diversity and productivity (Reclamation 2011d; Stevens et al. 1995). Following the first HFE in 1996, total vegetative cover on sandbars was reduced approximately 20%, but there was no significant change in wetland or woodland/shrubland area 6 months later (Kearsley and Ayers 1999). Vegetation may return quickly to sandbars following HFEs; herbaceous plant cover doubled within 6 months after the 2008 HFE, and clonal wetland plants such as common reed quickly established on sandbars and shorelines after the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Over the period of HFEs (since 1996), the long-term trend for vegetation on low stage-elevation sandbars has been one of rapid expansion in spite of the HFEs (Sankey, Ralston et al. 2015).

HFEs may result in minor short-term scouring of plants in the river channel and return current channel marsh communities followed by a rapid recovery, generally in around 6 months (Reclamation 2011b). HFEs, however, do not remove higher elevation vegetation (above 20,000 cfs; Ralston 2010). A September 2000 habitat maintenance flow of 31,000 cfs removed 57% of tamarisk seedlings, while native flood-adapted species increased, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Although some near-shore wetland plants were removed by the 1996 and 2008 HFEs, woody riparian plants were not (Kennedy and Ralston 2011). Very little change occurred in a Glen Canyon cattail/sedge marsh as a result of the 1996 HFE (Spence 1996). Minor increases in the height and cover of vegetation were observed, along with the appearance of three nonnative species that may have been dispersed by the HFE.

Low-elevation grass and shrub species in marshes in Marble Canyon and Grand Canyon may become buried with coarse sediment, followed by recovery within 6 to 8 months (Reclamation 2011b). Coyote willow, seepwillow, tamarisk, and some low-lying grasses and forbs were partially or completely buried by sediment during the 1996 and 2008 HFEs (Kennedy and Ralston 2011). Many wetland species are adapted to burial and regrowth; some, such as cattail, common reed, and willow, thrived after burial following the 1996 HFE (Kearsley and Ayers 1999), and coyote willow recovered quickly after the 2008 HFE (Kennedy and Ralston 2011). Burial during HFEs may favor such species and alter the riparian community structure (Kennedy and Ralston 2011). Soil seed banks can be reduced, as following the 1996 HFE when approximately 45% of the seeds and 30% of the species richness of seeds available for germination in near-surface soils was lost, due primarily to burial under sediment (Kearsley and Ayers 1999). Coarsening of sand grain size on sandbars as a result of sequential

HFEs tends to favor clonal species such as arrowweed, coyote willow, and common reed (Reclamation 2011b).

Although tamarisk has increased throughout the riparian corridor since construction of the dam, HFEs do not necessarily result in the spread of tamarisk. The 1996 and 2008 HFEs occurred in spring before tamarisk seed production. Tamarisk seedling establishment was uncommon following both HFEs (Kennedy and Ralston 2011; Kearsley and Ayers 1999). Tamarisk seedling establishment could be higher if HFEs occur during the time of seed production (Mortenson et al. 2012); however, native species such as willows can also benefit from HFEs during their seed production period (Kennedy and Ralston 2011). There was no evidence of spread of camelthorn, another nonnative riparian species, in study sites after the 1996 HFE (Kennedy and Ralston 2011; Kearsley and Ayers 1999).

Low steady flows have been shown to have effects on vegetation. Low steady flows can isolate some marsh patches and cause them to dry out (NPS 2005a). Mortality of horsetail at higher elevations above the water table was 55% during low steady flows in June through August of 2000 (Porter 2002). Those flows, which were preceded by higher spring flows, also resulted in prolific tamarisk seedling establishment on recently exposed sandbars at low and intermediate elevations in the Grand Canyon due to water availability and lack of competition (Porter 2002; Ralston 2011; Mortenson et al. 2012). Seedling production of native riparian species would have occurred prior to (willows) or later than (arrowweed, mesquite, and seepwillow [*Baccharis* spp.]) the low steady flows (Ralston 2011). Native plants also became established in low-elevation areas, but at a slower rate than tamarisk, potentially by vegetative reproduction (Porter 2002; Ralston 2011).

3.6.2.1 Tribal Perspectives on Vegetation

Vegetation plays an important role in the traditional cultural ties maintained by indigenous peoples within the Canyons. The American Indian Tribes with the closest ties to the Canyons have all identified culturally important plants in the Canyons. For example, plants are perceived by the Zuni as a vital part of the landscape and are sacred to the Zuni people. All plants were given to the Zuni by the ancestral, celestial, supernatural beings. The Zuni view all plants as the offspring of Mother Earth because it was she who gave the plants to the Zuni (Stevenson 1993). Native plants at *Chimik'yana'kya'de'a* are especially sacred as a result of their association with the Zuni emergence and migration. Zuni fraternities and esoteric groups consider these plants significant because of their past and present cultural importance and usage. Today, these plants are collected and used for ceremonial, religious, subsistence, and medicinal purposes.

Zunis use literally hundreds of plants for medicinal, cultural, or religious purposes. Stevenson (1914) documented 123 plants being used for various purposes. This amount vastly underestimates the true number of plants and their respective uses, because not all the uses of all plants are known to all Zuni people. General plant usage for consumption or other everyday use is commonly known to most Zunis. However, knowledge about some plants may be possessed only by the members of a particular religious or medicine society, and in some cases specific

esoteric uses may be known only by a particular Zuni individual. Plants played key roles in aiding the Zuni during their search for the middle place, as recounted in the Zuni emergence and migration narrative.

Zunis continue to rely on medicinal plants, herbs, fetishes, and other remedies that have served them through the ages. Camazine (1978) identified nearly 100 plants still used by Zunis for medical treatments. As a result of four previous monitoring trips through the Grand Canyon, the Zuni religious leaders preliminarily identified 32 plants of cultural importance in the spring during which these trips were taken; however, medicinal plants and plants with religious importance can be gathered as well during the other three seasons (winter, fall, and summer).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai ethnobotanical resources along the Colorado River corridor. These include the disruption of riparian and nearshore plant ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, as well as the related increased human activity that results in impacts such as trail-making and camping. Furthermore, changes in plant communities themselves are not the only causes of concern. The effects of these changes on all of the various forms of animal life that depend on plant communities for food, cover, nesting, and overall habitat must also be considered. Understanding of the intricate web of nature is often elicited through the study of Traditional Ecological Knowledge, one aspect of which acknowledges the past as a time when people and animals understood one another, and are still considered relatives

Many of the natural resources in the Canyons are considered cultural resources by the Tribes. Plants have an important role in Hopi culture; they are used in ceremonies and serve as clan totems, as medicines, in farming and food production, and for innumerable utilitarian purposes. During Hopi ethnobotanical research in the Canyons, 141 plant species were identified as culturally significant. Many important plant species specifically associated with water are found throughout the Canyons. Beyond the direct role plants play in human life, they are also recognized by the Hopi as a vital component of the ecosystem, which provides a habitat for many forms of animal life

According to the Navajo guiding principles, or teachings about plants, first and foremost, plants are people, and like people they move around, and they are male and female. To collect them, you must know them and talk with them. Even the use of plants in the food category involves prayers and offerings, which are also essential for medicinal plants. To know plants is to be familiar with the landscape, the seasons, cosmology, and the history of the area, and the movements and the genealogy of Navajo people. Plants have kept people alive. In the old days, if the corn did not grow or a drought occurred, or an enemy descended on you, knowledge of plants would guide you to water, provide nourishment, and indicate the time of the season. Like ceremonies, knowledge of plants encompasses all of these disciplines (Roberts et al. 1995). More than 57 plants that are utilized in Navajo ceremonies for traditional purposes and to support the overall health and well-being of the Navajo people have been identified in Navajo cultural resource inventory reports, as well as during annual monitoring trips (NNHPD 2015).

The many different kinds of plants that are present in and around the canyon provide food, medicine, homes, tools, and other items to the Navajo people. Many of the plants found within the Grand Canyon are considered Navajo medicines. For example, Ntl′ iz (offerings) were planted, specifically Baaashzhinii (jet), which then created nididlidii, Indian Rice Grass; the seed of this plant is black, and it is baashzhinii. Dootlizhii (Turquoise) was planted next and up grew Diwozhii Libaha; next abalone was planted and up grew Tl′ oh′ alts′ ozi; and next white shell was planted, and up grew Gahtsoh daa'. These plants provided food for sheep and horses (Roberts et al. 1995).

3.6.3 Special Status Plant Species

A number of special status plant species are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead (Table 3.6-2). None of these species are federally listed, proposed for listing, or candidates for listing. Several special status species are potentially within the influence of Glen Canyon Dam operations. Satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*) are all located within the range of daily operations. The Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), giant helleborine (*Epipactis gigantea*), and lobed daisy (*Erigeron lobatus*), located above the level of daily flows but below the 45,000-cfs stage elevation, could be affected by HFEs. The main populations of the primrose, helleborine, and daisy are in springs up tributaries away from the river. Mohave prickly pear is also found in sandy flats above the 45,000-cfs stage elevation. Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*) are located above the level of HFEs but potentially within their influence. Sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*) could be affected by changes in the elevation of Lake Mead.

Several special status species occurring within the Colorado River corridor are located outside of dam operational effects (Makarick 2015) and therefore were dismissed from consideration in the impact analysis. These include Grand Canyon cave-dwelling primrose (*Primula specuicola*), Grand Canyon beavertail cactus (*Opuntia basilaris* var. *longiareolata*), Kaibab agave (*Agave utahensis* ssp. *kaibabensis*), McDougall's yellowtops/Grand Canyon flaveria (*Flaveria mcdougallii*), Narrow phacelia/narrow scorpion weed (*Phacelia filiformis*), Desert rose/Grand Canyon rose (*Rosa stellata* ssp. *abyssa*), Canyonlands sedge/Kaibab sedge (*Carex curatorum*), Ragged rock flower (*Crossosoma parviflorum*), Button brittlebush/resin brittlebush (*Encelia resinifera*), Heermann's buckwheat (*Eriogonum heermannii* var. *argense*), Willow glowweed/burroweed (*Lorandersonia salicina*), Ringstem (*Anulocaulis leiosolenus* var. *leiosolenus*), Chaparral yucca/Our Lord's candle (*Hesperoyucca whipplei*), and Pillar false gumweed (*Chrysothamnus stylosus*). Sentry milk-vetch (*Astragalus cremnophylax* var. *cremnophylax*), a federally listed endangered species, is known only from the South Rim of the Grand Canyon near pinyon-juniper woodlands and therefore outside of dam operational effects.

TABLE 3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Camissonia specuicola ssp. *hesperia*	Grand Canyon evening primrose, Kaibab suncup	None	GCNP-SC	Sandy or gravelly beaches and dry washes, often on limestone substrates (Brian 2000); located below the 45,000-cfs stage elevation, potentially affected by HFEs; Lower Granite Gorge, below Diamond Creek, Separation Canyon to Spencer Canyon (AZGFD 2013).
Eriogonum viscidulum	Sticky buckwheat	NCE	BLM-S, GCNP-SC	Mojave mixed scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Astragalus geyeri	Geyer's milkvetch	NCE	BLM-S	Creosote bush scrub; Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Arctomecon californica	Las Vegas bear poppy	NCE, ASR	GCNP-SC, BLM-S	Desert scrub; near RM 45, Lake Mead shoreline (Reclamation 2000, 2007a); affected by increases in reservoir elevation.
Opuntia phaeacantha var. *mohavensis*	Mohave prickly pear	ASR	GCNP-SC	River level, length of Colorado River (Brian 2000); located below the 45,000-cfs stage elevation; potentially affected by HFEs.
Erigeron lobatus	Lobed daisy, lobed fleabane	None	GCNP-SC	Rocky slopes, beaches, in sandy soils; located below the 45,000-cfs stage elevation; potentially affected by HFEs; RM 15–237 (Brian 2000).
Epipactis gigantea	Giant helleborine	ASR	GCNP-Rare	Moist soil on seepage slopes, cliff bases, along rivers, hanging gardens and seeps; located below the 45,000-cfs stage elevation; potentially affected by HFEs; from Vasey's Paradise to Grand Wash Cliffs (RM 32–277) (Brian 2000).

TABLE 3.6-2 (Cont.)

Scientific Name	Common Name	State Status[a]	Federal Status[b]	Habitat/Location
Euphorbia aaron-rossii	Marble Canyon spurge, Ross spurge	None	GCNP-Rare	Loose, sandy soil of old river bars and dunes, occasional talus slopes and rocky ledges located above the 45,000-cfs stage elevation, but potentially within influence of HFEs in Glen Canyon; also RM 3.5–53 (Brian 2000; AZGFD 2013).
Imperata brevifolia	Satintail	None	GCNP-Rare	Rocky canyons and wet places; located within the influence of daily operations, Clear Creek to Diamond Creek (RM 83.5–225) (Brian 2000).
Leersia oryzoides	Rice cutgrass	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Lycopus americanus	American bugleweed	None	GCNRA-Rare	Wet marshes; located within the influence of daily operations; one patch at Leopard Frog Marsh RM –8.8L (NPS 2014b).
Ptelea trifoliata	Hop-tree	None	GCNRA-Rare	Located above the 45,000-cfs stage elevation, but potentially within influence of HFEs; RM –7 terrace, 1 small stand (NPS 2014b)

[a] State status codes include ASR = salvage restricted, Arizona Department of Agriculture; NCE = critically endangered, Nevada.

[b] Federal status codes include BLM-S = Bureau of Land Management sensitive; GCNP-Rare = Grand Canyon National Park rare; GCNP-SC = Grand Canyon National Park species of concern; GCNRA-Rare = Glen Canyon National Recreation Area rare; USFS-S = U.S. Forest Service sensitive.

3.7 WILDLIFE

This section describes those animal species found in the Colorado River Ecosystem downstream of Glen Canyon Dam to Lake Mead in both the riparian zone and adjacent upland vegetation communities. Along the river corridor, 90 mammals, 373 birds, 9 amphibians, 47 reptiles, and several thousand invertebrate species have been identified (NPS 2014b; Reclamation 1995; Stevens and Waring 1986b). Many wildlife species are habitat generalists, using ecosystems from both the riparian zone and upland communities to meet basic requirements. Some species are habitat specialists, requiring specific vegetation composition and structural components to meet their needs, and therefore may only occur within specific habitats within the river corridor. There is an ecological relationship between river flow and habitat for riparian and terrestrial wildlife, as illustrated in Figure 3.7-1 using birds as an example. Any changes to shoreline vegetation can affect wildlife habitat. In general, many wildlife species, including invertebrates, have benefited from increased riparian vegetation along the Colorado River corridor (King 2005).

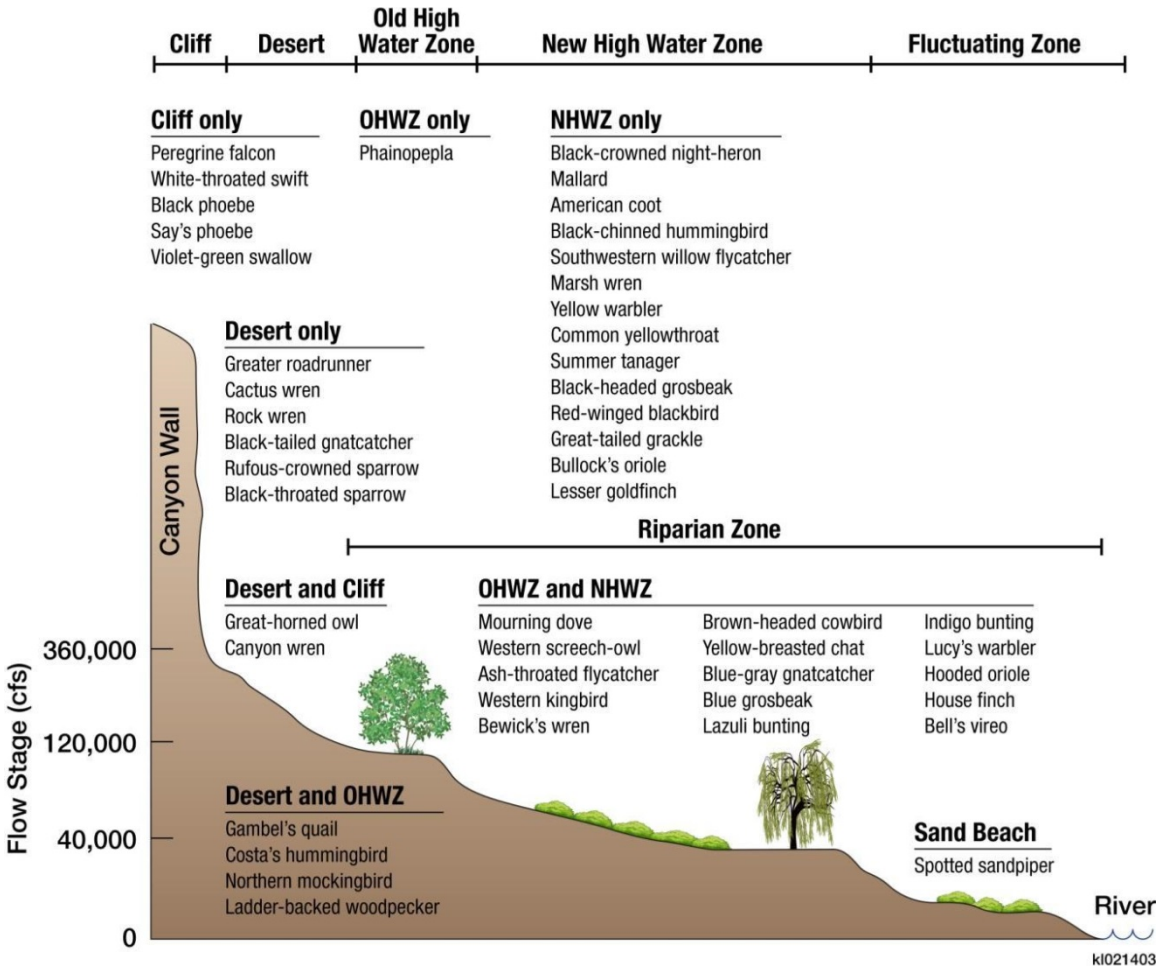

FIGURE 3.7-1 Riparian Zones Used by Nesting Birds (modified from Reclamation 1995)

3.7.1 Invertebrates

The riparian and terrestrial habitats along the Colorado River corridor through Glen, Marble, and Grand Canyons support a large and diverse invertebrate community. The increase in post-dam riparian vegetation increased the amount of habitat and forage for riparian and terrestrial invertebrates (Stevens and Waring 1986b). After construction of the dam, terrestrial insect populations were more abundant and diverse in the riparian zone than in the surrounding desert environment (Carothers and Aitchison 1976). Thousands of invertebrate species from over 260 families of arthropods are known to occur in the riparian corridor of the Grand Canyon (Stevens and Waring 1986b; Reclamation 1995). These invertebrate taxa are numerically dominated by terrestrial flies and adult forms of aquatic flies, herbivorous insects (especially cicadas, leafhoppers, and aphids), ground-dwelling forms of spiders and scorpions, beetles, and many different species of wasps, bees, and ants. These invertebrates fill a variety of ecological roles and serve as pollinators, regulate populations of other invertebrates, and provide food resources for many terrestrial and aquatic wildlife species. Invertebrates are discussed here based on the habitats they use. Threatened, endangered, and sensitive invertebrate species that may occur along the river corridor are discussed in Section 3.7.5.1.

Aquatic invertebrates downstream of Glen Canyon Dam form the food base for fish and other species at higher trophic levels. Dominant aquatic invertebrates include midges, blackflies, and the amphipod *Gammarus lacustris* (Section 3.5.1). Invertebrate species, particularly midges and blackflies, which develop in the river and emerge to complete their life cycles among riparian and terrestrial habitats, serve important ecological functions as potential prey to both aquatic and terrestrial organisms. For example, light trap sampling reveals that midge emergence peaks in lower Marble Canyon, but midge emergence is abundant throughout the river, both close to and distant from tributaries. Adult midges contribute to the terrestrial prey base from May through October (Kennedy, Muehlbauer, et al. 2014).

Most invertebrate species life cycles are entirely terrestrial. Ground-dwelling invertebrates, such as harvester ants (*Pogonomyrmex californicus*), occur at or just below the ground surface and are known to colonize camping beaches and other sandy areas. In addition to harvester ants, scorpions are also found on beaches (Carothers and Brown 1991). Before construction of the dam, annual flooding would remove invertebrate species from beach areas.

Other terrestrial invertebrates that inhabit riparian vegetation and open sand communities include cicadas, leafhoppers, armored scale insects, and robber flies. Invertebrate abundance and species richness among riparian vegetation largely depend on the supporting vegetation. For example, tamarisk is the most abundant woody plant along the river corridor, but it generally supports only four or five species of insects. Coyote willow, on the other hand, supports many species of insects. Occasional high invertebrate biomass in tamarisk communities results from outbreaks of leafhoppers (Carothers and Brown 1991), which provide an important food source for other invertebrates, amphibians, reptiles, birds, and mammals. In summer, insect biomass on tamarisk is often greater than in other riparian plant communities due to high flower numbers that attract insect pollinators. Therefore, tamarisk could increase overall biomass and diversity of arthropods (van Riper et al. 2008).

The tamarisk leaf beetle was intentionally introduced in the western United States in 2001 (Nagler and Glenn 2013) to help control or eradicate tamarisk, and were first observed downstream of Glen Canyon Dam in 2009 (Section 3.6.2). The beetle, which defoliates tamarisk, has been effective in killing large numbers of tamarisk along the river corridor downstream of Glen Canyon Dam. This die-off may have both negative and positive impacts for nesting bird species. For example, leaf beetle defoliation of tamarisk may reduce the suitability of available nest sites among tamarisk stands, but leaf beetles may also represent an important food source for birds (Nagler and Glenn 2013). However, along the Dolores River in southwestern Colorado, the diet of insectivorous birds consists of few tamarisk leaf beetles (2.1% by abundance and 3.4% by biomass) even though the beetles composed 24% and 35.4% of arthropod abundance and biomass, respectively, in the study area (Puckett and van Riper 2014).

3.7.2 Amphibians and Reptiles

More than 55 reptile and amphibian species occur downstream of Glen Canyon Dam, including 3 amphibian and 24 reptile species documented in the riparian zone of the river (Carothers and Brown 1991; Kearsley et al. 2006). The highest densities and diversity of amphibians and reptiles tend to occur in riparian areas nearer the river's edge due to the presence of water, abundant vegetation, and invertebrate food. The amphibian species along the river corridor are the canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Bufo punctatus*), and Woodhouse's toad (*Anaxyrus woodhousii*) (NPS 2014c). Amphibian breeding, egg deposition, and larval development generally occur in backwaters or along the shallow water of aquatic and riparian habitats. The northern leopard frog (*Lithobates pipiens*), identified as an AZ-SGCN (AZGFD 2012), is discussed in Section 3.7.5.2.

The most common lizard species along the river corridor are the side-blotched lizard (*Uta stansburiana*), western whiptail (*Aspidoscelis tigris*), desert spiny lizard (*Sceloporus magister*), and tree lizard (*Urosaurus ornatus*) (Kearsley et al. 2006). Tree lizards use shoreline habitats proportionally more than other reptile species (Kearsley et al. 2006). Within the New High Water Zone, lizards feed on harvester ants and other insects in close proximity to the river's edge (Carothers and Brown 1991). Warren and Schwalbe (1985) noted that lizard numbers in the New High Water Zone were lowest in dense tamarisk sites. Lizards in the New High Water Zone may prefer relatively open areas such as rocks and boulders, bare soil, sand, or litter. Other lizard species, such as the zebra-tailed lizard (*Callisaurus draconoides*), may be associated with sand substrates (Stevens 2012), the availability of which can be influenced by Glen Canyon Dam flows. The high and moderate densities of lizards along the shoreline and riparian habitats, respectively, are probably due to food availability on debris along the shoreline and in riparian plants (Warren and Schwalbe 1985).

Three chelonian species occur in the area: the spiny softshell (*Apalone spinifera*), Agassiz's desert tortoise (*Gopherus agassizii*), and Morafka's desert tortoise (*Gopherus morafkai*). The spiny softshell was an introduced species into the Colorado and Gila Rivers in Arizona, and now also occurs in California, Utah, Nevada, and New Mexico (Riedle 2006). It occurs in the lower Grand Canyon/upper Lake Mead area. The Agassiz's desert tortoise (formerly known as the desert tortoise – Mojave population), a federally threatened species,

inhabits the north side and west end of the Grand Canyon (NPS 2005a). It inhabits Mojave desertscrub. The Morafka's desert tortoise (formerly known as the desert tortoise – Sonoran population) occurs along the southwestern end of the Grand Canyon and around Lake Mead. It generally inhabits creosote bush flats in basins and mountain bajadas, occasionally occurring on rocky slopes. The Joshua tree forest along the rim of the Lower Gorge is an important component of its habitat (NPS 2005a). As both species spend much of their lives in burrows, neither occurs in areas inundated by Colorado River flows.

More than 20 snake species occur within the greater Grand Canyon area (NPS 2014c). The more common species in riparian areas downstream of Glen Canyon Dam include the Grand Canyon pink rattlesnake (*Crotalus viridis abyssus*), speckled rattlesnake (*Crotalus mitchellii*), black-tailed rattlesnake (*Crotalus molossus*), common king snake (*Lampropeltis getula*), and gopher snake (*Pituophis catenifer*) (Kearsley et al. 2006; NPS 2014c).

3.7.3 Birds

Spence et al. (2011) reported 316 bird species from the GCNRA, and Gatlin (2013) reported 362 species from the Grand Canyon. NPS (2014c) reported that 373 bird species have been recorded in the greater Grand Canyon region, with 250 species documented from the river corridor. Riparian habitats along the river provide breeding habitat, migratory stopover sites, and wintering areas for birds throughout the year (Spence 2006; Spence et al. 2011; Gatlin 2013). Several of the species that breed along the river corridor are considered obligate riparian species. These species include the Lucy's warbler (*Oreothlypis luciae*), Bell's vireo (*Vireo bellii*), common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-breasted chat (*Icteria virens*), and black-chinned hummingbird (*Archilochus alexandri*). The brown-headed cowbird (*Molothrus ater*), a brood parasite, is also relatively common during the breeding season (Spence 2006; Spence et al. 2011; Gatlin 2013).

Birds that nest in the riparian zone along the river corridor (Figure 3.7-1) are directly and indirectly affected by Colorado River flows. River flow influences the distribution and composition of riparian vegetation, which affects invertebrate abundance (prey) and nest site availability (Carothers and Brown 1991). Only the species that nest right at the water's edge are directly influenced by fluctuating flows (Spence 2006). Important correlates with bird species richness and abundance include canopy cover, size and shape of riparian patches, and canopy volume and structure (Sogge et al. 1998; Spence 2006). The abundance of many bird species that use riparian areas (in the lower Colorado River) was highest at intermediate tamarisk levels (40–60%). In tamarisk-dominated habitats, the highest number of birds per census point occurred in areas where native vegetation composed 20–40% of the habitat. Bird numbers continue to increase with increasing amounts of native vegetation up to about 60%, but did not increase in numbers beyond that point (van Riper et al. 2008). Wintering birds did not show a significant relationship with the amount of tamarisk in the habitat. They are not strongly associated with vegetation structure but rather with habitats that provide abundant food sources of fruit and seeds (van Riper et al. 2008).

Of the 30 bird species that nest in the riparian zone, at least 23 eat insects or feed insects to their young. Other birds that do not nest in the riparian zone may still feed on insects within this zone. Yard et al. (2004) examined the diets of six insectivorous bird species along the Colorado River in GCNP. All species consumed similar quantities of caterpillars and beetles, but use of other prey taxa varied. Nonnative leafhoppers (*Opsius stactagolus*) that inhabit tamarisk made up a large portion of Lucy's warbler diets (49%); ants made up 82% of yellow-breasted chat diets; and the adult stage of aquatic midges made up 45% of yellow warbler diets. Overall, terrestrial insects made up 91% of bird diets compared to 9% of prey from adult insects that emerged from aquatic habitats (Yard et al. 2004).

The winter terrestrial bird community is diverse, with 75 species recorded. Diversity peaks in the lower portion of the Grand Canyon, particularly below RM 205 (Spence 2006). The most common wintering terrestrial species are migrants, with ruby-crowned kinglet (*Regulus calendula*) being most abundant followed by white-crowned sparrow (*Zonotrichia leucophrys*), dark-eyed junco (*Junco hyemalis*), and song sparrow (*Melospiza melodia*). Most of the winter terrestrial birds feed primarily on fruit and seeds (Schell 2005; van Riper et al. 2008).

More than 40 waterbird species inhabit the river corridor (Spence 2006; Spence et al. 2011; Gatlin 2013). Waterbirds include waterfowl (e.g., ducks and geese), wading birds (e.g., herons), and shorebirds (e.g., sandpipers and killdeers). Waterfowl are present mainly during the winter months, while wading birds and shorebirds occur primarily as migrants or during summer (Stevens, Buck, et al. 1997). The winter waterfowl density in portions of the Grand Canyon can be large; 31 species have been reported between Lees Ferry and Soap Creek, at a density of up to 250 individuals per mile (Spence 2014b). Common waterfowl species include American coot (*Fulica americana*), American widgeon (*Anas americana*), bufflehead (*Bucephala albeola*), common goldeneye (*B. clangula*), common merganser (*Mergus merganser*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), lesser scaup (*Aythya affinis*), mallard (*A. platyrhynchos*), ring-necked duck (*Aythya collaris*), and Canada goose (*Branta canadensis*). Other than great blue heron (*Ardea herodias*) and spotted sandpiper (*Actitis macularia*), which are fairly common winter and summer residents along the river, wading birds and shorebirds are rare in this area (Kearsley et al. 2003; Spence 2006). Increased waterfowl numbers downstream of Glen Canyon Dam developed in response to increased aquatic productivity and open water, which provides wintering habitat for aquatic birds (NPS 2013b). Fish-eating birds in the Grand Canyon include herons, gulls, mergansers, bald eagles (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*) (Wasowicz and Yard 1993).

Several bird species appear to benefit from increased riparian habitat and river clarity and productivity resulting from Glen Canyon Dam operations. For example, the increase in riparian vegetation resulting from dam operations is believed to have resulted in the range expansion of breeding songbirds such as Bell's vireo (Brown et al. 1983; LaRue et al. 2001). Increases in abundance and species richness of aquatic bird populations have been attributed to increased river clarity and productivity associated with Glen Canyon Dam operations (Spence 2006). The majority of waterfowl tend to concentrate in the upper portion of the Grand Canyon due to the greater primary productivity that benefits dabbling ducks and greater water clarity for diving ducks. Recently, a large great blue heron rookery was established on both sides of the Colorado River just below Glen Canyon Dam. In May 2013, there were 22 active nests and an estimated

60 to 80 individuals. These birds benefit from the increased availability of prey from higher trout productivity of recent years and the increased water clarity. A pair of ospreys successfully nested at the base of Glen Canyon Dam in 2014 (Spence 2014a,b).

Threatened, endangered, and sensitive bird species that may occur along the river corridor are discussed in Section 3.7.5.3.

3.7.4 Mammals

More than 90 mammal species occur downstream of Glen Canyon Dam (NPS 2014c), of which approximately 34 species occur along the river corridor (Carothers and Aitchison 1976; Suttkus et al. 1978; Kearsley et al. 2006). Only three mammal species in the project area require aquatic habitats: beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter (*Lontra canadensis*). Muskrats are extremely rare in the Grand Canyon, but are occasionally observed in the Little Colorado River (Reclamation 2011d). They construct bank dens or use dens of other animals (Erb and Perry 2003). Despite occasional reports of river otters in the Grand Canyon, no reliable documentation of their presence has occurred since the 1970s (Kearsley et al. 2006). River otters are classified as extirpated in the Grand Canyon (Reclamation 2011d) despite the apparent presence of suitable habitat (Carothers and Brown 1991).

Beaver occur throughout the river corridor, from Glen Canyon Dam to the Grand Wash Cliffs where riparian vegetation is well established. Beavers cut willows, cottonwoods, tamarisk, and shrubs for food and can substantially affect riparian vegetation (Carothers and Brown 1991; Dettman 2005). For example, Mortenson et al. (2008) hypothesized that beaver may indirectly promote the invasion of nonnative tamarisk in riparian communities by preferentially feeding on native competitors such as coyote willow. Beavers in the Grand Canyon excavate lodges in the banks of the river, with the entrance located underwater and a tunnel leading up under the bank to a living chamber. Increases in the population size and distribution of beavers in Glen Canyon and the Grand Canyon have occurred since the construction of the dam. These increases are likely due to the increase in riparian vegetation and relatively stable flows (Carothers and Brown 1991; Kearsley et al. 2006).

Small mammal abundance and richness are greatest in the Old High Water Zone where steeper slopes, rock falls, and canyon wall crevices provide greater structure for wildlife habitat (NPS 2005a). Rodents (mice) are the most abundant small mammals within the riparian zone. Common species include the cactus mouse (*Peromyscus eremicus*), rock pocket mouse (*Chaetodipus intermedius*), and rock squirrel (*Spermophilus variegatus*) (Carothers and Brown 1991). The deer mouse (*Peromyscus maniculatus*) is the only mouse species that depends directly on the riparian zone (Reclamation 1995).

A least 20 species of bats are documented downstream of Glen Canyon Dam (NPS 2014c). Bats in the Grand Canyon typically roost in rock crevices, caves, and trees of desert uplands but forage on insects along the Colorado River and its tributaries. The most common bat species along the river corridor are the western pipistrelle (*Pipistrellus hesperus*),

American free-tailed bat (*Tadarida brasiliensis*), pallid bat (*Antrozous pallidus*), Yuma myotis (*Myotis yumanensis*), and California myotis (*Myotis californicus*). Bats are also important prey for raptors such as the peregrine falcon (*Falco peregrinus*) (Carothers and Brown 1991).

A number of mammal species occur below Glen Canyon Dam. These include cougar (*Puma concolor*), coyote (*Canis latrans*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), American badger (*Taxidea taxus*), raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), western spotted skunk (*Spilogale gracilis*), American hog-nosed skunk (*Conepatus leuconotus*), ringtail (*Bassariscus astutus*), and long-tailed weasel (*Mustela frenata*). Omnivorous scavengers such as the ringtail and western spotted skunk have likely increased in numbers due to an increase in riparian habitat and, more importantly, increases in campers and river runners (Dettman 2005).

Large ungulates occurring in the Grand Canyon include the desert bighorn sheep (*Ovis canadensis nelsoni*) and mule deer (*Odocoileus hemionus*). The Grand Canyon contains one of the largest and most continuous naturally persisting populations of desert bighorn sheep in North America (Bendt 1957; Guse 1974; Wilson 1976; Walters 1979; Holton 2014). GCNP has prioritized the need to inventory and monitor bighorn sheep, and AZGFD lists desert bighorn sheep as an AZ-SGCN (AZGFD 2012). The Navajo Nation listed this subspecies as Group 3 (highly likely to become extinct throughout its range on the Navajo Nation).

Bighorn sheep in the Grand Canyon occupy an environment that is unique relative to other desert bighorn sheep ranges. Most desert bighorn sheep populations occupy arid mountain ranges with limited (largely point) water sources and are near enough to other populations for effective dispersal and interbreeding. By contrast, bighorn sheep in the Grand Canyon live in a comparatively isolated, very deep canyon with abundant free water along the bottom (Holton 2014). Bighorn sheep routinely use free water and do not often move farther than 1.2 to 5 mi from water sources (Turner et al. 2004; Epps et al. 2007; Longshore et al. 2009). Bighorn sheep in the Grand Canyon routinely come to the river to drink and forage during the summer months (Carothers and Brown 1991). Holton (2014) reported that most ewes in the Grand Canyon remained near the river year-round, rarely moving more than a few hundred yards above the river.

Human-related barriers that restrict or eliminate dispersal to and colonization of suitable ranges affect the viability of desert bighorn sheep (Bleich et al. 1990; Epps et al. 2007). Swift wide rivers are noted to effectively delimit bighorn ranges (Graham 1980; Wilson et al. 1980; Smith and Flinders 1991). The Colorado River likely serves as a natural impediment for interbreeding and connectivity between populations (Holton 2014). Bighorn in the Grand Canyon have not been seen crossing the Colorado River since construction of Glen Canyon Dam. However, some individual bighorns have been more genetically similar to bighorn herds from the opposite side of the river, suggesting that recent ancestors crossed the river (Holton 2014). Prior to construction of the dam, seasonally low water along the Colorado River likely allowed movement across the river. Early naturalists at the Grand Canyon speculated that a bighorn, before the dam was built, could perhaps boulder-hop across the Colorado River without ever touching water. Consistent high flows of the Colorado River have likely created a

formidable barrier, eliminating seasonal movements of bighorn sheep across the river and potentially restructuring the population in GCNP over the last 50 years (Holton 2014).

Studies also indicate that bighorn sheep populations may be limited through resource competition with feral burros (*Equus asinus*). In areas of sympatry, the shared foods consumed by burros may be twice the amount consumed by bighorn sheep. The burro is apparently a superior competitor compared to bighorn sheep. Following competitive equilibrium, the bighorn sheep would be relegated mainly to surviving in the most rugged habitats that could not be efficiently exploited by burros (Seegmiller and Ohmart 1981). Carothers (1977) reported that burros had affected natural communities in the three distinct plant associations (pinyon-juniper woodlands, high desert blackbrush community, and Mojave Desert vegetation type) that occur below the rims of the Grand Canyon. The most widespread impact of burro-related change was the reduction and elimination of palatable grasses and their replacement by unpalatable shrubs. Burro activity also increased soil compaction and accelerated soil loss (Carothers 1977). Burro control has been conducted in the Grand Canyon in an attempt to prevent them from denuding plateaus of grass and other forage plants consumed by native big game species such as bighorn sheep (Wright 1992). Low numbers of burros remain in the western portion of GCNP and are removed whenever possible (NPS 2005a).

Mule deer occur in relatively low densities along the river corridor as compared to the densities on the North and South Rims of the Grand Canyon. Small herds of deer are commonly seen along the river in the upper reaches of the canyon, from Buck Farm to Kwagunt Canyons. Anecdotally, mule deer have been observed swimming across the river (NPS 2014c).

3.7.5 Special Status Wildlife Species

Threatened, endangered, and sensitive wildlife species include species that may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are any of the following:

- Listed or proposed for listing as threatened or endangered plant and wildlife species under the ESA (including experimental, nonessential populations) and designated and proposed designated critical habitat;
- Candidates for listing as threatened or endangered species under the ESA;
- State of Arizona Species of Greatest Conservation Need (AZ-SGCN); or
- Bald or golden eagles protected by the Bald and Golden Eagle Protection Act of 1940 (BGEPA).

Eleven threatened, endangered, and sensitive wildlife species may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead. These species and their critical habitats are discussed below.

3.7.5.1 Invertebrates

The Kanab ambersnail (*Oxyloma haydeni kanabensis*) (Table 3.7-1) is the only threatened, endangered, or sensitive invertebrate species that occurs along the Colorado River in the Grand Canyon. The Kanab ambersnail was listed as an endangered species under the ESA on April 17, 1992 (FWS 1992). However, recent evidence from anatomical and molecular genetics studies indicates that this is a geographically widespread taxon whose listing under the ESA may have been incorrect (Littlefield 2007). In a study of *Oxyloma* specimens collected from 12 locations throughout the western United States, including Kanab ambersnail from the Grand Canyon, morphometric and genetic results indicated that the Kanab ambersnail can be regarded as a member of the same species as the other *Oxyloma* populations analyzed (Culver et al. 2013). However, until this taxonomic change occurs, the Kanab ambersnail remains a listed species (FWS 2011b). No critical habitat is designated for this species.

Globally, the Kanab ambersnail is only found in three locations. Two of these are within the Grand Canyon: the riparian vegetation at Vasey's Paradise and Elves Chasm. Vasey's Paradise is at RM 31.5 and Upper Elves Chasm is at RM 116.6. The latter population was created from snails translocated from Vasey's Paradise (Sorensen and Nelson 2000; FWS 2008). The locations of these sites within the Grand Canyon are shown in Figure 3.7-2. The third location for the Kanab ambersnail is Three Lakes near Kanab, Utah (FWS 1995a).

The Kanab ambersnail lives in association with watercress (*Nasturtium officinale*), cardinal monkeyflower (*Mimulus cardinalis*), cattails (*Typha*), sedges (*Carex*), and rushes (*Juncus*). Populations within the Grand Canyon occur in areas with water sources originating from limestone or sandstone geologic strata (Spamer and Bogan 1993; FWS 1995a). The increase in cover, reduction in beach-scouring flows, and introduction of the nonnative watercress led to a >40% increase in suitable Kanab ambersnail habitat area at Vasey's Paradise compared to pre-dam conditions (Stevens, Protiva, et al. 1997).

Kanab ambersnails live 12 to 15 months and are capable of self-fertilization. Mating and reproduction occur from May to August. Subadults dominate the overwinter population. Snails enter dormancy in October–November and become active in March–April. Overwinter mortality ranges between 25 and 80% (Stevens, Protiva, et al. 1997; IKAMT 1998). During mild winters, they can continue their life cycle without dormancy or may go in and out of dormancy several times throughout the winter (Sorensen and Nelson 2002).

Based on annual survey data, live counts of Kanab ambersnails at Vasey's Paradise declined in 2011 from previous years, although the ambersnail habitat at Vasey's Paradise was in overall good condition in 2011. At Elves Chasm, live counts of ambersnails remained higher in 2011 than previous years, and habitat at this location was in good condition in 2011 (Sorensen 2012). The population at Vasey's Paradise generally occurs at elevations above 33,000-cfs flows. However, as much as 7.3% of the Vasey's Paradise population occurs below the elevation of 33,000 cfs flow and as much as 16.4% of the population occurs below the elevation of 45,000 cfs flow. The Elves Chasm population is located above the elevation of 45,000-cfs flow (Reclamation 2011d).

TABLE 3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream from Glen Canyon Dam
Invertebrates			
Kanab ambersnail	*Oxyloma haydeni kanabensis*	ESA-E; AZ-SGCN	Known at only two locations within the Grand Canyon: Vasey's Paradise and Elves Chasm. These spring-fed sites occur along the river corridor. Lives in association with watercress (*Nasturtium*), monkeyflower (*Mimulus* spp.), cattails (*Typha* spp.), sedges (*Carex* spp.), and rushes (*Juncus* spp.).
Amphibians and Reptiles			
Northern leopard frog	*Lithobates pipiens*	AZ-SGCN	Presumably extirpated from Glen and Grand Canyons.
Birds			
American peregrine falcon	*Falco peregrinus*	AZ-SGCN	Common along the river corridor in summer, with about 100 pairs nesting along the cliffs of the inner Grand Canyon. Most migrate south in winter. In the Grand Canyon, common prey items in summer include riparian bird species, many of which feed on invertebrates that emerge out of the Colorado River and the adjacent riparian zone. In winter, a common prey item is waterfowl.
Bald eagle	*Haliaeetus leucocephalus*	AZ-SGCN; BGEPA	Wintering populations are known to occur in Marble Canyon and the upper half of the Grand Canyon. Wintering individuals are known to occur at tributary confluences.
California condor	*Gymnogyps californianus*	ESA-XN; AZ-SGCN	An experimental nonessential population occurs within the Grand Canyon. Releases of condors near the Grand Canyon began in 1996. The beaches of the Colorado River through the Grand Canyon are frequently used by condors for drinking, bathing, preening, and feeding on fish carcasses. An increase in interactions between condors and recreationists within the Grand Canyon has been observed.
Golden eagle	*Aquila chrysaetos*	AZ-SGCN; BGEPA	Rare to uncommon permanent resident and a rare fall migrant. Prefer rugged terrain of cliffs and mesas, and nests on cliff ledges. Migrants use sheer cliffs of the Glen Canyon area to hunt. Feeds on mammals, birds, and reptiles.

TABLE 3.7-1 (Cont.)

Common Name	Scientific Name	Status[a]	Habitat and Distribution Downstream of Glen Canyon Dam
Birds (Cont.)			
Osprey	*Pandion haliaetus*	AZ-SGCN	Large numbers use the Colorado River corridor during fall migration, usually August–September with a peak in late August. An osprey pair successfully nested near the base of Glen Canyon Dam in 2014.
Ridgway's rail (Yuma)	*Rallus obsoletus yumanensis*	ESA-E; AZ-SGCN	Casual summer visitor to marshy mainstem riparian habitats below Separation Canyon (e.g., in the Spencer Canyon and Burnt Springs areas near RM 246 and RM 260, respectively). Sight records in the study area are quite distant from its breeding range on the lower Colorado River.
Southwestern willow flycatcher	*Empidonax traillii extimus*	ESA-E; AZ-SGCN	Observed throughout the Grand Canyon in riparian habitats along the river corridor, including those dominated by invasive tamarisk. In recent years, flycatchers have consistently nested along the river corridor as new riparian habitat, primarily tamarisk, has developed in response to flow regimes. Resident birds have been documented in a small stretch of Marble Canyon and the lower Canyon near the inflow of Lake Mead.
Western yellow-billed cuckoo	*Coccyzus americanus occidentalis*	ESA-T; AZ-SGCN	Known to occur at a number of sites in the Grand Canyon near the Lake Mead National Recreation Area delta. The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, surveys for this species at these sites resulted in no detections in 2007.
Mammals			
Spotted bat	*Euderma maculatum*	AZ-SGCN	Rarely encountered throughout the State of Arizona, but may occur in areas near cliffs and water sources. Roosts primarily in crevices and cracks in cliff faces. Bats have been known to roost in cliff faces along the river corridor. Foraging may occur in riparian areas in the action area.

[a] ESA = Endangered Species Act; E = listed as endangered; T = listed as threatened; XN = experimental nonessential population; AZ-SGCN = Arizona Species of Greatest Conservation Need; BGEPA = Bald and Golden Eagle Protection Act.

Sources: AZGFD (2001c, 2002d–h, 2003b, 2006b, 2008, 2011a–b, 2012); FWS (1967; 1992; 1995a,b; 1996; 2014b); Gatlin (2013); NatureServe (2014); NPS (2015a); Reclamation (1995, 2007d).

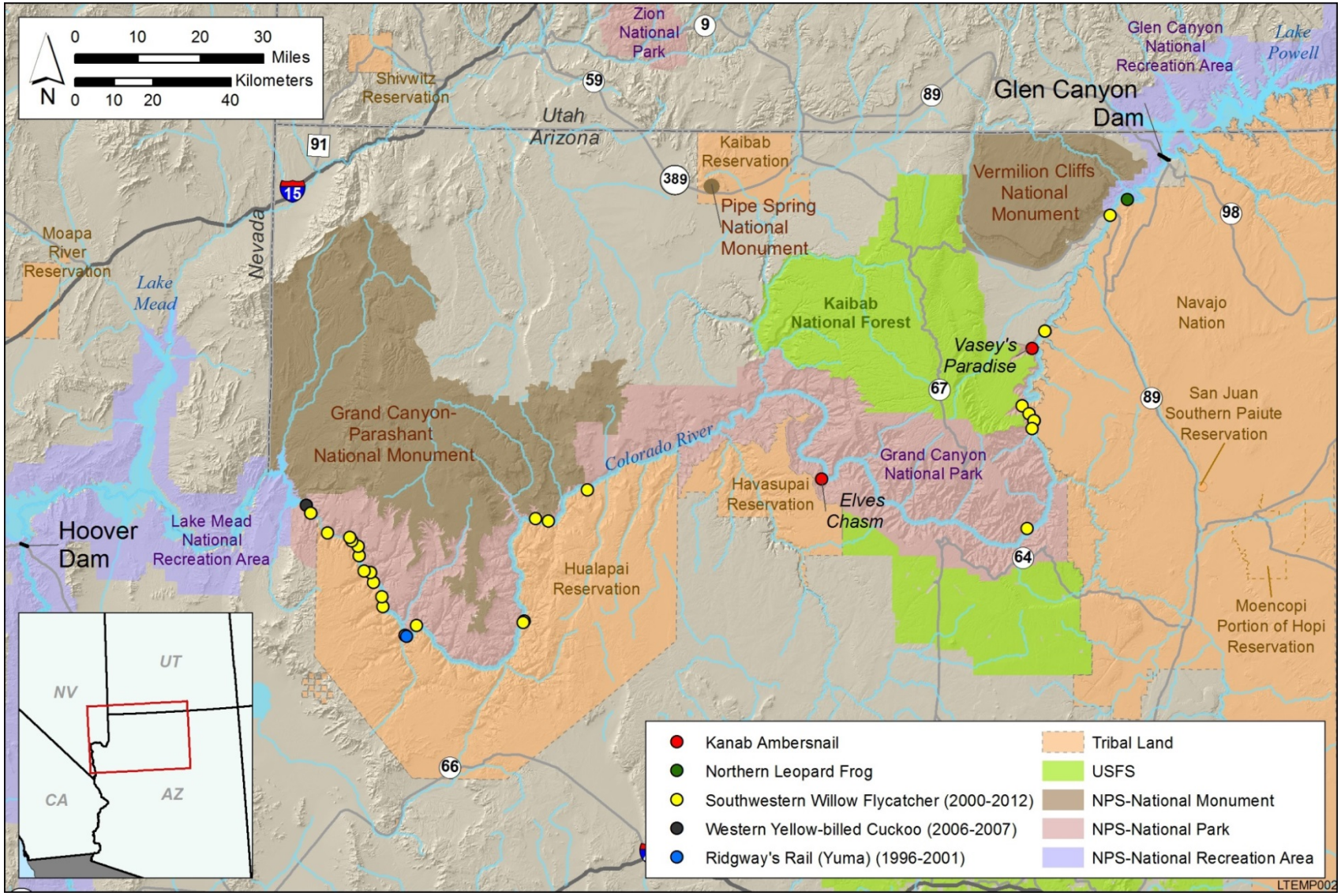

FIGURE 3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor (Sources: Drost et al. 2011; FWS 2011b; Johnson et al. 2008; NPS 2013e; Stroud-Settles 2012, 2013)

3.7.5.2 Amphibians and Reptiles

The northern leopard frog (*Lithobates pipiens*) is the only threatened, endangered, or sensitive amphibian or reptile species that occurred recently along the Colorado River downstream from Glen Canyon Dam (Table 3.7-1). Although the northern leopard frog is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). In 2006, the FWS was petitioned to list the frog in 18 western states but, in 2011, the agency found that listing of this species was not warranted (76 FR 61896). The northern leopard frog occurs in northeastern and north-central Arizona in and near permanent water with rooted aquatic vegetation (AZGFD 2002h). Populations of the northern leopard frog along the lower Colorado River have declined since the construction of Glen Canyon Dam. Leopard frogs have disappeared from 70% of the known sites above and below Glen Canyon Dam, and there appear to be declines among some of the remaining populations (Drost 2005; Drost et al. 2011). Populations above the dam are declining for a number of reasons, particularly due to the introduction of nonnative fishes and changes in habitat. In years when the reservoir is full, nonnative fishes can move into tributary canyons occupied by the northern leopard frog in Glen Canyon.

The leopard frog breeds from mid-March to early June. Females lay up to 5,000 eggs. The tadpoles hatch in about a week and metamorphosis occurs in about 3 months (AZGFD 2002g). Tadpoles consume algae, plant tissue, organic debris, and small invertebrates; while adults prey on invertebrates and rarely small vertebrates (AZGFD 2002h).

The only known population of the northern leopard frog below the dam was located in Glen Canyon in a series of off-channel pools at RM 8.8 (Figure 3.7-2). Marsh habitat at this location was fed by a natural spring. Dominant vegetation included water sedge (*Carex aquatilis*) and southern cattail (*Typha domingensis*). Inundation at this site occurs at approximately 21,000 cfs. Following the experimental flood of 1996, the number of frogs at this location was estimated at a high of 177 individuals (Reclamation 2008c). Since that time, the population size has decreased. In 2004, only two adults were found (Drost 2005), and the northern leopard frog has not been observed since (Drost et al. 2011). It is assumed that the northern leopard frog population at this site has been lost due to loss of pond and marsh habitat. The species is presumed extirpated in Glen and Grand Canyons (downstream from Lees Ferry).

No listed or sensitive reptile species occur in the river corridor downstream of Glen Canyon Dam.

3.7.5.3 Birds

Threatened, endangered, and sensitive bird species that may occur in the aquatic and riparian habitats along the Colorado River downstream of Glen Canyon Dam include the American peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), California condor (*Gymnogyps californianus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*), southwestern willow flycatcher (*Empidonax traillii extimus*), and western yellow-billed cuckoo (*Coccyzus americanus occidentalis*). The distribution, habitat, and population trends of these species along the river

corridor downstream of Glen Canyon Dam are described below and summarized in Table 3.7-1. The Mexican spotted owl (*Strix occidentalis lucida*; federally listed as threatened) is known to occur in the Grand Canyon but typically inhabits higher elevation forested side canyons above the river corridor (Bowden 2008).

American Peregrine Falcon

The American peregrine falcon was listed as endangered under the ESA on June 2, 1970. Following restrictions on organochlorine pesticides in the United States and Canada, and implementation of various management actions, including the release of approximately 6,000 captive-reared falcons, recovery goals were substantially exceeded in some areas, and on August 25, 1999, the falcon was removed from the federal list of threatened and endangered species (FWS 1999). This species is identified as an AZ-SGCN (AZGFD 2012).

Although peregrine falcons are uncommon year-round residents in the project area, the population has gradually increased since the 1970s (Carothers and Brown 1991). Peregrine falcons, which generally mate for life, nest regularly in Marble Canyon between Lees Ferry and the Little Colorado River confluence where cliffs >150 ft are abundant (Schell 2005). About 100 pairs of peregrine falcons nest along the cliffs of the inner Grand Canyon (NPS 2014c). In Arizona, peregrine falcons return to breeding areas from mid-February to mid-March, with egg laying occurring anytime from mid-March through mid-May. Fledging occurs from May to August (AZGFD 2002g). In the Grand Canyon, common prey items in summer include the white-throated swift (*Aeronautes saxatalis*), swallows, other song birds, and bats (Carothers and Brown 1991; Stevens et al. 2009). In winter, most adult falcons migrate south. For those falcons that remain for the winter, waterfowl is a common prey item (Schell 2005).

Bald Eagle

The bald eagle was originally listed as an endangered species under the ESA in 1967 and down-listed to threatened status in 1995. It was removed from the federal list of threatened and endangered species on July 9, 2007 (FWS 2007b). It is still federally protected under the BGEPA. This species is identified as an AZ-SGCN (AZGFD 2012).

A wintering concentration of bald eagles was first observed in the Grand Canyon in the early 1980s, and numbers had increased by 1985 (Brown et al. 1989; Brown and Stevens 1997). Territorial behavior, but no breeding activity, has been observed in the canyon. This wintering population was monitored through the 1980s and 1990s in Marble Canyon and the upper half of the Grand Canyon. The number of Grand Canyon bald eagles during the winter (late February and early March) ranged from 13 to 24 birds between Glen Canyon Dam and the Little Colorado River confluence from 1993 to 1995 (Sogge et al. 1995). A concentration of wintering bald eagles often occurred in late February at the mouth of Nankoweap Creek, where large numbers of rainbow trout congregated to spawn (Gloss et al. 2005). However, a flash flood destroyed the trout spawning habitat and separated the tributary mouth from the Colorado River, so the eagles no longer congregate at that tributary. Small numbers of wintering eagles (1–3) have also been

noted around Bright Angel Creek, presumably also preying on nonnative fish. Since 1996, the number of wintering bald eagle observations in the Grand Canyon has declined.

California Condor

The California condor was listed as an endangered species under the ESA on March 11, 1967 (FWS 1967), and is identified as an AZ-SGCN (AZGFD 2012). By the 1930s, it was considered extirpated from the State of Arizona (NPS 2014c). A captive rearing program was initiated in 1983 to assist in recovery efforts. On October 16, 1996, it was announced that a nonessential population of condors would be established in northern Arizona (FWS 1996). On October 29, 1996, six condors were released at Vermillion Cliffs near Glen Canyon. Since that time, there have been additional releases, and the experimental population that inhabits the Grand Canyon as of September 2014 included 76 individuals (NPS 2014c). California condors are opportunistic scavengers, preferring carcasses of large mammals, but they will also feed on rodents and fish. Depending on weather conditions and the hunger of the bird, a California condor may spend most of its time perched at a roost. Roosting provides an opportunity for preening, other maintenance activities, and rest, and possibly facilitates certain social functions (FWS 1996). Nest sites often occur in caves and rock crevices (NPS 2014c).

California condors often use traditional roosting sites near important foraging grounds. Cliffs and tall conifers, including dead snags, are generally used as roost sites in nesting areas. Although most roost sites are near nesting or foraging areas, scattered roost sites are located throughout their range. California condors frequent beaches of the Colorado River through the Grand Canyon (Reclamation 2011b). Activities include drinking, bathing, preening, and feeding on fish carcasses. Condor monitors noted an increase in interaction between rafters and condors in 2002 as rafting parties sought out unused beaches for lunch stops, exploration, and close observance of condors. There have been several instances of immature condors approaching campsites.

Golden Eagle

The golden eagle is federally protected under the BGEPA and is identified as an AZ-SGCN (AZGFD 2012). It is a rare to uncommon permanent resident and a rare fall migrant throughout the region (Gatlin 2013). Preferred habitat is rugged terrain of cliffs and mesas, with nests built of large sticks on cliff ledges (NPS 2015a). Nesting has been documented from several areas of GCNRA. From November through March, the golden eagle can be observed on the high cliffs around Lake Powell (NPS 2015a). Winter aerial surveys have documented 3 to 25 individuals per survey. Since 2002, there has been a steady decline in golden eagle numbers within the Glen Canyon region (Spence et al. 2011). The golden eagle generally feeds on small mammals (e.g., rabbits and ground squirrels), but it also preys on large insects, birds, reptiles, and carrion, and can feed on mammals up to the size of small deer (NatureServe 2014; NPS 2015a).

Osprey

Although the osprey is not listed under the ESA, it is identified as an AZ-SGCN (AZGFD 2012). Reclamation (1995) stated that the osprey was a rare fall, spring, or accidental transient in the Grand Canyon. However, large numbers of ospreys now use the Colorado River corridor during fall migration, usually August–September with a peak in late August. There can be 10 to 12 individuals between Glen Canyon Dam and Lees Ferry on any given day during that period. An osprey pair nested near the base of Glen Canyon Dam in 2014 and 2015. In 2014, three eggs were laid and, although all three hatched, only one hatchling survived to fledge (Spence 2014a). One hatchling also fledged in 2015. Because nest sites are typically used for many years (AZGFD 2002f), this nest may be used in the future. The osprey feeds almost exclusively on fish, although it will also prey on snakes, frogs, shorebirds, and waterfowl (AZGFD 2002f).

Ridgway's Rail (Yuma)

The Yuma clapper rail (now known as the Ridgway's rail [Yuma]) was listed as endangered under the ESA in 1967 (FWS 1967) and is identified as an AZ-SGCN (AZGFD 2012). It inhabits marshes dominated by emergent plants. Emergent plant cover is more important than the plant species or marsh size. Areas with high coverage by surface water, low stem density, and moderate water depth are used for foraging; sites with high stem density and shallower water near shorelines are used for nesting (Reclamation 2008d). Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrush with a mix of riparian tree and shrub species (NPS 2013e). It is a casual summer visitor to marshy mainstem riparian habitats along the Colorado River below Separation Canyon (Figure 3.7-2). These sightings are far from the species' breeding range on the lower Colorado River (Gatlin 2013). Individuals were recorded in GCNP from 1996 to 2001. The Ridgway's rail (Yuma) was observed between Spencer Canyon (RM 246) and the GCNP boundary (RM 277), with nesting confirmed in 1996. Individuals have also been observed near Burnt Springs (near RM 260). It is not known whether cattail habitat is present in sufficient quantities to support nesting (NPS 2013e). Ridgway's rails (Yuma) feed on a variety of aquatic and terrestrial invertebrates, and on small fish and amphibians. A minor component of its diet consists of plant matter (e.g., seeds and twigs) (Reclamation 2008d). Threats to rails come from fluctuating flows during the breeding season (March–August) when there are eggs, less-mobile young birds, or flightless adults in the molting season (August).

Southwestern Willow Flycatcher

The southwestern willow flycatcher (flycatcher) is a neotropical migrant that nests in dense riparian habitats in the six southwestern states of California, Nevada, Utah, Colorado, Arizona, and New Mexico. The Pacific lowlands of Costa Rica appear to be a key winter location for the southwestern willow flycatcher, although other countries in Central America may also be important (Paxton et al. 2011). This subspecies of the willow flycatcher was listed as endangered under the ESA in 1995 (FWS 1995b). It is identified as an AZ-SGCN

(AZGFD 2012). Historically, the range of the flycatcher in Arizona included portions of all major watersheds (FWS 2002b); however, these watersheds have changed in many cases. As a result, most of the areas where flycatchers were locally abundant now support few or no individuals (FWS 2002b). Habitat and population numbers of southwestern willow flycatchers have declined in recent decades due to several factors, including loss, degradation, and fragmentation of riparian habitat; invasion by nonnative plants; brood parasitism by brown-headed cowbirds; and loss of wintering habitat (Stroud-Settles et al. 2013). Under the species recovery plan (FWS 2002b), the Colorado River downstream of Glen Canyon Dam falls within the Middle Colorado Management Unit delineated within the Lower Colorado Recovery Unit. Critical habitat for the southwestern willow flycatcher has not been designated by the FWS between Glen Canyon Dam and Lake Mead (FWS 2005, 2013b).

The southwestern willow flycatcher eats insects and needs riparian habitats to complete its life cycle. It breeds and forages in dense, multi-storied riparian vegetation near saturated soils, slow-moving water, or surface water (Sogge et al. 1995). The southwestern willow flycatcher breeds across the lower southwest from May through August (Reclamation 2007d). The southwestern willow flycatcher arrives on the breeding grounds throughout May and early June, eggs are generally laid beginning in May, and fledging occurs between June and August (Sogge et al. 1997, 2010). Occupied sites most often have a patchy interior of dense vegetation or dense patches of vegetation intermingled with openings. Most often, this dense vegetation occurs within the first 3 to 4 m above the ground (FWS 2002b). The structures of occupied patches vary, with a scattering of small openings, shorter vegetation, and open water. Occupied patches can be as small as two acres and as large as several hundred acres, but are typically >10 m wide (Reclamation 2007d).

The southwestern willow flycatcher historically nested in native plants such as willows, buttonbush, boxelder, and seepwillow (Stroud-Settles et al. 2013). It also nests in patches dominated by exotic plant species such as tamarisk and Russian olive (Sogge et al. 1997; Stroud-Settles et al. 2013). The Grand Canyon does not provide extensive stands of dense riparian habitat suited for breeding willow flycatchers. The majority of habitat patches in the Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result, the majority of flycatcher habitats in the Grand Canyon are marginal and, unless current hydrological conditions change, these patches will likely continue to decline. Furthermore, the recent arrival of the tamarisk leaf beetle has transformed and will continue to transform the patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013).

Surveys for the flycatcher have occurred in the Grand Canyon, mainly along the main stem of the river corridor, since 1982. The number of nesting flycatcher detections have declined since the 1980s, and nesting flycatchers have not been confirmed in the Grand Canyon since 2007. Except for 2008, when no nests were identified, nest surveys were not conducted between Lees Ferry and Phantom Ranch between 2007 and 2012. No nest surveys occurred between Phantom Ranch and Diamond Creek between 2005 and 2012, and no nest surveys occurred between Diamond Creek and Pearce Ferry between 2009 and 2012 (no nests were observed during surveys made in 2008) (Stroud-Settles et al. 2013). There is little information on the number of flycatchers present along the river before the construction of Glen Canyon Dam.

However, what data are available suggest that historically flycatchers were not common breeders along the Colorado River in the Grand Canyon (Sogge et al. 1997; Stroud-Settles et al. 2013). Studies conducted along the river from 1982 to 1991 and from 1992 to 2001 detected 14–15 breeding pairs per decade of surveys between Lees Ferry and Phantom Ranch (Stroud-Settles et al. 2013).

The river stretch from Lees Ferry to Phantom Ranch has been surveyed most consistently since 1982 and best represents the potential trend of the flycatcher in Grand Canyon (Stroud-Settles et al. 2013). There has been a noticeable decrease in the detection of breeding pairs since the 1990s along this stretch of river. The river stretch from Phantom Ranch to Diamond Creek has infrequent habitat patches. Surveys did not occur along this stretch until the 1990s and have produced minimal detections. The previous studies along the Diamond Creek–Pearce Ferry river stretch have varied considerably. A 5-year boost in detections along this stretch of river that occurred from 1997 to 2001 is likely due to favorable water levels of Lake Mead in combination with increased survey effort (Stroud-Settles et al. 2013). Surveys for the presence of southwestern willow flycatchers were conducted between Lees Ferry and Pearce Ferry in spring and early summers of 2010 through 2012. Ten individuals were detected during this period. All detections occurred on single occasions at a site, and not detected again in subsequent surveys. Detections were made at RMs 28.5, 50.3–50.7, 51.8–52, 183.5, 196.4, 217.6, 218, and 275. Although nest surveys were not conducted, 46 sites within the Grand Canyon were assessed for their suitability as southwestern willow flycatcher breeding habitat. Ten sites were designated as suitable habitat and 20 as potential habitat. These sites were located between RM 28.5 and RM 275 (Stroud-Settles et al. 2013).

The Colorado River corridor continues to provide essential habitat for migrating southwestern willow flycatcher, but the presence of breeding flycatchers is less common. Suitable habitat patches below Diamond Creek need to be surveyed more frequently, and any suitable sites should be at the forefront for habitat improvement and restoration work (Stroud-Settles et al. 2013).

Western Yellow-billed Cuckoo

The western yellow-billed cuckoo distinct population segment was designated as a threatened species under the ESA on October 3, 2014 (FWS 2014b). This species is also identified as an AZ-SGCN (AZGFD 2012). Proposed designated critical habitat does not occur between Glen Canyon Dam and Lake Mead. A 24-km continuous segment of the Colorado River between the upstream end of Lake Mead and the Kingsmen Wash area in Mohave County is the closest unit of proposed designated critical habitat (FWS 2014a).

The western yellow-billed cuckoo is a neotropical migrant bird that breeds and summers in northern Mexico and the western United States. Cuckoos were once considered abundant throughout the riparian floodplain along the lower Colorado River (Table 3.7-1). However, cuckoo populations have suffered severe range contractions during the last 80 years; currently western populations breed in localized areas of California, Arizona, New Mexico, western Texas, and northern Mexico, with irregular breeding in Utah and western Colorado

(Johnson et al. 2008). Factors that have contributed to population declines of the western yellow-billed cuckoo include habitat loss, fragmentation, and degradation of native riparian breeding habitat; possible loss of wintering habitat; limited food availability; and pesticide use (Johnson et al. 2010; FWS 2014a).

The western yellow-billed cuckoo requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory. It rarely nests (2.5% of nests) in areas dominated by tamarisk (Johnson et al. 2010; Schell 2005). In Arizona, western yellow-billed cuckoo occur most often in sites dominated by native tree species and at lower numbers in habitats consisting of mixed native or >75% tamarisk cover (Johnson et al. 2010). It forages almost entirely in native riparian habitat, as the large caterpillars on which it feeds depend on cottonwoods and willows and do not occur on tamarisk (FWS 2014a). It may be unreasonable to expect the Grand Canyon to serve as functional breeding habitat for the western yellow-billed cuckoo due to inadequate riparian vegetation conditions (Schell 2005). Suitable habitat may have been limited, as pre-dam floodplain terraces were neither abundant nor generally sufficiently wide in the Grand Canyon.

The western yellow-billed cuckoo is known to occur at a number of sites in the lower Grand Canyon near the Lake Mead delta (Figure 3.7-2). The riparian community at these sites is primarily made up of willow, tamarisk, and seepwillow. In 2006, cuckoos occupied and bred in these sites. However, drops in Lake Mead water levels lower the water table and stress the vegetation at these sites. Surveys for this species at these sites resulted in 29 cuckoo detections in 2006 and no detections in 2007 (Johnson et al. 2008).

3.7.5.4 Mammals

The only threatened, endangered, or sensitive mammal species that may occur in riparian areas within the action area is the spotted bat. The spotted bat is not federally listed but is identified as an AZ-SGCN (AZGFD 2012). It is rarely encountered in Arizona, but may occur in areas where cliffs and water sources are nearby. Most individuals are observed in dry, rough desert shrublands or in pine forest communities. Roost sites are presumed to be crevices and cracks in cliff faces (AZGFD 2003b). The spotted bat is active in winter, particularly if hibernacula have low humidity. It tends to be relatively solitary but may hibernate in small clusters (AZGFD 2003b). Dominant prey items are moths, but also include June beetles and sometimes grasshoppers that are taken while on the ground (AZGFD 2003b).

3.7.6 Tribal Perspectives on Wildlife

Riparian and terrestrial wildlife play an important role in Tribal culture and religion. The loss of animals or plants may have a negative cultural impact on the life of the Tribes in the region.

In the Zuni belief system, as Winston Kallestewa explained (in Dongoske and Seowtewa 2013), “All animals are our ancestors that have come back to life in a different form—

that is why all living beings, even the smallest insect, are important to the Zuni people." Dickie Shack explained (in Dongoske and Seowtewa 2013) that common animals such as lizards play a role in Ant Medicine Society prayers, prayers so ancient that they are spoken in an archaic language, learned when the Zunis were on their migration. In addition, animals, plants, and insects play a fundamental role in Zuni clan identity and collectively as Zuni people. All animals came out of the underworld with the Zunis. They are all important because they have a purpose explained in Zuni religion and cannot be killed indiscriminately. Wildlife are the spiritual beings of the ancestors for the Zuni people and are mentioned in prayers and songs (Dongoske and Seowtewa 2013). Birds are incorporated into nearly every aspect of Zuni life (Ladd 1963). Because they are viewed as messengers from the ancestral celestial beings, their appearance is closely watched. Consequently, Zunis are generally excellent ornithologists. In discussing the cultural importance of birds with Zuni cultural advisors, one becomes quickly amazed at the accuracy and consistency with which they distinguish closely related species, and are able to relate precisely the season when each species is present. Throughout the migration of the Zuni people to find the Middle Place, they were also helped by birds: a raven took the bitterness away from the corn the Zunis had harvested and made it palatable; an owl helped them by making the corn which they had harvested soft enough to eat. Although birds are probably the most important animals to Zuni, they are far from the only animals that Zunis view as religiously or culturally important. All animals have their place of reverence in Zuni cosmology (Tyler 1964). As mentioned above, even if Zunis did not need to collect any of these animals, their appearance is emblematic and auspicious of natural events, or human's response to them. During the Zunis' effort to emerge and reach the upper world, they were helped by small creatures: a locust who, like the three birds before him, attempted to reach the upper world, and a spider and a water strider who eventually direct the Zuni people to Halona-itiwana, the Middle Place. Zunis have a special relationship with water creatures, and this stems from events during their search for the Middle Place.

The Navajo perspective is that bighorn sheep, deer, wild horses, beaver, foxes, mountain lions, red-tailed hawks, owls, eagles, yellowbirds, bluebirds, black tipped birds, vultures, crows, butterflies, and many other species of wildlife were and continue to be hunted for food, ceremonial equipment, and other uses for the Navajo people. Wildlife are essential to all aspects of Navajo life. The river forms a natural boundary that protects the Navajo and helps to define the extent of Navajo land; it protects the Navajo and provides many things to Navajo people. Offerings are made to the river for protection. The water is used in a lot of ways and can lead to a good way of life for all people, and that is why people make offerings to the river. If this is not done, then the people will scatter. The offerings are much like the ones offered to the sacred mountains (Roberts et al. 1995).

For the Hopi, snakes and other reptiles play valued cultural roles in history and ceremonial activities. The presence of the Snake and Lizard clans at Hopi testifies to their ongoing importance. The Snake ceremony has its origins in the Canyons and is associated with the journeys of Tiyo down the Colorado River (Eggan 1971). Birds are a valuable cultural resource to the Hopi people. Feathers of a great many species are used in ceremonial and ritual contexts. Of particular importance are eagles, whose nests are viewed as shrines and used as receptacles for prayer offerings. Maintaining healthy populations of birds is part of the overall balance of the world.

Bighorn sheep are revered and culturally significant for nearly every Tribe with historical ties to the Grand Canyon. Historically, they were important for food, hides, and materials used in making tools and implements. The Havasupai have a close cultural affinity with the bighorn sheep and do not hunt them. The ram horns feature in the Tribal seal and Tribal identity. They furthermore figure prominently in cosmology and star lore, and are considered relatives that, when the need arises, give up their life to provide sustenance.

3.8 CULTURAL RESOURCES

Cultural resources are typically categorized as archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties, ethnographic resources, and museum collections. Many natural resources, such as plants and plant gathering areas, water sources, minerals, animals, and other ecological resources, are also considered cultural resources, as they have been integral to the identity of Tribes in various ways. For some Tribal people, archaeological resources are considered to be markers left by their ancestors, the embodiment of those who came before and are imbued with the spirits of the ancestors. They represent a physical link to the past. The physical attributes of cultural resources are often nonrenewable, especially archaeological sites, which often represent ancestral homes for the park's traditionally associated Tribes.

The National Historic Preservation Act (NHPA) is the overarching law concerning the management of historic properties on federal lands. Numerous other regulatory requirements pertain to cultural resources and are presented in Chapter 1. Historic properties are a subset of cultural resources. Historic properties are defined in the NHPA (16 USC § 470w(5)) as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion on, the National Register of Historic Places, including artifacts, records, and material remains related to such a property or resource." Historic properties must be taken into consideration during the planning of federal projects. Historic properties can be either man-made or natural physical features associated with human activity and, in most cases, are finite, unique, fragile, and nonrenewable. For example, historic properties can include traditional cultural properties (TCPs), which are properties that are important to a community's practices and beliefs and that are necessary for maintaining the community's cultural identity. Historic properties can also include certain archeological sites or historic districts, such as the Lees Ferry and Lonely Dell Ranch Historic District, containing multiple interrelated archaeological or historic elements. Under the NHPA, the American Indian Religious Freedom Act, and Executive Order 13007, federal agencies are also required to consider the effects of their actions on sites, areas, and other resources (e.g., plants) that are of cultural and religious significance to Native Americans, Native Alaskans, and Native Hawaiians. Native American graves, funerary objects, sacred objects, or objects of cultural patrimony are protected by the Native American Graves Protection and Repatriation Act. Also under the GCPA, cultural resources were identified as one of the resources that must be protected, mitigated, and improved, in a manner fully consistent with and subject to Section 1802(b) of the GCPA.

Historic properties on federal lands are managed primarily through the application of laws, regulations, executive orders, and policies. Guidance on the application of these laws is

provided through various means. Most federal agencies have published guidance on how to appropriately manage historic properties on their lands. Guidance for historic property management in all NPS units comes from the *NPS Management Policies 2006* (NPS 2006d) and NPS-28, *Cultural Resource Management Guideline* (NPS 1998). Park-specific guidance for GCNP and GCNRA is provided through both parks' General Management Plan and the GCNP Colorado River Management Plan (CRMP). Additional direction in GCNP is derived from the 2010 Foundation Statement and, for GCNRA, the 2015 Foundation Statement. The Reclamation policy concerning cultural resources is outlined in Policy LND P01, which ensures compliance with existing cultural resource law and Directives and Standards LND 02-01, which identifies Reclamation's roles and responsibilities as they relate to cultural resources.

The management of historic properties along the Colorado River in GCNP and GCNRA is guided by NHPA and NPS-28. Several agreements have been executed resulting from environmental studies concerning the operation of Glen Canyon Dam and the management of the resources in the two national park units. The 1995 EIS for operations of Glen Canyon Dam (Reclamation 1995) was accompanied with the signing of an NHPA Section 106 Programmatic Agreement (PA) in 1994. The agreement was among the Arizona State Historic Preservation Office, the Advisory Council on Historic Preservation, Reclamation, NPS, the Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, Shivwits Paiute Tribe, and the Pueblo of Zuni. The 1994 PA addressed management of more than 300 cultural resources that could be affected by dam operations. These sites included the 323 sites that compose the Grand Canyon River Corridor Historic District. As agreed to by the signatories of the 1994 PA, a new PA is being developed in conjunction with the LTEMP EIS based on research and monitoring along the river and the resulting new information accumulated since 1996. This draft PA currently is being developed as allowed in Title 36, *Code of Federal Regulations,* Part 800.14(1) (ii) (36 CFR 800.14 b(1) (ii)) when effects on historic properties cannot be fully determined prior to approval of the undertaking. The draft PA outlines general and specific measures Reclamation (as lead federal agency for operation of Glen Canyon Dam and with responsibility for the NHPA Section 106 mitigation of effects from dam operations) and the NPS will take to fulfill their responsibilities regarding the protection of historic properties under the NHPA.

The NHPA applies to federal undertakings and undertakings that are federally permitted or funded. The regulations implementing Section 106 of the NHPA, codified at 36 CFR Part 800, define the process for identifying historic properties and for determining if an undertaking will adversely affect those properties. The regulations also establish the processes for consultation among interested parties, the agency conducting the undertaking, the Advisory Council on Historic Preservation (ACHP), State Historic Preservation Officers (SHPOs), Tribal Historical Preservation Officers (THPOs), and for government-to-government consultation between federal agencies and American Indian Tribal governments. The NHPA, in Section 106, addresses the appropriate process for mitigating adverse effects. The implementing regulations also address the process for mitigating adverse effects.

3.8.1 Area of Potential Effect

NHPA compliance includes the definition of an Area of Potential Effect (APE), which is defined in 36 CFR 800.16(d) as:

> Area of potential effects means the geographic area or areas within which an undertaking may directly or indirectly cause alterations in the character or use of historic properties, if any such properties exist. The area of potential effects is influenced by the scale and nature of an undertaking and may be different for different kinds of effects caused by the undertaking.

The undertaking is the proposed operation of Glen Canyon Dam for a period of 20 years under the LTEMP, including any related non-flow actions that could affect historic properties. Dam operations under the LTEMP are anticipated to continue to include recurring flows that may fully utilize the capacity of the powerplant turbines and bypass tubes (i.e., HFEs). The undertaking may include LTEMP activities other than Glen Canyon Dam operations (i.e., non-flow actions such as vegetation management, nonnative fish monitoring, and fish control).

Regulations by the Council on Environmental Quality (CEQ) encourage, "[t]o the fullest extent possible" that National Environmental Policy Act of 1969, as amended (NEPA) documents be "integrated with environmental impact analyses and related surveys and studies required by the . . . National Historic Preservation Act of 1966" (Section 1502.25 in CEQ 1978). Regulations by the ACHP contain similar goals (Section 800.8 in ACHP 2004). Accordingly, this LTEMP EIS describes the compliance process that is ongoing pursuant to Section 106 of the NHPA.

While the NHPA process is described in this LTEMP EIS, NHPA and NEPA each require a different consultation process, different legal standards, and different concluding documents, even though some aspects are similar. NEPA analyzes the impact of "proposed actions" and their alternatives (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) on the "affected environment." The "affected environment" includes a broad range of resources, such as biological, socioeconomic, aquatic, cultural, and recreation resources.

The NHPA focuses on effects on "historic properties" (properties that are eligible for or listed on the *National Register of Historic Places* [NRHP]) rather than NEPA's focus on the effects on a broader range of resources. Specifically, the NHPA requires consultation on the potential for an "undertaking" (here, Glen Canyon Dam operations and non-flow actions identified in the LTEMP) to affect "historic properties" within a designated "area of potential effect."

The APE for NHPA purposes may be geographically different from the affected environment for NEPA purposes. Here, several of the Tribes participating in the NHPA consultation process have indicated that the Canyons as a whole are a place of great cultural importance and requested an APE for the undertaking that extends "rim-to-rim" of the affected Canyons. This APE is geographically different than the affected environment defined in the

LTEMP EIS, and it specifically focuses on analyzing effects on historic properties rather than NEPA's analysis of the effects of an action on a broader array of resource conditions. The NHPA undertaking will be addressed within the geographic scope of the APE per NHPA standards, just as the NEPA proposed action will be addressed within the geographic scope of the affected environment per NEPA standards. A different geographic scope for the APE under the NHPA is limited to NHPA purposes and does not expand the scope of the affected environment for NEPA purposes.

For the purposes of the Section 106 process, Reclamation has defined the APE in the draft PA (available at the time of printing of this final EIS) as:

> …the area of direct or indirect effects to the character or use of historic properties on the Colorado River Corridor in Glen, Marble, and Grand Canyons from Glen Canyon Dam to the western boundary of Grand Canyon National Park, including direct or indirect effects that may be caused to historic properties by the Undertaking from rim to rim of the canyons.

There are a number of ways in which dam operations may affect cultural resources, including the periodicity of inundation and exposure, changing vegetation cover, streambank erosion, slumping, and influencing the availability of sediment. Direct and repeated inundation/exposure may affect resources such as the Spencer Steamboat, which is in the active channel (Figure 3.8-1), or Pumpkin Springs, a TCP along the bank that is subject to inundation during high flows (e.g., equalization flows and HFEs). Streambank erosion, slumping, flow-related deposition, and indirect effects of deposition may affect cultural resources contained within terrace contexts in proximity to inundated areas. Fine sand or sediment can be blown from flow-deposited source areas and deposited on cultural sites (East et al. 2016) (Figure 3.8-2). The effects of deposition or erosion may be negative or positive depending on the nature of the site. One important recent finding is that sandbars created by high-flow events at Glen Canyon Dam can provide sources of windblown sand that can cover archaeological sites (East et al. 2016) as well as anneal, or reverse, the formation of gullies (Sankey and Draut 2014). In this context, changes in dam operations can affect erosion rates on archaeological sites (East et al. 2016, Collins et al. 2016). In addition, bank deposition and aeolian transport of sediment can affect the character of other types of TCPs. The activities of research and monitoring may also have the potential to negatively affect the character-defining elements of archaeological sites and TCPs.

For purposes of this analysis, a review of sites inventoried and monitored as of 2016, and additional analysis performed by Reclamation and NPS working with USGS and GCMRC researchers using their classification system cited above,[9] it was determined that up to

[9] USGS and GCMRC developed a system for classifying the geomorphic settings of archaeological sites, based on the degree to which they can receive windblown sand from deposits from recent HFEs, to address how archeological sites are linked to modern river processes (East et al. 2016). Surveys have documented approximately 300 to 500 archaeological sites in the river corridor of Glen, Marble, and Grand Canyons. As of January 2015, USGS had examined 358 sites in GCNP to establish the potential effects of windblown sands at these locations. This review did not include a small number of sites in GCNRA, which are expected to be classified by GCMRC in 2016.



FIGURE 3.8-1 Spencer Steamboat (Photo by Susanna Pershon, Submerged Cultural Resources Unit, NPS)



FIGURE 3.8-2 A Roasting Pit Feature (Prehistoric Food Preparation Location) in a Grand Canyon Dune

220 archeological and historic site properties could be affected by dam operations or non-flow aspects of this NEPA action. Determinations of eligibility have been completed for all known properties. Additional information, including inventory and monitoring, data recovery activities, and completion of determinations of eligibility for sites along the river, are continuing to provide up-to-date information on sites potentially affected.

3.8.2 Description of Cultural Resources and Site Types

Glen, Marble, and Grand Canyons are significant for their human history and their ongoing roles in the lives and traditions of today's American Indians of the Colorado Plateau. Archaeologists generally divide the nearly 12,000 years of human history of the Grand Canyon region into six broad periods: Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric, and Historic. The human story is represented in each of these periods along the Colorado River from Glen Canyon Dam to Lake Mead. What follows is a description of the Western Euro-American (i.e., non-Tribal) view of the types of cultural resources and the time frames into which those resources fall (see Section 3.9 for the Tribal view of the history and meaning of the Grand Canyon).

3.8.2.1 Archaeological Resources

Archaeological resources are defined as "any material remains or physical evidence of past human life or activities which are of archeological interest, including the record of the effects of human activities on the environment. They are capable of revealing scientific or humanistic information through archeological research" (NPS 2006b).

Archaeological research along the Colorado River corridor in Glen and Grand Canyons began in 1869 with the first report of ruins by John Wesley Powell (Powell 1875). In the early 1930s, professional archeology began in the region with Julian Steward's work in the Lees Ferry area (Steward 1941). Later, in 1953, Walter Taylor began work along the Colorado River in the Grand Canyon (Taylor 1958). From 1956 through 1963, one of the largest single archeological salvage projects in the United States was undertaken in the Glen Canyon region to mitigate for the construction of Glen Canyon Dam (Jennings 1966). Because dam construction predated the passage of NHPA in 1966, pre-dam mitigation was conducted under the auspices of the Historic Sites Act of 1935 and then the Reservoir Salvage Act of 1960. Pre-dam mitigation was performed by the University of Utah, the Museum of Northern Arizona, and the NPS.

For the pre-dam mitigation effort, archeological salvage was limited to the north and south sides of the Colorado River above the dam up to Hite, Utah, and to portions of the San Juan River. No survey and excavation occurred below the site of Glen Canyon Dam. A complete archaeological inventory of the river corridor, encompassing all traversable terrain between Glen Canyon Dam and Separation Canyon from the river up to and including pre-dam river terraces, was completed in 1991 for the 1995 Glen Canyon Dam EIS (Fairley et al. 1994). This and subsequent survey efforts have documented nearly 500 properties in the near-shore environment of the river from Glen Canyon Dam to Lake Mead.

To help understand what they encounter, archaeologists divide human history into sequential periods on the basis of distinctive changes in technology, subsistence practices, and/or sociopolitical organization. Below are descriptions of these periods and the types of archaeological resources typical for those periods that are found along the Colorado River from Glen Canyon to Lake Mead. The following discussion is based on chronological divisions in general use in the American Southwest, as modified for the Grand Canyon region by Fairley (2003). Details of individual sites and determinations concerning which sites could be affected and how many potential effects may be mitigated will be addressed through the PA process.

Classifications and distinctions described in this section are based on physical archeological evidence and do not incorporate ethnohistoric data. Many Tribes' oral histories and perspectives do not necessarily agree with the classifications and distinctions described in this section.

PaleoIndian Period (10,000–6,000 BC)

Sites from this time period are characterized by very distinctive spear points used to hunt large animals such as mammoth, sloth, bear, and wolf. These distinctive spear points are found across Arizona, New Mexico, and Texas. Three locations within GCNP have yielded fragmentary spear points dating from this Clovis and Folsom tradition. Three additional sites in the western Grand Canyon are also believed to contain Paleoindian artifacts. Within GCNRA, Paleoindian points have been found at six sites. Five were found in the northernmost part of the park and one west of Lees Ferry. These sites reflect characteristics of the Clovis, Folsom, and Plano technological complexes of the Paleoindian period.

Archaic Period (6,000–500 BC)

Sites dating from this time period contain smaller, but distinctive, projectile points (dart points). There is also evidence of experimentation with cultivating plants. Artifacts include small processing stones such as one-handed manos and grinding slabs, and abundant plant remains found in a trash context. These items suggest increased activities toward plant processing and more reliance on plants as a food source than was evident during the Paleoindian Period. Elaborate multicolored rock art and split-twig figurines found in cave settings are hallmarks of the Grand Canyon Archaic Period. Archaic Period sites include hunting blinds, lithic scatters at meadow edges and water holes, temporary camps, rock art, and split-twig figurine caches (Figure 3.8-3). Another distinctive aspect of the Archaic cultural history along the Colorado River corridor in GCNRA during the Archaic Period is a certain distinctive style of petroglyphs known as the Glen Canyon Linear Style (Figure 3.8-4).

Formative: Basketmaker Period (500 BC–700 AD)

This period is distinguished by extensive use of baskets, sandals, and textiles, and some important technological advancements, such as the development of the bow and arrow and the



FIGURE 3.8-3 An Archaic Period Site on the Colorado River in GCNP



FIGURE 3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA

beginnings of pottery manufacture. Habitations are often single pit houses with bell-shaped pits dug for storage. There is evidence of increased reliance on cultivated plants, primarily corn and squash. The western Grand Canyon has the largest concentration of sites from this time period within the Grand Canyon.

Formative: Ancestral Puebloan and Cohonina (700–1300 AD)

Typical of these periods are the distinctive masonry structures and apartment-like dwellings (pueblos) that the ancestral Puebloan people lived in during this time (Figure 3.8-5). This period is characterized by more permanent settlements and reliance on agriculture—most notably beans, corn, squash, and cotton—and pest-resistant storage features. Evidence of craft specialization, including distinctive ceramic designs, allows archaeologists to attribute occupation dates to sites and associated deposits with specific cultural groups. The majority of GCNRA and GCNP sites are of Puebloan age. Puebloan people were occupying the area north (Virgin Branch), south and east (Kayenta Branch) of the Colorado River during the Formative Period. Modern Puebloan Indians consider themselves to be descendants of these ancestral people.



FIGURE 3.8-5 Puebloan Era Architecture along the Colorado River in GCNP

The Cohonina people were a distinctive cultural group living in a discreet area running east to west between the San Francisco Peaks and the Grand Wash Cliffs, and north to south from the Colorado River to the Mogollon Rim during AD 700–1175. Both their home sites and distinctive ceramics identify them as culturally separate from the neighboring Puebloan groups. Cohonina sites in the Grand Canyon consist of settlements located on both sides of the river, use of multiple areas for resource procurement, and small camps or hamlets. The Hopi, Hualapai, and Havasupai consider themselves descendants of the Cohonina archaeological culture.

Late Prehistoric (1250–1540 AD)

Current evidence indicates that ancestral Puebloan populations moved out of the Canyons as the Southwest became drier and cooler in the 13th century, while people from the west continued to expand their land base and further incorporated the Canyons into their seasonal hunting and gathering cycles. These groups were less sedentary and less reliant on crops, and they lived in smaller camps, built brush structures, and used communal roasting features and small clusters of fire pits. The ancestral Pai and Southern Paiute were well established in the Canyons during this time. Archaeologists have identified different pottery types of both local and imported varieties that are characteristic of cultural transitions during this period.

Protohistoric Period (1540–1776 AD)

The Protohistoric Period contains evidence of incursions by white settlers and miners: European explorers, specifically Spanish expeditions in search of gold and wealth, but with an ancillary mission of converting native people along the way to Christianity. Although the experience of indigenous groups with these contacts varied widely, much of the region immediately in the vicinity of the Grand Canyon and Colorado River was not greatly affected, especially in the western canyon country. Growing familiarity with horses and items of European manufacture was likely, however. This period witnessed the greatest expansion of the Pai and Southern Paiute into the Grand Canyon and along the river corridor. Archaeological evidence suggests that the ancestral Puebloan peoples who had previously occupied the Canyon had already shifted settlements to the east by this time.

3.8.2.2 Historic Resources

Historic resources represent the period from 1776 to the present. The period is characterized by incursions by Europeans and later by Euro-American exploration along the Colorado River. In GCNRA, the Dominquez-Escalante Expedition in 1776 crossed the Colorado River at what is now Lees Ferry. That same year, Fr. Francisco Garces led a separate Spanish expedition from the southwest, up the lower Colorado River, and then overland; he visited Hualapai and Havasupai settlements in the western Grand Canyon area, even relying on Hualapai guides for part of his journey (Coues 1900). Euro-American expeditions include the 1869 Powell expedition and the 1889–1890 Stanton expedition, among others. The historic period ends with the engineering tests for the Marble Canyon Dam site in the late 1950s.

During the 19th century, in response to the growing pressures brought by the increasing numbers of European and Euro-American settlers, some indigenous groups retreated to smaller territories, formed aggregate villages, and used side canyons as places of refuge. Small bands of Hualapai and Southern Paiute wishing to avoid conflict with the U.S. Army stayed in western Grand Canyon, largely out of reach of soldiers on horseback. Havasupai Indians lived at Indian Garden along the Bright Angel Trail and in a permanent settlement in the South Rim Village area. Southern Paiute bands used large areas across the Tuweep Valley for habitation and resource procurement. Navajo lived along the south, east, and north rims and within the Canyon for seasonal and religious purposes. Ultimately, however, the designation of permanent reservations by treaty or executive order led to the forced or coerced relocation of Tribes out of vast areas of their ancestral territories.

Native American sites from the Historic Period in the Grand Canyon are characterized by a blending of the old and traditional with the new and innovative. Pottery and tools made of stone and bone are found along with metal and glass projectile points. Metal buckets, kitchen cutlery, and canned food and beverage containers are found in at such sites.

Types of historic resources found along the mainstem of the Colorado River include artifact caches and isolated occurrences, abandoned boats, dwellings, remnants of mining operations, camps, ranching, features related to dam site development, trails, inscriptions, and plaques. Historic era American Indian use of areas along the Colorado River is evidenced from numerous locations along the riverbanks. Remnants of hogans, extraction sites (i.e., mines) and small camps are remnants of this time. Of the total number of identified archeological sites along the mainstem Colorado River, at least 71 have a Euro-American historical component (Fairley et al. 1994; Reclamation 1995).

In GCNRA, Lees Ferry was settled by John D. Lee who established one of the primary river ferry crossings at this location (Figure 3.8-6). The remains of the Charles H. Spencer Steamboat, a steamboat launched in 1912, which transported coal to Lees Ferry, located in the bed of the river at Lees Ferry, was listed on the NRHP in 1974 as part of the Lees Ferry and Lonely Dell Ranch Historic District (Figure 3.8-1). A separate nomination was prepared for the steamboat, which was listed as an individual property in 1989. Historic campsites, corrals, and inscriptions are evidence of historic ranching and sheepherding. In response to mass unemployment during the Depression, the Civilian Conservation Corps (CCC) built structures, fire towers, and historic trail and road features that all constitute remains of activities intended to facilitate visitor use, as well as resource protection. The Marble Canyon Dam site, the physical remains of engineering tests for a dam that was not built, constitutes a significant part of the recent past. The site and related encampments have been determined eligible for listing on the NRHP.



FIGURE 3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA

3.8.2.3 Cultural Landscapes

As defined in the NPS *Cultural Resource Management Guideline* (NPS 1998), cultural landscapes are settings that humans have created in the natural world. They are intertwined patterns of things both natural and constructed, expressions of human manipulation and adaptation of the land (see Section 3.9 for a description of the Tribal perspective on cultural landscapes). One type of cultural landscape, the historic vernacular landscape, which is a landscape that evolved through use by the people whose activities or occupancy shaped it, is represented in the Colorado River corridor at both Lees Ferry and Phantom Ranch.

At Lees Ferry, the Colorado River briefly flows free of canyon walls, historically the only place in over 400 mi that it could be accessed on both banks by wagon. This natural attribute has influenced the site's history for 130 years. Today, historic buildings and a cemetery, shade trees, an orchard, fields, trails, and dugways carved into the river bluffs combine with more contemporary structures to illustrate the site's use as a farm and a vital ferry link between settlements in Utah and Arizona. The establishment of USGS gaging stations that are used today to fulfill terms of the Colorado River Compact, a dude ranch, and an access point for river runners are also present at Lees Ferry.

At Phantom Ranch, major side canyons and perennial tributaries provided the natural context for what would become the nexus of a cross-canyon corridor and the most popular site in the inner Canyon. Here, historic guest lodges and NPS buildings, livestock structures, cottonwood trees, a campground, bridges across Bright Angel Creek and the Colorado River, and

a network of trails document 80 years of recreational activity at the very bottom of the Grand Canyon.

On a broader scale, the entire river corridor can be viewed as a cultural landscape in which American Indians for millennia have farmed, hunted, gathered plants and minerals, and performed rituals. Ancient trails, remnants of stone structures, traces of fields, and prayer objects enshrined in travertine and salt are enduring evidence of a subtly altered landscape. Integral to this landscape are the animals, plants, and minerals traditionally used and valued by American Indians. Aspects of American Indian cultural landscapes are discussed in Sections 3.8.2.4 and 3.9 and throughout this document.

3.8.2.4 Traditional Cultural Properties and Ethnographic Resources

"A traditional cultural property, then, can be defined generally as one that is eligible for inclusion in the NRHP because of its association with cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community" (Parker and King 1990). Like historic properties, TCPs are given consideration under the NHPA of 1966, as amended. During research related to Glen Canyon Dam operations and sponsored by Reclamation, five Tribes identified cultural resources of importance to them in the river corridor that are TCPs. This includes Grand, Marble, and Glen Canyons, and the Colorado and Little Colorado Rivers.

Ethnographic resources often overlap with archaeological sites and other resources of ongoing traditional cultural importance. "Park ethnographic resources are the cultural and natural features of a park that are of traditional significance to traditionally associated peoples. These peoples are the contemporary park neighbors and ethnic or occupational communities that have been associated with a park for two or more generations (40 years), and whose interests in the park's resources began before the park's establishment" (NPS 2006d).

American Indian people consider the broader area of Glen and Grand Canyons to be of traditional, even sacred, importance (Hopi CPO 2001; Dongoske 2011a; Maldanado 2011; Coulam 2011). More information regarding the perspective of the Canyons as a TCP is presented in Section 3.9. This information has been furnished by interested Tribes at the request of Reclamation and NPS, in order to aid in public understanding of their concerns.

3.9 TRIBAL RESOURCES

The Colorado River, as it flows through the Glen, Marble, and Grand Canyon (the Canyons), has a prominent place in the traditional cosmology of the indigenous peoples of the Southwest and continues to have an important place in contemporary American Indian cultures and economies. The Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes all have strong cultural ties to the Colorado River and the Canyons, and these Tribes have provided information on the determination of eligibility of the Colorado River and the Canyons as TCPs.

For these Tribes, the Canyons are more than just beautiful scenery. The Canyons are alive. The Colorado River, the canyons it has carved, and the resources it supports over a vast landscape are all considered sacred to these Tribes. Many Tribal members regard the Canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. They are important to the genesis of the Tribes and to their contemporary ways of life rooted in traditions engendered by those experiences. Many Tribes see themselves as connected to the Colorado River and its Canyons and as stewards over the living world around them, including water, earth, plant life, and animal life.

Although archaeological data can provide significant evidence of past lifeways, it tells only part of the story. Within this landscape are culturally important natural resources and significant cultural landscapes that serve as the settings for Tribal histories and spiritual narratives. Many Tribes have adapted their role as stewards to the modern environment by submitting documentation to support their contention that portions of the Colorado River and the Canyons through which it flows should be considered a TCP. Various elements within this boundary are considered contributing elements to the TCP (Hopi CPO 2001; Dongoske 2011b; Maldanado 2011; Coulam 2011). This documentation provides information supporting a determination of the eligibility of the TCP and many, but not all, associated elements located in or along the Colorado River for listing on the *National Register of Historic Places*. These TCPs have been determined eligible by the Arizona SHPO (Reclamation 2011a). Some of the elements of these TCPs have been disclosed and other elements are considered confidential, but all are considered significantly important. Traditional narratives of Tribal history and understandings of traditional landscapes, combined with archaeological data, provide a comprehensive representation of American Indian lifeways.

The following discussion of the importance of the Canyons and the Colorado River for the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes, and their monitoring of these resources was written, for the most part, by the LTEMP EIS staff and edited and approved by Tribal representatives from each Tribe. Tribal representatives from the Hopi, Hualapai, Navajo, and Zuni contributed their own text.

3.9.1 Fort Mojave Indian Tribe

The *Pipa Aha Macav*, or "people by the River" (Fort Mojave 2012), are the northernmost of the Yuman-speaking Tribes who established themselves along the banks of the Colorado River well downstream from the Canyons. Traditionally, they lived in sprawling settlements adjacent to and above the Colorado River floodplain, moving to the floodplain in the spring after seasonal floods receded. Taking advantage of fresh moist silt deposited by river flooding, they planted and harvested corn, beans, and squash, but also ranged widely, hunting, fishing, gathering mesquite, and trading. They established the Mojave Trail and participated in a trading network that stretched from the Pacific Coast to the Pueblos of the Southwest (Stewart 1983). Although they ranged widely, their cultural center remained the river, which was created by *Mutavilya* along with all plants and animals, which were drawn from the water (Fort Mojave 2012; Otero 2012). Like their upstream neighbors, the Tribe views the river as a living

being to which they are connected. In the words of one Tribal member, "The river is the basis of who we are" (Otero 2012). In the Mojave worldview, members of the Tribe are related to the natural world by family ties and have stewardship responsibilities for its plants and animals. For the Mojave, some trails have spiritual as well as temporal significance. The Salt Song Trail, an important ritual trail tied to the afterlife, includes portions of the Grand Canyon.

The construction of dams along the Colorado River fundamentally changed the Mojave lifeway. No longer could they make use of the river's annual floods to refresh their fields, but even as they have adapted to changing circumstances, the river and their relationship to the natural world based on spiritual ties have remained. The Mojave continue to be concerned about the declining numbers of plants and animals in their homeland and the increase in nonnative species. Created from the water, the natural world is affected by the way the river flows. Living downstream from the project area, they are concerned about the effects of dam operation on water quality and pollution (Otero 2012).

3.9.2 Havasupai

The Havasupai Tribe and Tribal members have a history interwoven with that of GCNP since creation of the park from within the Havasupai aboriginal territory. Members of the Havasupai Tribe have access to locations of importance within GCNP guaranteed by the 1919 Act establishing Grand Canyon National Park (40 Stat. 1175, 1919) and the 1975 Grand Canyon Enlargement Act (88 Stat. 2089, 1975). The members of the Havasupai Tribe have statutory rights of access to areas on public lands, including any sacred or religious places or burial grounds, native foods, paints, materials, and medicines (16 USC 228i(c)).

The Havasupai view everything in and around the Grand Canyon as sacred in all aspects of their cultural, spiritual, and traditional life (Reclamation 1995). The Havasupai were signatories to the 1994 PA (Reclamation 1994), yet chose not to participate in the GCDAMP. The Tribe works closely with the NPS for protection of cultural sites, historic locations, and water resources. They are a member of the Native Voices on the Colorado River, a group that works with the Grand Canyon Colorado River Outfitters Association to increase understanding of Tribal relationships with the Grand Canyon from their own perspective (NVCR undated). Members of the Havasupai Tribe have worked as interpreters in GCNP.

3.9.3 Hopi

Hopi culture begins with the emergence of people into the present world from the *Sipapuni*, a spring located in the bottom of the Grand Canyon (Yeatts 2013). After emergence, the ancestral Hopi people (*Hisatsinom*) migrated in all directions around what is now the southwestern United States. During the migration period, the Hopi Clans formed and ultimately came together at the center of their universe: the Hopi Mesas. For many of the clans, the Canyons served as a home during a portion of their travels.

The Hopi ancestors have been in the Grand Canyon region for more than a thousand years (Yeatts 2013). Their presence in the Canyons (*Öngtupqa*) is well documented in the archaeological record. These ancestral archaeological sites are considered the footprints left by the *Hisatsinom* as tangible markers of their covenant with the caretaker of the earth, *Masaw*, and as a cultural claim to the land. At least 180 archaeological sites in the Colorado River corridor and in the Canyons are considered by the Hopi Tribe to be ancestral homesites.

Evidence shows that sustained use of the Canyons by the *Hisatsinom* began around A.D. 700–800 (Yeatts 2013). Use increased through time with numerous small pueblo sites dotting most of the arable land in the Canyon bottom by A.D. 1000. Both the northern and southern rims of the Canyons were similarly occupied during this time period, and a trade network extended out in all directions, linking the habitants of the Canyons to the broader region. Associated with some of these pueblos were *kivas*, ceremonial structures found in every modern Hopi village and the focus for religious activities. Just as modern Hopi villages have shrines associated with them, so do these prehistoric counterparts. While people may no longer regularly deposit offerings at these shrines, they are still considered active and sacred locations. Similarly, the sites are not considered to be "abandoned" but are still viewed as serving as the homes of those who have passed on. Proper respect for and treatment of the dead are extremely important values in Hopi culture, and protection of their resting places is paramount. The Hopi people have a spiritual obligation to serve as stewards of this land and, over the years, have developed a monitoring program that evaluates Hopi values for the health on *Öngtupqa* (the Canyons) through time (Yeatts and Husinga 2012). The Hopi are concerned with the erosion caused by the operation of Glen Canyon Dam and the effect recreation has on places of cultural importance (Yeatts and Husinga 2012). Further, and as highlighted in other sections of this document, the Hopi consider plants, animals, springs, water, landforms, minerals and other geologic deposits, and the Canyons as a whole to be sacred, contributing to the overall extreme cultural importance of the place.

3.9.4 Hualapai

The Hualapai consider the Grand Canyon and Colorado River region a great cultural landscape, especially the stretch from the Little Colorado River downstream to the confluence of the Colorado with the Bill Williams River in west-central Arizona. As of 2011, 28 places along the river are periodically monitored, in addition to an emphasis on the Colorado River itself and its tributary canyons, which the Hualapai also consider TCPs (Jackson-Kelly et al. 2011). Furthermore, many of the ancestral archaeological sites along the river are cited as TCPs, as well, but are not necessarily monitored due to difficult or obscure access and the fact that they are located in fragile contexts where periodic monitoring would simply result in undesirable impacts. Monitoring activities also include the consideration of ethnobotanical resources. When considering the intricacies of the Hualapai people's historical, cultural, and spiritual relationship to the Canyon, it is very difficult and even imprudent to attempt to assign a number to quantify significant Hualapai cultural resources along the complex landscape of the Colorado River corridor. For the most part, an evaluation of the "health" of these places is essentially a holistic response to not simply a defined point on the land, but more of the spiritual well-being one feels when standing there, as if the land was expressing its own condition through the person charged

with evaluating that condition. This could include the prevalence of visitors and the availability of privacy, the incidence and cause of erosion, the quality of water, or any number of other factors. The Hualapai's participation in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon extends back to the early 1990s and has been a consistent presence in management decisions.

The Colorado River and its Canyons are significant spiritual and physical landmarks for the Hualapai. The Hualapai consider the river the backbone, or *Ha'yiđađa*, of the landscape and to have healing powers (NPS 2011). Today, this is symbolized by its placement in the center of the Hualapai seal (Hualapai Tribe 2013). The Hualapai worldview holds that the Colorado River provides a life connection to the Hualapai as it flows through the landscape connecting the Canyons and the riparian ecosystems that sustain the Tribe. *Ha'thi-el* (Salty Spring), a sacred spring within the Canyons, contains a petroglyph site that tells of the creation of the Hualapai and other Pai peoples (HDCR 2010).

The Hualapai have occupied and used the lands and waters lying within their ancestral territory, including their present reservation, since time immemorial. The Hualapai traditionally benefited from both hunter-gatherer and agricultural subsistence practices. Throughout the year, the people collected various plant foods that were available depending on the season, such as agave in the spring, grass seeds in summer, and piñon in the uplands in the fall. Access to these resources often involved moving camps seasonally for closer proximity. Important cultural and spiritual lessons were passed down from elder to child during these recurring seasonal rounds (HDCR 2010). Plants were important not only for food but also for medicine and for materials for making baskets, cradleboards, shelter, and other useful items.

Although permanent water sources were sometimes scarce over large areas, the Hualapai were able to establish gardens and small fields in optimal locations, including along the Colorado River. Typical crops include corn, beans, and squash, as with other Tribes in the region. Seeds were often traded with neighboring people, especially the Mojave, Havasupai, and Hopi. Near springs, small terraces were established where water could be diverted. In larger streams, they made use of alluvial terraces that flooded over during spring runoff, enriching the soil as well as providing moisture for young seedlings. Irrigation channels were sometimes used to augment runoff and create more dependable watering systems, such as along the Big Sandy River. Unique to certain locations in the western Grand Canyon and along the lower Colorado River, such as around Pearce Ferry and Willow Beach, actual floodwater farming was practiced, similar to Ak-Chin strategies practiced in southern Arizona.

Larger game animals included mule deer, bighorn sheep, and pronghorn antelope, but rabbits and other small game were also important. Game animals provided materials for shelter, clothing, tools, weapons, and ceremonial objects, in addition to being vital food sources. The Hualapai were considered excellent hunters and commonly traded hides and dried meat with their neighbors in virtually every direction, including across the river to the north. This pattern of subsistence continued for many centuries.

Although sporadic contact with European (mainly Spanish) explorers started in 1776, it was not until the mid-19th century that Hualapai people had extensive dealings with Euro-

American settlers. At first, these interactions appeared to be fairly amicable, but as the newcomers' hunger for land, minerals, water, and grass for livestock grew, trouble ensued by the mid-1860s. After a period of conflict with these intruding Euro-American miners, ranchers, and, inevitably, the U.S. Army, a truce was forged in 1868. Most Hualapai were persuaded to congregate at Camp Beale Springs near present-day Kingman, Arizona, where they maintained relatively good relations with the commanding officer, Captain Thomas Byrne (Casebier 1980). This eventually led to a number of Hualapai men joining the Army as scouts for General George Crook in 1873, during which time they performed admirably, according to Crook's own words. However, once their service was no longer required, in 1874, many of the Hualapai were removed from their homeland and forced into an internment camp at La Paz, Arizona, near the present-day town of Ehrenberg. Many Hualapai perished from malnutrition, excessive heat, and disease while interred at the camp, and those that were eventually released returned to their homeland to find it irrevocably altered by the rush of Euro-American migration. Only those that lived in the most remote and rugged canyons near the Colorado River avoided this ordeal. The Hualapai commemorate the march to La Paz, and this tragic period of their history, through an annual relay run known as the La Paz Run (HDCR 2010).

Finally, in 1883, the Hualapai Reservation was established by executive order. It comprised just a fraction of their original territory, but included 108 mi of the Colorado River country and was at least part of their ancestral homeland. Evidence of their occupancy, use, and ownership of their ancestral territory is contained in numerous and widespread archaeological sites, family and Tribal records, oral traditions, and legends, and is embedded in the names of landmarks and sacred places throughout the Canyons and surrounding areas (Reclamation 1995). The Hualapai believe they are entrusted with the responsibility of caring for the land within their ancestral homeland, both on and off the reservation, and are actively involved in preservation activities and environmental stewardship throughout the Colorado River drainage.

The Hualapai participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and as a PA signatory. At that time, a total of 18 cultural resource sites were identified within the Canyons as archaeological sites and/or traditional cultural places associated with the Tribe, although many more have been identified since then. In addition, 46 culturally significant plant species were identified within the river corridor.

Currently, the Hualapai are active members of the Adaptive Management Working Group (AMWG) and the Technical Work Group (TWG), and they participate in the monitoring and assessment of cultural and natural resources throughout the Grand Canyon, using a combination of traditional ecological and cultural knowledge and modern survey techniques (Jackson-Kelly 2008).

Hualapai monitoring programs have identified a number of issues that are negatively affecting Hualapai archaeological sites, ethnobotanical resources, and other TCPs along the Colorado River corridor. These include the disruption of riverine ecology due to fluctuating river flows resulting from Glen Canyon Dam operations, and the related increase in human activity, such as trailing and camping on beaches near ancestral sites. The dramatic increase in the number of boaters and recreationists since the early days of river running is always a matter of concern, as evidenced by occurrences of artifact piling, trail erosion, and the occasional

discovery of displaced artifacts and even human remains. The long-term trend of these phenomena presents challenges in preserving the integrity and significance of fragile and nonrenewable resources.

In April of 2010, Mr. Wilfred Whatoname, Sr., the Chairman of the Hualapai Tribe, sent a letter of testimony to the Natural Resources Committee Joint Oversight Field Hearing, entitled "On the Edge: Challenges Facing Grand Canyon National Park." The letter requested assistance in the restoration of funds for monitoring of Tribal resources and reiterated the Hualapai Tribe's commitment to preserving its natural and cultural resources (Whatoname 2010). The Hualapai are also members of Native Voices on the Colorado River (NVCR undated). The Tribe is a Cooperating Agency for the preparation of this LTEMP EIS and has continued to develop, refine, and expand its program of monitoring cultural and natural resources along the river, including further implementation of traditional ecological knowledge.

3.9.5 Navajo Nation

For the Navajo Nation, or *Diné*, the Canyons downstream from Glen Canyon Dam are culturally and historically significant. The Colorado River and Little Colorado River are seen as deities, and their confluence is associated with Changing Woman, the most important Navajo traditional deity. Navajo lore includes an account of how Haash′ cheeh Zhin., or "Humpback God," created the Grand Canyon by dragging his cane from east to west, creating a great chasm to drain a flooded world (Two Bears 2012; Roberts et al. 1995). Glen Canyon, Marble Canyon, Grand Canyon, and Little Colorado Canyon are home to many Navajo deities. Oral traditions recount how these deities bestowed important ceremonial knowledge and taught the people how to use the resources found throughout the landscape (Two Bears 2012).

Ethnohistoric accounts, as well as archaeological and linguistic evidence, suggest that the Apacheans (Athabaskan-speaking ancestors of the Navajos and Apaches) entered the North American Southwest sometime between A.D. 1000 and the 1600s. During this time, the Apacheans traded and intermarried with neighboring groups, resulting in the traditional Navajo culture of today (Brugge 1983; Brown 1991). According to traditional Navajo narratives, they have always lived "among the four sacred mountains," having emerged from the four underworlds into this world at Mount Blanca (Two Bears 2012). By the mid-1800s, the Navajo were fully utilizing resources in and around the Canyons for farming, livestock grazing, plant gathering, hunting, and religious purposes (Navajo Nation 1962, undated). The Canyons also served as a place of refuge from Mexican slave raiders, other Indian Tribes, and the U.S. Army. During the 1860s, when Navajos were conquered by the U.S. Army and interned at Fort Sumner, New Mexico, many Navajos escaped to the Canyons and lived there for many years. The Canyons continued to provide protection to the Navajo and their herds of sheep, goats, and horses during the federally imposed livestock reduction program of the 1930s and 1940s. Rivers, springs, and seeps in the Canyons have provided water to people and livestock for generations. Sites and remains of historic Navajo dwellings and sweat lodges in the Canyons retain importance for the Navajo (Roberts et al. 1995).

Both the Colorado River and the Little Colorado River protect and give life to the Navajo. Offerings seeking the rivers' protection continue to be made to the Colorado River. Floodplains have provided arable land for corn fields, and the higher terraces have provided habitat for wild game such as deer and bighorn sheep, as well as important food, medicinal, and ceremonially important plants, which continue to be used today (Roberts et al. 1995).

Many mineral sources of cultural importance to the Navajo are found in the Grand Canyon, including salt, red ochre, and quartz crystals. The salt source within the Grand Canyon is personified as Salt Woman. A journey to Salt Woman consisted of following the Salt Trail down the walls of and into the Grand Canyon, stopping periodically to make offerings and perform rituals. To enter the Canyon, an individual had to be prepared mentally, physically, and spiritually, and enter the Canyon in good faith, as it was the final resting for the spirits of their ancestors (Roberts et al. 1995).

Many of the Canyon's trails and river crossings retain important cultural meanings both ritually and historically. The stories associated with the trails keep alive traditions of Navajo history. The trails led to refuge, hunting, gathering, and trade with neighboring Tribes (Roberts et al. 1995; Linford 2000).

Nihoo′ kaa Diné é bila Ashdla′ii, or the earth surface people as referred to within Navajo society, have long since been immersed in continuing and maintaining the process of the Fundamental, Natural, and Sacred laws that were bestowed within the people since the beginning of the emergence from the first world or Ni′ Hodilil (Black World). Through the passage of each world after Ni′ Hododlizh (Blue World), Ni′ Holtso (Yellow World), and Ni′ Halgagh (White World), and finally the fifth and present world, Ni′ Hodisqous (Glittering World), the Navajo people have carried the teachings and ordinance with them as they entered the present world.

The Navajo Nation views this space as a Traditional Cultural Landscape, beginning at the Animas River, into the San Juan River, into the head waters of the Green River, into the Colorado River, Lake Powell, Glen Canyon, Marble Canyon, and Grand Canyon, through the Little Colorado River, and Lake Mead, all the way into the Gulf of California and the Pacific Ocean. This Traditional Cultural Landscape includes the tributaries within the Canyon corridors, the riparian species, wildlife, fisheries, botanical, and biological entities, insects, birds, vertebrates, and invertebrates, as well as all creatures within the Canyon as culturally significant to the Navajo people. The Colorado River and the Little Colorado River have specific functions in the ceremonial sphere of the Navajo people—the river is a protector of our people.

The Navajo have participated as a Cooperating Agency in the development of NEPA documents concerned with environmental impacts on canyon resources downstream of Glen Canyon Dam. The Navajo participated in in-depth cultural studies, which have identified important archaeological, geological, botanical, and biological resources and TCPs within the Colorado River corridor, and have provided monitoring and mitigation recommendations for culturally important resources that are affiliated with the Navajo Nation. Important cultural places include trails, subsistence areas, migration places, spiritual landscapes, and archaeological sites that lie within and adjacent to GCNRA and GCNP (Thomas 1993; Roberts et al. 1995; Neal

and Gilpin 2000; NPS 2005a). Currently, the Navajo are active members of the AMWG and the TWG (Reclamation 2012b).

3.9.6 Pueblo of Zuni

The Grand Canyon and the Colorado River have been sacred to the Zuni people since their emergence onto the surface of the Earth. According to the traditional narratives that describe the emergence of the Zuni people (*A:shiwi*) from Earth Mother's fourth womb, sacred items that identify the Zuni people, the *Etdo:we* (fetish bundles), were the first to emerge; the people then came out into the sunlight world at a location in the bottom of the Grand Canyon near present-day Ribbon Falls. The creation narratives also describe the Zunis' subsequent search for the center of the world, *ldiwan'a* (the Middle Place). During this search, the people moved up the Colorado River and then up the Little Colorado River, periodically stopping and settling at locations along these rivers. At the junction of the Little Colorado and the Zuni Rivers, many of the supernatural beings, or Koko, came into existence. After a long search, the Zunis located the middle of the world and settled there. The Middle Place is located in today's village of Zuni.

The Pueblo of Zuni, the *A:shiwi,* continue to maintain very strong cultural and spiritual ties to the Grand Canyon, Colorado River, and the Little Colorado River because of their origin and migration narratives.

The Zuni River, Zuni Heaven (*Ko'lu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Grand Canyon have been important to Zuni culture and religion for many centuries, if not a thousand years. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Grand Canyon, including the Zunis' familial relationship with birds, animals, soils, rocks, vegetation, and water. The Grand Canyon is very sacred, and the Zuni people place prayers and offerings in the Zuni River every morning and evening which are then spiritually sent to the Grand Canyon via the Zuni River's confluence with the Little Colorado River, and the Little Colorado River's confluence with the Colorado River in Grand Canyon. The Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on Zuni.

The Canyons have significant religious and cultural importance to the Zuni. Zuni pray not only for their own lands but for all people and all lands. To successfully carry out the prayers, offerings, and ceremonies necessary to ensure rainfall for crops and a balanced universe, Zunis must collect samples of water, plants, soil, rocks, and other materials from various locations. Each part of the Zuni universe is interconnected. Plants, animals, and colors are associated with the various cardinal directions. Minerals, clay, rocks, plants, and water are used in prayers. Prayers are accompanied by offerings of prayer sticks. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni. The animals, the birds, insects, rocks, sand, minerals, plants, and water in the Grand Canyon all have special meaning to the Zuni people.

For the Zuni, traditional cultural places encompass a wide variety of cultural sites including, but not limited to, ancestral habitation sites; culturally significant archaeological/historic features; pictographs and petroglyph sites; collection areas for plants, water, and minerals; natural landmarks; prominent topographic features (e.g., mountains, buttes, and mesas); shrines; sacred sites; and pilgrimage trails and routes. All archaeological sites, including, but not restricted to, pictographs, petroglyphs, habitation areas, artifact scatters, special use areas, and other archaeological manifestations, are considered ancestral sites which imbue great cultural and religious significance to the Zuni people. For Zuni, these archaeological sites have never been abandoned but continue to maintain life and spiritual forces significant to the Zuni people. These archaeological sites are interconnected to one another by trails, and these trails connect the sites to the Zuni Pueblo. Trails often lead to shrines and offering places. Religious shrines are used by the Zuni to mark their land claim boundary, and these shrines today are considered sacred. Shrines and other sacred cultural markers act in Zuni culture as maps, charts, and other documents do in literate societies (Pandey 1995). The distribution of shrines on the landscape act as cognitive maps for the Zuni when visiting these places and play a significant role in reaffirming their cultural tradition and beliefs. Sacred shrines and offering places were used by the Zuni ancestors, the *Che:be:ya:nule:kwe* and the *Enoh:de:kwe*. Sacred shrines and offering places are often related to archaeological sites and are of great cultural and religious significance. These shrines and offering places are also imbued with life and spiritual forces. Shrines hold great significance to the Zuni and are considered sacred.

Shrines are also established at other places of significance within the Zuni cultural landscape. The Zuni people preserve and maintain these "markers," or locations, by making regular visits or pilgrimages to deposit offerings and to ask blessings upon the land. Their location is central to the purpose of the shrines. Thus, to disturb or move the shrines would be incompatible with the essence of their location with respect to the areas and the people they protect. Second, these locations have religious significance to the Zuni people, whether or not they appear to have been used recently. Once established, they continue to provide their protection in perpetuity.

The Zunis have many named places across their cultural landscapes that are interconnected by a series of trails. Trails are important because they maintain strong and continuous connections between the heart of the Pueblo of Zuni and many culturally important distant places on the Zuni landscape. Trails are blessed before their use, and once blessed, they are blessed in perpetuity. For the Zuni, there are many prayers and offerings that are required to be made prior to a trip and during a trip, along the trail to the place of emergence and the Grand Canyon. Prayers and offerings are made at springs and shrines along the trail. The trail, the springs, and the shrine area are all sacred. The trail from Zuni to the Grand Canyon thus has a continuously important religious meaning to the Zuni people. It is sacred and will also be used in the afterlife. Once a trail is blessed, it remains blessed permanently. The Zuni people have important concerns regarding the ancient Zuni trail from their village to the bottom of the Grand Canyon.

The Pueblo of Zuni participated in the development of the 1995 EIS (Reclamation 1995) as a Cooperating Agency and a PA signatory. Currently, the Pueblo of Zuni has active representation on the AMWG and the TWG. The Zuni religious leaders, on behalf of the Pueblo

of Zuni, have developed a monitoring program to identify impacts on important Zuni cultural resources in the Colorado River corridor resulting from the operation of Glen Canyon Dam. Erosion and visitor impacts (i.e., trailing, litter, vandalism, and unauthorized artifact collection or movement) have been identified as sources of impacts on archaeological sites and areas of cultural importance (Dongoske 2011a). The results of monitoring are presented directly to Reclamation and NPS.

On September 21, 2010, the Zuni Tribal Council passed resolution M70-2010-C086 which stated that the Zuni Tribe of the Zuni Indian Reservation "... asserts that the Grand Canyon, from rim-to-rim, and all specific places located therein including the confluence of the Colorado and Little Colorado Rivers, topographic and geologic features, springs, archaeological sites, mineral and plant collection areas, and any other places it so identifies as historically, culturally, or spiritually important to the Zuni Tribe within the Grand Canyon must, as a matter of the United States government's trust responsibility toward the Zuni Tribe, be assumed by all federal agencies to be eligible for the National Register of Historic Places and insists that all agencies of the United States Department of the Interior (a) accept and respect the above assertion with reference to any topographic or geologic feature, water body, or other place identified by the Zuni Tribe as historically, culturally, or spiritually important within the Grand Canyon; (b) respect Zuni tribal interests in and values ascribed by the Zuni Tribe and tribal members to such places; and (c) accept and respect that the continued mechanical removal of rainbow and brown trout at the confluence of the Colorado and Little Colorado Rivers is considered an adverse effect on a traditional cultural property that is eligible for listing on the National Register of Historic Places."

Appended to the Zuni Tribal Council Resolution was a Position Statement by the Zuni religious leaders. The Position Statement asserted that the *Newe:kwe*, *Makeyana:kwe*, *Uhuhu:kwe*, *Chikk'yali:kwe*, *Shuma:kwe*, *Halo:kwe*, *Sahniyakya*, *Shiwana:kwe*, Zuni Rain Priests, Zuni Kiva Groups, and other associated religious societies demonstrate their passionate support for the Pueblo of Zuni's cultural and religious objections (to mechanical removal of rainbow and brown trout), reflected in a letter from Zuni Governor Cooeyate to Mr. Larry Walkoviak, Regional Director, Bureau of Reclamation, dated June 30, 2010, on the past and proposed future mechanical removal management activities that consist of electroshocking and destroying thousands of rainbow trout and brown trout at the confluence of the Little Colorado River and Colorado River in the Grand Canyon. It is the Zuni religious leaders' position that all animals, including all aquatic life (e.g., native and nonnative fishes, insects, amphibians, snakes, and beavers), birds, plants, rocks, sand, minerals, and the water in the Grand Canyon are sacred, have special meaning, and a unique familial relationship to the Zuni people. The entire environment at the bottom of the Grand Canyon is sacred to the Zuni people and the Grand Canyon, including the confluence of the Little Colorado River and Colorado River, which are integrally connected to Zuni religious beliefs, ceremonies, and prayers.

The Zuni annual ceremonial activities carried out at Zuni are performed for the specific purpose to ensure adequate rainfall and prosperity for all life in the universe. The individual Zunis that are part of these respective Religious Societies pray, fast, and perform religious ceremonies not only for Zuni lands, but for all people and all lands. The ceremonies are performed as part of maintaining a balance with all parts of this interconnected universe. As a

direct consequence of maintaining this balance and interconnectedness with the universe, the Zuni religious leaders believe that the past and proposed future mechanical removal activities created, and will continue to create, a counter-productive energy to the Zuni respective ceremonial efforts to ensure rainfall, prosperity for all life, and to maintain a harmonious balance among the Zuni people. The Zuni religious leaders expressed that they were especially concerned that the continuation of the mechanical removal activities proposed for the confluence of the Little Colorado and Colorado Rivers within the Grand Canyon magnifies the negative effects of this action for the Zuni people and all life. The Grand Canyon is very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Grand Canyon that may have an impact on the Zuni.

In summary, the Zuni River, Zuni Heaven (*Ko'fu:wa/a:wa*), the Little Colorado River, the Colorado River, and the Canyons have been important to Zuni culture and religion for many centuries. Zuni religious beliefs, narratives, ceremonies, and prayers are intrinsically tied to the entire ecosystem of the Canyons, including the Zuni's familial relationship with birds, animals, soils, rocks, vegetation, and water. The Canyons are very sacred, and the Zuni people are concerned with activities that may affect the resources in this sacred place. Similarly, the Zuni people are concerned about activities that take place within the Canyons that may have an impact on the Zuni.

3.9.7 Southern Paiute Tribes

The Southern Paiute Tribes that have ties to the region and who are most directly tied to the project area include the Kaibab Band of Paiute Indians; the Paiute Indian Tribe of Utah, which consists of five bands of Southern Paiute (Cedar Band, Indian Peaks Band, Kanosh Band, Koosharem Band, and Shivwits Band); and the San Juan Southern Paiute. The Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah are also members of the Southern Paiute Consortium (SPC). The Kaibab Band represents the SPC in matters pertaining to Glen Canyon Dam and Colorado River management. Currently, the SPC is an active member of the AMWG and the TWG, and the San Juan Southern Paiute Tribe is a member of the AMWG (Reclamation 2012b).

The Canyons and the Colorado River have historic cultural significance as well as contemporary interest to the Southern Paiute. Traditional narratives of Paiute origin vary from band to band, but share a general central theme: "Southern Paiutes were the first inhabitants of this region and are responsible for protecting and managing this land along with the water and all that is upon and within it" (Bulletts et al. 2012).

The Southern Paiute maintain that when an undertaking is to occur in their traditional homeland, it is their divine right to understand that action and the impacts that could occur from that action (Stoffle et al. 1997). This is the reason the Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah formed the SPC in 1993 and participate in the management of lands throughout the Colorado River drainage, through improved government-to-government interaction in the GCDAMP. The consortium participates in and conducts its own assessments of

potential environmental impacts on ethnobotanical, geological, biological, and cultural resources, the results of which are provided in technical reports (Bulletts et al. 2012).

According to traditional Southern Paiute values, all plants, animals, and natural elements within that land should be respected and protected. The Southern Paiute have identified the Colorado River as one of their most powerful natural resources and consider the Colorado River corridor, as well as all natural and cultural resources within the corridor, as culturally significant features (Stoffle et al. 1995). The Southern Paiute have identified numerous archaeological sites, rock art sites, animal resources, ethnobotanical resources, traditional natural resources (soil, water, rocks, and minerals), and traditional and contemporary use areas within the Colorado River corridor that require monitoring and protection (Stoffle et al. 1994). Resources of importance continue to be monitored by the SPC on a rotating basis (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007).

3.9.8 Indian Trust Assets and Trust Responsibility

The DOI acknowledges its federal trust responsibility and the importance of Indian trust assets within the proposed action area. The trust responsibility consists of the highest moral obligations that the United States must meet to ensure the protection of Tribal and individual Indian lands, assets, resources, and treaty and similarly recognized rights. Secretaries of the Interior have recognized the trust responsibility repeatedly and have strongly emphasized the importance of honoring the United States' trust responsibility to federally recognized tribes and individual Indian beneficiaries (Secretarial Order 3335; DOI 2014). Indian trust assets are legal interests in property held in trust by the U.S. Government for Indian Tribes or individuals. Examples of such resources are lands, minerals, or water rights.

The action area is bounded on the east by the Navajo Indian Reservation and on the south by the Hualapai Indian Reservation. The DOI and Reclamation have ongoing consultation with these Tribes regarding potential effects of the proposed action on their lands, resources, trust assets, and reserved rights. High-flow releases will inundate shoreline areas historically affected by seasonal floods, and analysis of effects on resources show that the proposed action is not likely to impact Indian lands, minerals, or water rights.

3.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section describes the recreational and visitor-experience attributes found in the portions of GCNRA, GCNP, and LMNRA that are related to flows of the Colorado River. Recreational use is an important issue because the GCPA mandates that Glen Canyon Dam be operated in a manner that protects, mitigates adverse impacts to, and improves the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and in a manner fully consistent with and subject to 1802(b) of the GCPA. Most of the description provided here focuses on resources and activities found in the Colorado River Ecosystem from just below Glen Canyon Dam within GCNRA to the western

boundary of GCNP at RM 277. In addition, because of the potential for the alternatives to differentially affect seasonal (though not annual) reservoir levels of both Lake Powell in GCNRA and Lake Mead in LMNRA, this section also provides information on visitor use of both reservoirs and reservoir recreational facilities, principally boat launching facilities, that could be affected by the alternatives being evaluated. Recreation economics are discussed in Section 3.14 of this EIS.

3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area

The Glen Canyon reach of the Colorado River is an approximately 15-mi segment of the river between Glen Canyon Dam and Lees Ferry. Recreational activities include trout fishing, motor- and human-powered boating, commercial flat-water rafting, camping, photography, hiking, interpretation of historic and cultural properties, and sight-seeing.

The Glen Canyon General Management Plan (GMP) (NPS 1979) established management zones within GCNRA. The majority of the land along the Glen Canyon reach is located within the Natural Zone and is included in the park's wilderness recommendation. The river is managed to provide for recreation. Visitor services include facilities for camping and interpretation of resources (such as the descending sheep panel). The Navajo Indian Reservation extends along much of the east side of the river immediately adjacent to the GCNRA boundary.

3.10.1.1 Lees Ferry Recreational Fishery

The 15-mi Glen Canyon reach, upstream of Lees Ferry, supports a recreational fishery that is an important recreational and economic resource based largely on nonnative rainbow trout (Figure 3.10-1). Fish in all waters within GCNRA and GCNP are managed by the NPS, in coordination with the AZGFD and FWS. The condition of the recreational rainbow trout fishery within GCNRA can be affected by the operations of Glen Canyon Dam, which is operated by Reclamation. The Comprehensive Fisheries Management Plan (the Plan) for GCNP and GCNRA (NPS 2013e) identified the goals for this fishery (Section 1.10.3).

Dam operations and fishery management may affect the size and quality of the rainbow trout fishery and angler satisfaction. While there is a strong interest in maintaining the highly valued trout fishery in the Glen Canyon reach, there also is concern about the migration of trout to downstream areas, particularly near the confluence with the Little Colorado River, which is a key concentration area for the humpback chub, a federally listed endangered species.

The recreational fishery has evolved over time. From 1964 until 1991, the rainbow trout population of the Glen Canyon reach was sustained by annual stocking, but with the stabilization of flows by dam operations, the trout population eventually became self-sustaining, although stocking was continued through 1998. The trout population in the Glen Canyon reach has been monitored on a regular basis by the AZGFD since 1991. Key population characteristics identified



FIGURE 3.10-1 Glen Canyon Reach Rainbow Trout (Courtesy of George Andrejko, AZGFD)

from 1991 to 2009 inform an understanding of the relationships among dam operations, the trout population, and native fish populations (Makinster et al. 2011).

The trout population and accompanying angler success rate in the Lees Ferry fishery has been quite variable over the years in response to management actions, stocking, dam release regimes, and food availability. The periods from 1972 to 1978 and 1978 to 1984 were known as the fishery's Trophy Era and Quality Era, respectively (Reclamation 1995). It was during this time that the Lees Ferry fishery achieved an international reputation as the fishery producing 10- to 20-lb trout, and bag limits of 10 fish weighing a total of 40 lb were not uncommon. From 1978 to 1984, the number of large fish being taken declined, but creel census reports still showed an average weight of 2.79 lb for fish caught, and fish over 20 in. in length made up about 25% of the catch. From 1985 to 1988, fish longer than 20 in. made up less than 10% of the harvest and the percentage of 15-in. fish harvested continued to increase (Reclamation 1995). Section 3.5.3.1 presents additional discussion of the condition of the rainbow trout fishery.

An estimated total of 10,908 anglers used the trout fishery in 2014, of which 6,739 were boat anglers and 4,169 were walk-in anglers. Creel surveys conducted during 2014 found that overall angler success remained high, with 95% and 64% of the anglers catching at least one fish

in the boat-fishing section upriver of Lees Ferry or walk-in section accessed at Lees Ferry, respectively. Angler satisfaction on a scale of 1 to 5 remained high for both boaters and walk-in anglers, averaging 4.55 and 4.28, respectively (Rogowski, Winters, et al. 2015). The angler catch rate generally correlates with the size of the fish population; Figure 3.10-2 shows the angler catch rate from 1977 to 2014. Catch rates peaked in 1998 and increased sharply again after 2010, with 2012–2014 having the highest catch rates on record for boat anglers. Catch rates for boat anglers have been roughly twice the rates of walk-in anglers in recent years. This has been attributed to the ability of boat anglers to access preferred trout habitat; walk-in angling catch rates are better correlated to those from electrofishing surveys (Rogowski, Winters, et al. 2015). Electrofishing data from 1991 to 2014 show that there has been a long-term trend of decreasing fish size. In the 2014 electrofishing survey conducted in the Glen Canyon reach in spring, summer, and fall months, 17% of rainbow trout collected were less than 152 mm (6 in.) in length, 58% were in the 152–305 mm (6–12 in.) range, 24% were in the 306–405 mm (12–16 in.) range, and only about 1% were in the >405 mm (>16 in.) range (Rogowski, Winters, et al. 2015).

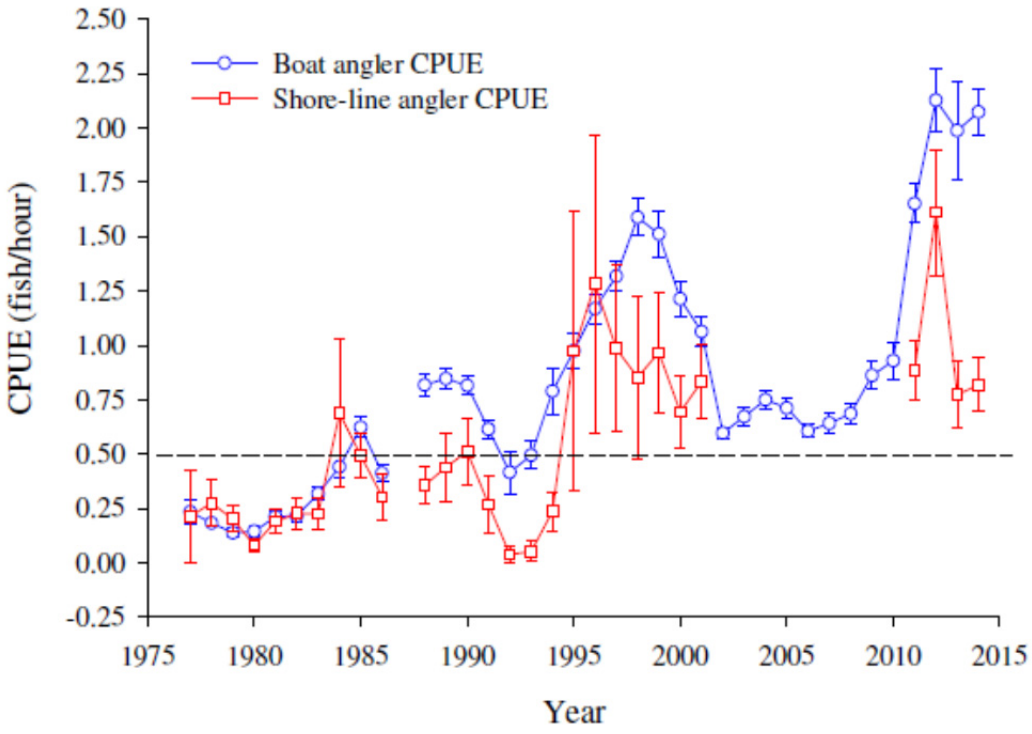

FIGURE 3.10-2 Mean Rainbow Trout Catch Per Unit Effort (CPUE, fish caught per hour) of Both Boat Anglers (blue) and Shore-Line Anglers (red) from Creel Surveys at Lees Ferry (Error bars represent 95% confidence intervals. The dashed line indicates the trigger point [0.5 fish/hour] for potential restocking of rainbow trout) (Source: Rogowski, Winters, et al. 2015)

Levels of Recreational Fishing Use

Fishing occurs year-round in the Glen Canyon reach, with the months of April and May being the peak months; however, substantial fishing use occurs from March through October in most years (Figure 3.10-3). Most fishing in the Glen Canyon reach is done from boats or is facilitated by boating access to gravel bars and riffles in the river upstream from the NPS Lees Ferry launching facility (Anderson, M. 2012). Fly fishermen fish both from boats and by wading bars, riffles, and along the shore, depending on river flow levels; spin fishermen more typically fish from boats. The availability of gravel bars for wading depends on river flow, with most bars being inundated at 15,000–16,000 cfs (Lovett 2013). There also is significant fishing use by walk-in anglers along the approximately 1.2 mi of shoreline between the Paria River confluence with the Colorado River and just upstream of the launch facility. A significant number of anglers also access the Colorado River below the Paria River confluence on Paria Beach, farther

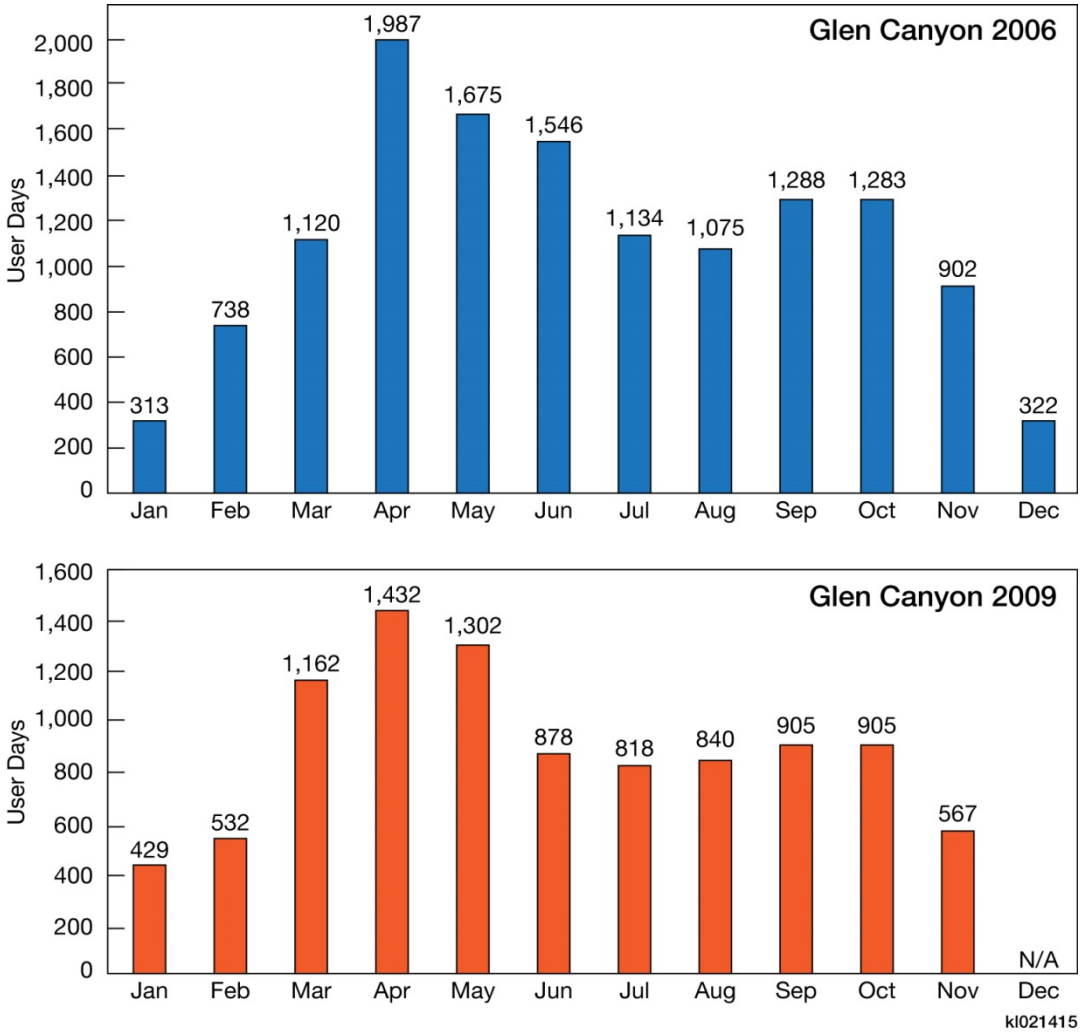

FIGURE 3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 (top) and 2009 (bottom) (User days for December 2009 were unavailable.) (Source: Reclamation 2011d)

downriver via a system of trails and across the river on Navajo Nation land. Power boaters can access almost the entire river upstream of the launch facility with only a small safety area below the dam being closed to access.

The AZGFD estimates that total fishing use in the Glen Canyon reach in 2011 was 87,000 hr (15,818 angler days)[10] (Anderson, M. 2012). It is estimated that 70,000 hr (12,727 angler days) of angling effort were expended by boating anglers and 17,000 hr (3,091 angler days) were expended by walk-in anglers. Angler use days peaked at 52,000 in 1983 (Figure 3.10-4), but eventually dropped to an average of about 3,400 angler days per year from the mid-1990s to 2009.

Based on AZGFD survey data, commercial guided fishing operations provided services for about 50% of the boating-based fishing use in the Glen Canyon reach in 2011 (Anderson, M. 2012). In that year, there were five NPS-authorized commercial fishing guide operations in the Glen Canyon area that provided boats and guide services in the Glen Canyon reach (Blaise 2012). The AZGFD surveys did not identify any walk-in fishing use being supported by commercial guides. NPS requires guide services to obtain a commercial use authorization to operate in GCNRA; guide services are also required to report the number of anglers they serve. The total reported number of commercial clients for the five commercial fish

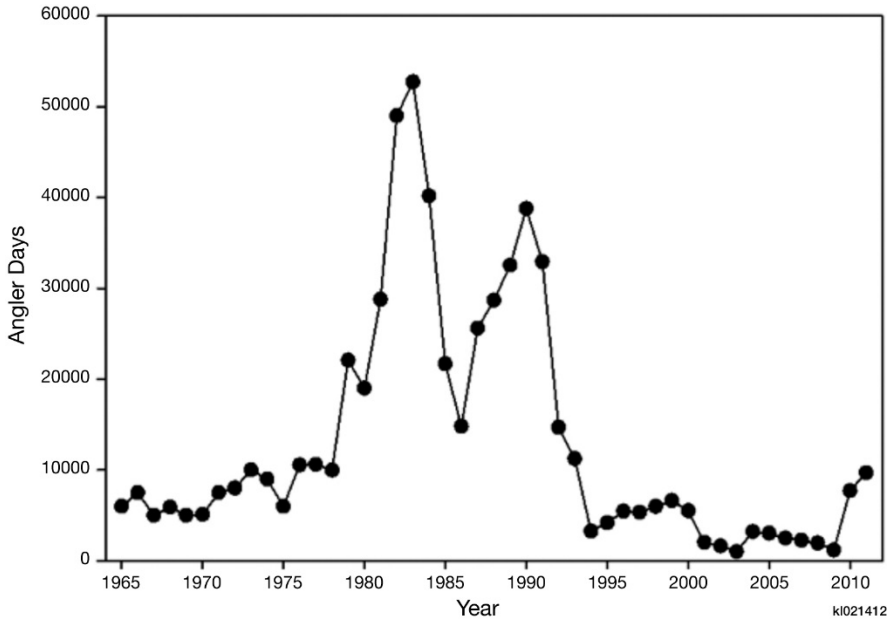

FIGURE 3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 (Source: AZGFD 2012)

10 The methodology for calculating angler days depends on the assumed duration of an angler day. The computations here are based on the AZGFD statewide standard of 5.5 hr per trip, but it is understood that if other durations were used, the number of angler days would be somewhat different.

guiding operations in the 4 years beginning in 2009 was 2,652, 2,665, 2,731, and 3,210, respectively (Blaise 2012; Seay 2013). Historical levels as high as 4,000 clients per year reported for a single operator provide some perspective on the current level of commercial use (Gunn 2012).

Important Attributes of Fishing in the Glen Canyon Reach, and Angler Satisfaction

The quality of the fishing experience in the Glen Canyon reach has been studied to help understand what characteristics of fishing in the area are most important to participants. A study was conducted by Bishop (Bishop et al. 1987), during the period when dam operations resulted in large and rapid fluctuations in water flows, and shortly thereafter, when the trout fishery was regularly producing large fish. Stewart et al. (2000), in another study, identified the flow regimes preferred by anglers. Although the two studies were completed under very different operating criteria, anglers in both studies identified a marked preference for flows in the 8,000 to 15,000 cfs range. The Bishop et al. (1987) study further identified a preference for steady, non-fluctuating flows. In the Stewart et al. (2000) study, fluctuating flows were not identified as an issue. Because fluctuations had been reduced to MLFF levels by the time of the study, attitudes toward higher levels of fluctuations could not be investigated. In both studies, anglers showed a clear dislike of flows below 3,000 to 5,000 cfs.

Another attribute of fishing in the Glen Canyon reach affects fishermen who wade and fish from the shore and gravel bars. High water levels, as well as rapid changes in water levels, directly affect the safety of wading fishermen due to the potential for being swept away by the river current. The 1995 Glen Canyon Dam EIS (Reclamation 1995) included a reference to three drownings that were possibly related to river stage or stage change and noted that high flows (30,000 cfs or more) reduced the safety of wading in the river. After the adoption of the MLFF operating protocol in 1996, ramping rates were restricted, which has likely reduced the level of this risk, as has the reduction of normal high flows to 25,000 cfs.

3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach

The 15-mi Glen Canyon reach supports several recreational activities in addition to fishing, including river floating, camping, and recreational boating. In calendar year 2012, the NPS estimated that 210,627 recreation users visited the area (NPS 2014d). About 25% of the annual visitors accessed the Glen Canyon reach via the pontoon-raft concession that departs from near the dam and travels to Lees Ferry.

The NPS facilities at Lees Ferry consist of launch ramp, campground, restroom, and interpretive facilities, as well as hiking trails. Upstream of the Lees Ferry launching facility, there are six designated, boat-accessible-only, camping areas.

An NPS launching facility is the main access both for trips going downstream through the Grand Canyon and for fishermen and other boaters heading upstream into the Glen Canyon reach. Other facilities nearby interpret the human history and existing historic structures

associated with the historic Lees Ferry crossing. Aside from the courtesy dock located next to the launch ramp, facilities in this area are not directly affected by river fluctuations.

Camping in the Glen Canyon reach is allowed in six designated areas. These areas are located on sediment terraces and beaches. Figure 3.10-5 shows the general location of the six designated campsite areas; Figure 3.10-6 illustrates the affected shoreline environment in the GCNRA area.

In addition to recreational power boating, the NPS authorizes one concessionaire, Colorado River Discovery (CRD), to provide a variety of river services in the Glen Canyon reach. The most popular of these is a half-day guided trip that originates at the dam; most CRD trips are motorized pontoon rafts; however nonmotorized full-day trips are also offered.

The most popular trips are run twice a day during the main part of the recreation season. The rafts have a maximum capacity of 22 people (Figure 3.10-7). At the end of the trip, passengers are transported by bus from Lees Ferry back to Page. The passenger numbers served by CRD are shown in Table 3.10-1. The trips generally originate in Page, Arizona, at the company's rafting headquarters. The company provides transportation to the launch site, which involves traveling through a 2-mi-long tunnel that provides access to the river near the base of the dam. CRD also offers a "backhaul" service that transports private canoes/kayaks upstream from Lees Ferry into the Glen Canyon reach.

HFEs create operational issues for the rafting concessionaire, including cessation of operations for a period of days and the need to move mooring docks and rafts or to relocate operations to the Lees Ferry launch site, which is a less economically desirable location.

Although the concessionaire does not operate during an HFE, the departure/mooring docks for the day-rafting operation are located just below the dam, and HFEs in excess of power-plant capacity of 31,500 cfs require that the concessionaire's rafts either be removed from the river or relocated because of turbulence caused by the discharge from river bypass tubes. The concessionaire also must remove boarding steps that allow passengers to get from the dock to the boats. With 21 boats, this is a major amount of work that disrupts business operations.

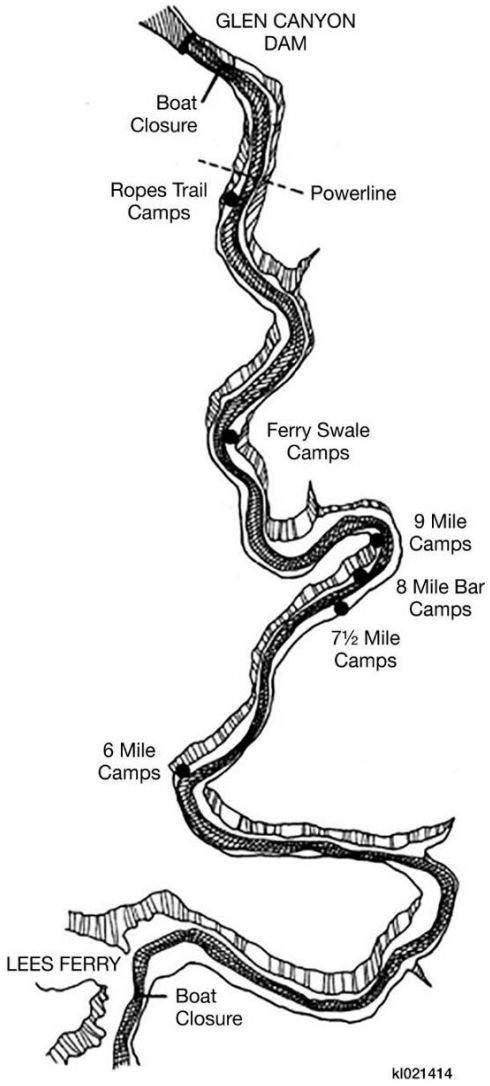

FIGURE 3.10-5 Designated Campsite Areas in the Glen Canyon Reach (GCNRA 2014)



FIGURE 3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite (courtesy of GCNRA)



FIGURE 3.10-7 Pontoon Raft Operated by Colorado River Discovery

TABLE 3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013

Month	2009	2010	2011	2012	2013[a]
January	0	0	0	0	0
February	159	8	19	48	100
March	2,211	2,131	1,922	2,163	2,416
April	5,256	4,599	4,533	4,801	3,914
May	6,346	6,629	6,831	7,438	6,684
June	9,333	9,905	9,444	10,372	8,880
July	9,256	9,887	9,389	9,515	8,661
August	7,866	7,367	7,050	7,773	6,479
September	5,415	6,287	6,001	6,300	5,245
October	3,825	3,824	3,978	4,363	1,311
November	735	687	458	535	562
December	0	0	0	0	8
Totals	50,402	51,324	49,625	53,308	44,260

[a] The 2013 passenger counts were affected by the closure of AZ Highway 89 in February 2013.

Source: Blaise (2014).

During the 2012 HFE event, the concessionaire indicated that the business was disrupted for 2 days before and after the HFE, as well as during the HFE.

In cases of extended high flows (such as 1983–1984), rafting operations have been relocated to the Lees Ferry launch site where they continued limited and modified operations. These operations require the rafts to travel upriver against heavy current with a reduced passenger load. In this scenario, the rafts travel upriver through a portion of the canyon using an outboard motor before floating back down to the starting point (Grim 2012). During high-flow events (other than scheduled HFEs), docking at Lees Ferry is more difficult than normal because the dock is actually in the river channel, as opposed to being out of the main current. Departing from Lees Ferry rather than the dam keeps the business functional to some degree, but the economics of this type of operation are unfavorable compared to normal operations.

River fluctuations were identified as an issue for both anglers and white-water boaters in previous studies (Bishop et al. 1987; Stewart et al. 2000). However, both studies found that daily river level fluctuations had no impact on the satisfaction level for day-rafting clients.

HFEs create steep banks in some portions of the river that make access from boats to the upper sediment terraces more difficult, as shown above in Figure 3.10-6 (Grim 2012; Hughes 2014a). Eventually most steep areas are eroded by use, restoring easy access to the terraces, but in some locations, the banks have been steepened to such a degree that visitor access is adversely affected. The six designated recreation sites located on these sediment terraces are shown above in Figure 3.10-5.

3.10.2 The Colorado River in Grand Canyon National Park

GCNP is a world-renowned recreational destination that was designated as a World Heritage Site in 1979. The 1,217,261-ac park contains 1,143,918 ac proposed for wilderness designation, including 10,919 ac of potential wilderness along the Colorado River corridor. Annual visitation to the park has exceeded 4 million visitors since 1992, and 5.5 million visitors were recorded in 2015. Most visitors focus on the developed facilities on the South Rim of the canyon, where the majority of the visitor services, facilities and administrative offices are located.

While GCNP is a destination for millions of visitors, the focus of this EIS is on the Colorado River corridor, which constitutes a small percentage of the acreage of the park and small portions of both Glen Canyon and Lake Mead National Recreation Areas. The CRMP, completed in 2006 (NPS 2006b), set goals for managing visitor use and protecting resources along the river corridor. The CRMP established a visitor capacity based on the number, size, and distribution of campsites; natural and cultural resource conditions; and visitor experience. The NPS established a capacity of 60 trips at one time, which is managed through daily launch limits, group size, and trip length. The CRMP also established a 6.5-month no-motors season to provide enhanced wilderness opportunities. The CRMP outlines a Research, Monitoring, and Mitigation Program that manages resources in the river corridor within an adaptive management framework (NPS 2006c).

A whitewater trip through all or part of the Grand Canyon is a rich and complex recreational experience, valued for the sights and sounds of the canyon, the whitewater, and superb opportunities for varied recreational experiences. Recreational river use in the Grand Canyon expanded from 150 people per year in 1955 to 16,500 in 1972 and to the 2006 CRMP levels of about 24,657 visitors per year.

Visitor use is measured in user days (e.g., one person on the river for a day), and is managed to offer a variety of trip types throughout the year. Trips are conducted using a variety of types and sizes of boats and rafts; group sizes can range up to 32 people (including guides); trip lengths range up to 25 days; trips can be run by commercial companies or by private individuals; and there are various means of joining trips, including launching from Lees Ferry, hiking into or out of the canyon to join or leave a trip at Phantom Ranch, and limited access by vehicle and helicopter (commercial use only) to join trips in the western portion of the Grand Canyon.

Commercial river trips are offered from April through October, and noncommercial trips occur year round. Peak use occurs in May through September, as shown in Figure 3.10-8.

Most Grand Canyon river trips begin at Lees Ferry (RM 0) and take out at Diamond Creek (RM 226) or at Pearce Ferry (RM 280) in LMNRA. When Lake Mead water levels were higher prior to the onset of drought in 2000, trips also regularly ended at South Cove (RM 295) on Lake Mead. Prior to the drought, reservoir travel began at Separation Canyon, and many trips either motored or were towed by jet boats that came upriver from Lake Mead to their take-out points at Pearce Ferry or South Cove.

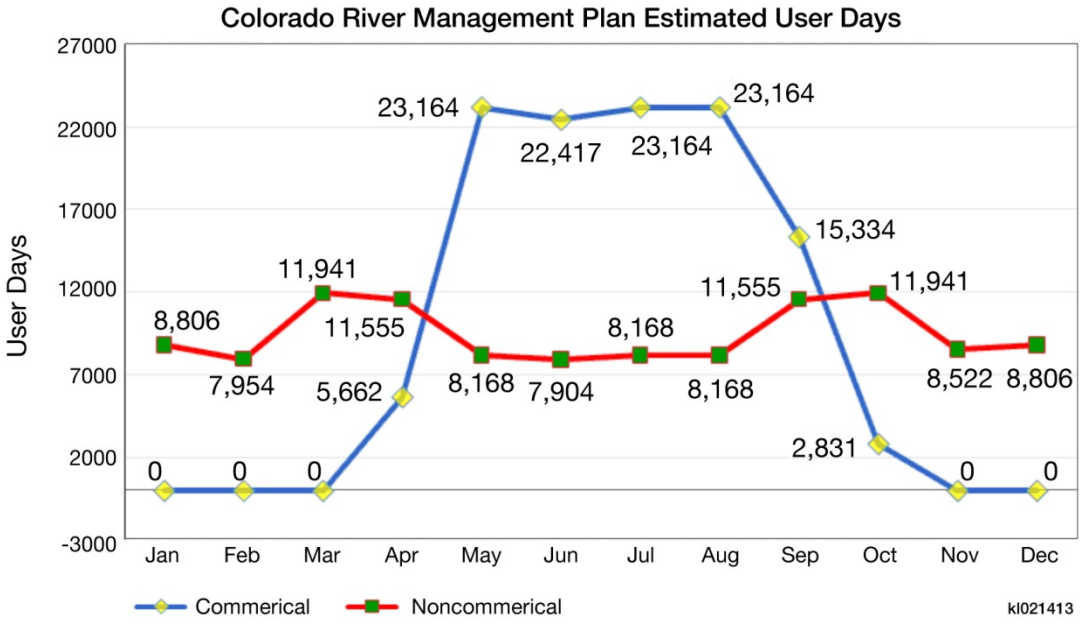

FIGURE 3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month (Source: Reclamation 2011b)

The Lower Gorge of the Grand Canyon is defined as the 51-mi section of river below Diamond Creek (RM 226) to Pearce Ferry (RM 280). Recreational use of the Lower Gorge is described in the CRMP and is managed by the NPS and the Hualapai Tribe, whose reservation is on the south side of the river (located approximately between RM 164.5 and RM 273).

Types and levels of recreational use in the Lower Gorge vary greatly from those above Diamond Creek, primarily due to road and boat access to the river by way of the Hualapai Reservation at Diamond Creek and to the influence of Lake Mead. In addition to river trips that launch from Lees Ferry and continue into the Lower Gorge, the NPS permits noncommercial (private) and educational trips launching from Diamond Creek. Also, the Hualapai Tribe operates its own river program that provides commercial trips beginning at Diamond Creek and other sites on Tribal lands.

Most trips spend fewer than three nights total in the Lower Gorge, although it is possible to spend more if boaters are interested in reservoir travel or off-river hiking. Backcountry permits are required to camp off the river in GCNP, and Hualapai Tribal permits are required for activities on the reservation, including hiking, camping, and conducting research.

3.10.2.1 Campsites in Grand Canyon National Park

River-accessed campsites within GCNP are a memorable aspect of any recreational experience along the river. The number of available campsites and the amount of campsite area at any particular time are affected by river flow (i.e., fewer campsites are available at higher

flows, and vice versa). Because of their singular importance in supporting river use, there have been numerous campsite inventories over the years; NPS reported in the CRMP that there are more than 200 regularly used camping beaches in the GCNP planning area. The number and usability of campsites vary from year to year based on several factors, including flow regimes; vegetation changes; erosion from tributary flooding, wind, or recreation use; or closure of sites to protect sensitive resources (NPS 2005a). An updated campsite inventory conducted by the NPS in 2011, identified and classified, by capacity, 235 campsites between Lees Ferry and Diamond Creek.

Preferred beach characteristics for both camping and stops for lunch include a strong preference for shade, larger rather than smaller beaches, and the availability of hiking opportunities (Stewart et al. 2000). "Campable area" is the term used to describe the area of a beach where people set up camp, moor boats, cook, and sleep. The criteria used to define campable area include a smooth substrate, preferably sand, with no more than 8 degrees of slope, and with little or no vegetation (Kaplinski et al. 2010).

Campsites are further classified as being located in either critical or noncritical reaches of the river. A critical reach is any contiguous stretch of river in which the number of available campsites is limited because of geomorphic setting (e.g., narrowed canyon width), high demand for nearby attraction sites, or other logistical factors (e.g., exchange points). Noncritical reaches are those stretches in which campsites are relatively plentiful, resulting in little competition for most sites (Kearsley and Warren 1993).

Campsites vary in size and not all can accommodate the maximum group of 32 described in the CRMP. Researchers, using campsite inventories, have developed three general categories: small camps (1 to 12 people); medium camps (13 to 24 people); and large camps (25 or more people) (NPS 2005a). The results of five campsite inventories conducted between 1973 and 2011 are shown in Figure 3.10-9.

The highest number of camps (particularly large camps) recorded was documented during the inventory conducted immediately following the 1983 flood. By contrast, the 1991 inventory shows 75% fewer large camps than in 1983, while the 2003 inventory shows an even further reduction (NPS 2006b). Compared to 1973, there was about a third as many large camps and a third fewer total camps in 2003 (NPS 2005b). The loss of the large campsites is especially problematic, given the number of large commercial trips during the summer season. The loss increases the potential for groups to camp in close proximity to one another, especially in the critical reaches. This loss led the NPS to reduce group size as identified in the CRMP.

The most important finding regarding campsites in the Grand Canyon is that they are becoming smaller and less abundant. A synthesis of geomorphic data on sandbars below Glen Canyon Dam reported a 25% reduction in the sandbar area within the 87-mi reach from Lees Ferry to Bright Angel Creek between 1984 and 2000 (Schmidt et al. 2004). A study completed in 2010 summarizing detailed topographic campsite monitoring of a sample of 38 sites in GCNP showed that the total amount of high-elevation campsite area above the elevation of 25,000 cfs flow decreased 56% between 1998 and 2006. Figure 3.10-10 shows the described trend for high-elevation campsite area. The primary factors identified in campsite loss

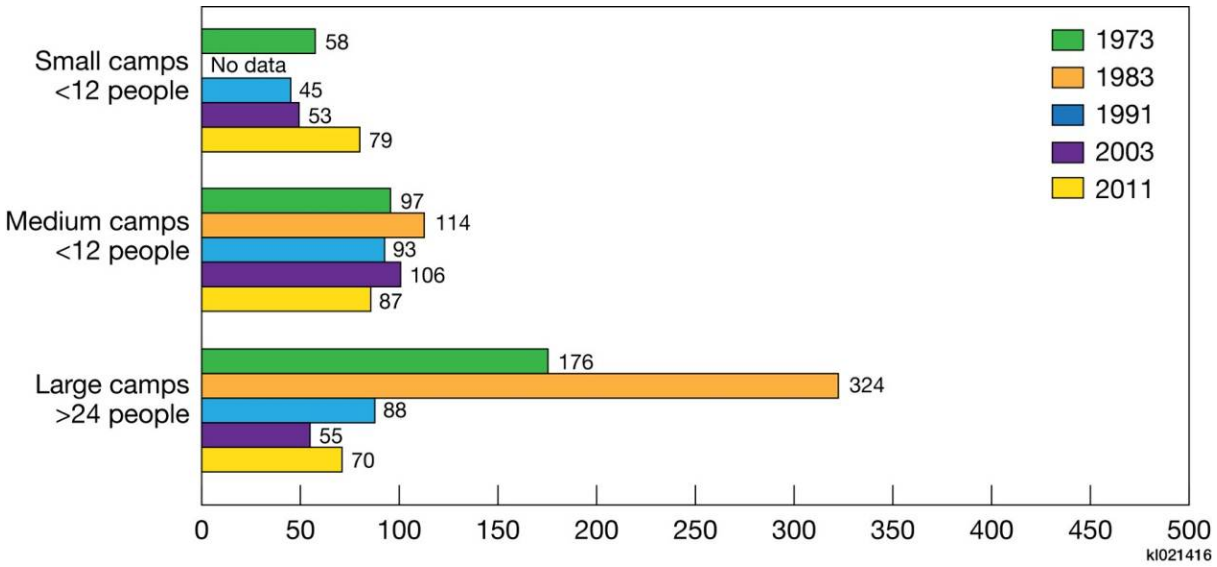

FIGURE 3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP (Sources: NPS 2005a; Jalbert 2014)

were riparian vegetation growth and sandbar erosion. These losses happened in spite of a temporary increase of 29% in campsite area between the inventories in 2003 and 2005 that was related to both the 2000 summer low steady flow experiment and the 2004 HFE (Kaplinski et al. 2010). The diminishing availability of campable area, particularly in some of the narrower reaches of the river corridor, is an important issue for national park managers and recreational river runners.

The 2010 Kaplinski et al. study agreed with the findings of Kearsley and Warren (1993) that campsite area in critical reaches decreased primarily due to erosion, and in noncritical reaches, due to increased vegetative cover. Figure 3.10-11 plots the loss of high-elevation campsite area in critical and non-critical reaches.

Over the long term, eddy-sandbar size can only be increased if (1) adequate sediments are available for deposition, (2) high-flow deposition is substantial, (3) high flows occur frequently, and (4) erosion that occurs between high flows is less than the deposition. Thus, the net effect of high flows in building eddy sandbars results from the magnitude and the frequency of high flows and the deposition they cause. Erosion ensues rapidly after each high flow, and the rate of erosion declines thereafter but persists. The longer the time period between HFEs, the more erosion occurs (Melis 2011).

High flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, 2008, 2012, 2013, and 2014 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons. Grams et al. (2010) reported that more erosion occurs when total flow is large (excluding HFEs). Fluctuating flows under normal dam operations between HFEs can erode sandbars and campsites.

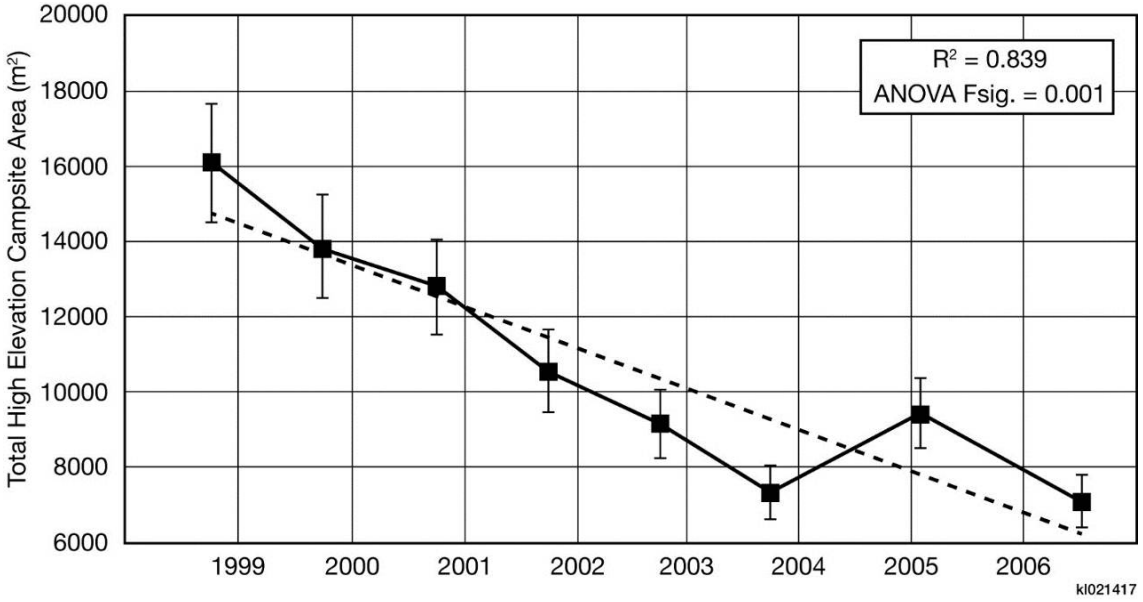

FIGURE 3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 (with 10% uncertainty bands; the dashed line shows the linear regression fit) (Source: Kaplinski et al. 2010)

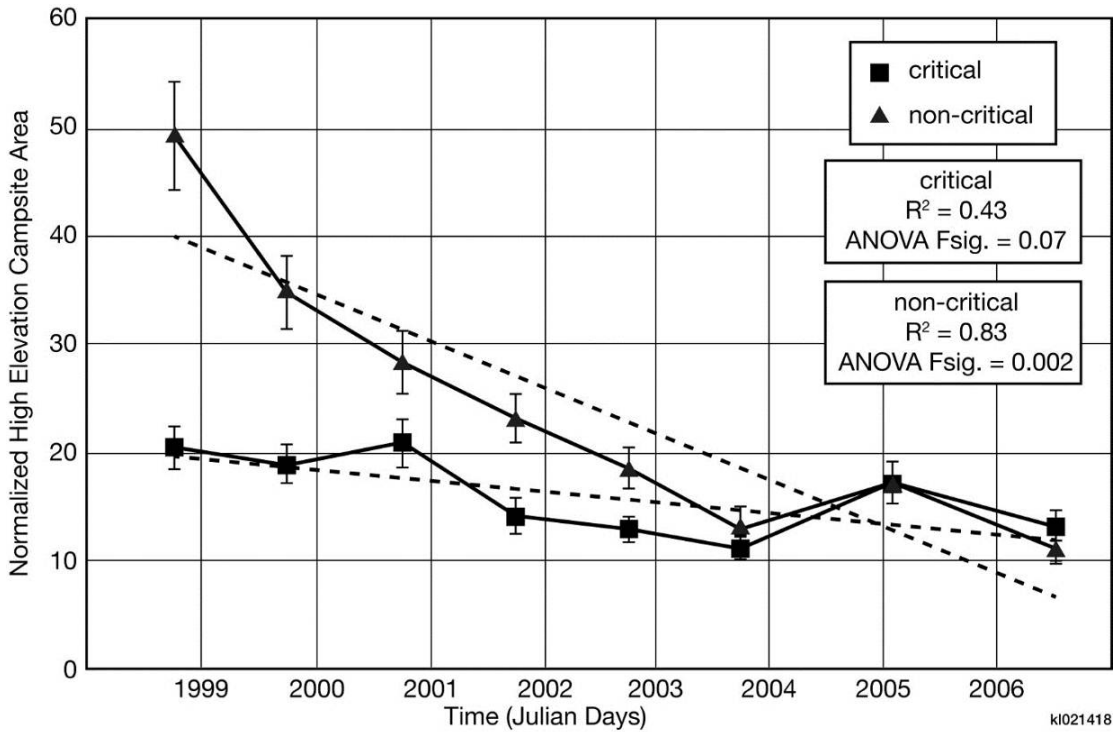

FIGURE 3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006 (with 10% uncertainty bands; the dashed lines show the linear regression fit) (Source: Kaplinski et al. 2010)

3.10.2.2 River Flow and Fluctuation

The effect of river flows on recreation in the Grand Canyon has been the subject of studies on the Colorado River for many years that have utilized information from river guides and river trip participants to understand what attributes of river trips are important and how they can be affected by variable river flows (Bishop et al. 1987; Hall and Shelby 2000; Shelby et al. 1992; Stewart et al. 2000; Roberts and Bieri 2001; Ralston 2011). The operation of Glen Canyon Dam commenced in 1963, and the flow regime of the river was first modified in 1991 to address issues that were affecting downstream resources (Reclamation 1995). Principal among these changes was a change in the maximum level of daily river fluctuations from 30,500 cfs to 5,000 cfs, 6,000 cfs, or 8,000 cfs, depending on the scheduled monthly release volumes.

Participants on Grand Canyon river trips have consistently identified several flow-related attributes as being important to their overall trip satisfaction; these include the presence of large rapids, being the only camping group at a beach, and having large beaches for camping (Bishop et al. 1987; Stewart et al. 2000). Large rapids are a function of higher flows. Bishop et al. (1987) found a strong preference among boaters for flows in the range of 25,000–35,000 cfs, a flow range that has been less common since 1996. Flows in this range provided the further benefit that passengers were less likely to be required to walk around rapids. Conversely, higher flows were identified as a potential contributor to crowding at campsites and attractions (Bishop et al. 1987).

The Bishop study (Bishop et al. 1987) further evaluated whitewater boater's preferences with respect to levels of daily flow fluctuations. The study, which was conducted at a time when very large fluctuations were common, identified fluctuations in excess of 10,000 cfs as being noticeable and perceived as less natural to canyon visitors. High fluctuations, ranging from 3,000 to 25,000 cfs/day, were also noted as contributing to issues related to selection of campsites, time allowed at attractions, mooring and tending of boats, transiting major rapids, and trip scheduling. Although such high levels of daily fluctuations are greater than under any LTEMP alternatives, river guides in the Bishop study were also asked to evaluate fluctuation levels that happen to overlap with the alternatives. River guides reported that tolerable fluctuations increased with increasing average daily flow, as shown in Table 3.10-2 (adapted from Bishop et al. 1987), and that the ability to run a whitewater raft trip was particularly sensitive to flow fluctuations when daily flows were low. Based on interviews with guides, the authors concluded that the identified "tolerable" fluctuation ranges were more of a "wish" in the eyes of the guides than specifically "tolerable," as identified on survey forms, and noted that guides stated that predictability in fluctuations is a key factor (Bishop et al. 1987).

Shelby et al. (1992) documented that with daily fluctuations of 9,000–10,000 cfs, boatmen reported problems with boats "left hanging" on beaches by receding water levels. By the time of the Stewart et al. (2000) study, daily fluctuations had been reduced by the MLFF operating regime (capped at 8,000 cfs). Stewart et al. (2000) indicated that "the negative effects of fluctuating flows on recreational use were not substantial problems," but also recorded that "user attitudes and preferences regarding constant flows" had not changed since the 1987 Bishop study.

TABLE 3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders

River Flow (cfs)	Tolerable Within-Day Fluctuation (cfs)[a]
5,000–9,000	2,400–3,400
9,000–16,000	3,900–4,800
16,000–32,000	6,400–7,200
32,000 and up	7,900–9,800

[a] Range of mean daily tolerable fluctuations reported by commercial motor guides, commercial oar guides, and private trip leaders who had experienced fluctuations of 15,000 cfs in the Grand Canyon.

Source: Bishop et al. (1987).

It is clear from numerous studies that river flow and management regimes affect whitewater rafting experiences (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000; Ralston 2011). There is general agreement that flows in the 20,000 to 25,000 cfs range are considered to be near optimum for all types of whitewater trips (commercial oar and motor trips and private trips); there is also general agreement that flows of less than about 10,000 cfs are considered to be marginal, while flows of less than 5,000 cfs are considered to be highly unsatisfactory (Bishop et al. 1987; Stewart et al. 2000).

Time Off of the River

A large array of attraction sites, short to long hikes, and campsites are parts of the experience of most river trips through GCNP. There are more than 100 attraction sites available along the river that can be incorporated into a trip, depending on the time available. Most river trips are run on a planned schedule, but longer trips (in number of days) tend to have more flexibility than shorter trips (Roberts and Bieri 2001).

For a river trip of a given distance, river flow rate affects the time available for off-river activities. River flow affects boat speeds, even for motor trips, which affects distance traveled per unit of time. Roberts and Bieri (2001), in their study of the effects of the low steady summer flow experiment of 2000, documented that at a normal flow of 19,000 cfs, river trips spend approximately 7 hr "off river" engaged in activities such as hiking and visiting attraction sites, while during an 8,000-cfs low-flow study, groups spent only about 3.5 hr in these activities. Bishop et al. (1987) recorded that guides indicated that at around 30,000 cfs, additional attraction sites could be included into itineraries. Interestingly, Roberts and Bieri (2001) documented that although substantially less time was available for attraction stops at low flows, the average number of stops stayed near to the norm for average flows. The explanation for this appears to be that some attractions are simply "must see," and a shorter amount of time was allotted for each

attraction rather than dropping a site. It was also recorded that some sites become more preferred at lower flows because the activities at those sites require less time to complete. These observations confirmed findings regarding flow impacts on river trips of previous studies (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000).

Studies have also documented that river flows can affect the choice of campsites, how late campsites are reached, how early trips need to break camp, how much or little boatmen are required to row or run motors to keep a trip on schedule, and how many layover days can be taken. Bishop et al. (1987) and Stewart et al. (2000) speculated that the optimum flow level for a Colorado River trip is in the 20,000–25,000 cfs range because of the flexibility that flow offers in accommodating the various competing needs of these trips.

During low-flow periods, in addition to reducing the amount of time at attraction sites, river guides may ask their group to break camp early or they may arrive at camp later in the day than under normal flows. This reduces the amount of camp time, which can also reduce overall trip satisfaction because of the reduced opportunity to explore the areas around camp, to participate in camp activities, or to simply relax.

Having a wilderness experience is one of the top five attributes sought by whitewater boaters (Bishop et al. 1987; Stewart et al. 2000). River flows can have effects on the wilderness experience in at least two ways. The extent that flows limit or reduce the amount of time visitors can spend enjoying the off-river activities affects this aspect of their wilderness experience. In addition, low flows require more motor use during motor-powered river trips (Bishop et al. 1987; Stewart et al. 2000) to maintain schedules. This introduces an additional noise component to the boaters and to the surrounding environment that detracts from the wilderness experience.

Whitewater Boating Experience

One of the attributes desired by participants in river trips is the opportunity to experience big rapids with large waves and a roller-coaster-type ride (Bishop et al. 1987; Stewart et al. 2000). The condition of rapids is related to the flow, with low levels tending to reduce the size of the rapids and the quality of the ride, while high flows tend to wash out smaller rapids. The perception of the quality of rapids is important to an individual's river experience; most related studies were conducted prior to implementation of MLFF and generally identify flow levels of 20,000 to 25,000 cfs as being the optimum "ride" for most participants (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000). Walking around rapids has been identified as one of the attributes that negatively affects the perception of river trips (Bishop et al. 1987; Stewart et al. 2000). Under reduced normal high-flow levels, having participants walk around rapids now is more likely to be related to lower flows.

Availability of Campsites

Higher flows result in reduced campsite area, which can lead to campsites being pushed into more sensitive riparian and old high-water zones. They can also result in more competition

for campsites, especially in the critical reaches. Reduced campsite availability can further lead to camps being located more closely together, adversely affecting a sense of solitude and the wilderness experience. In addition, higher flow fluctuations, such as those greater than an 8,000-cfs daily range, affect the ability to both moor boats with less need to attend to them during the night and to access campsites from the river level (Bishop et al. 1987). Current fluctuation levels under MLFF have reduced but not eliminated this issue compared to previous operations (Stewart et al. 2000).

3.10.2.3 Hualapai Tribe Recreation Program

The Hualapai Tribe has implemented a comprehensive recreation services program utilizing Tribal lands that border the Colorado River in the Grand Canyon to generate income for the Tribe. The Tribe, through its Grand Canyon Resort Corporation, manages several businesses that provide recreation services, including a river rafting company. Hualapai River Runners (HRRs) is the only Tribally owned and operated river rafting company on the river. HRR offers commercial motorized day trips from the Diamond Creek and Quartermaster areas on motorized 22-ft pontoon boats. Under a Memorandum of Understanding between the Hualapai Tribe and the NPS, HRR trips are subject to operational standards required of all NPS river concessionaires.

HRR currently offers two types of river trips: (1) short 15-minute boat rides above and below the Quartermaster area (RM 260); this services people who have purchased a tour package that generally originates in Las Vegas, in which passengers are ferried to the launch site by helicopter; and (2) 1-day whitewater raft trips that put in at Diamond Creek and take out at Pearce Ferry. Both types of trips also occur during HFEs (Havatone 2013).

The Tribe authorizes the use of helicopter landing pads (on Reservation lands) both above and below Diamond Creek. The pad near Whitmore (RM 187) is used to exchange passengers from commercial river trips. The helicopter pads at RM 261 are used for day trips that do not involve on-river activities. Helicopter pads at RM 262 and RM 263 are leased to helicopter companies serving HRR river trips, pontoon trips, and trips not involving on-river activities. Noncommercial river rafting passengers do not exchange at these pads.

The landing at Diamond Creek is a major access point to the river and is a prime take-out location for NPS-permitted river trips originating at Lees Ferry. Approximately 85% of noncommercial river rafting trips and a large percentage of commercial trips end at Diamond Creek (NPS 2006b). Diamond Creek is also the starting point for Hualapai Tribe commercial trips through the lower Grand Canyon and for a few noncommercial trips. The Hualapai Tribe maintains the Diamond Creek road and charges a fee for tourists and river runners entering or exiting the river via this road.

The Hualapai Tribe has articulated concerns over the operation of Glen Canyon Dam generally and the effects of HFEs specifically (Havatone 2013). This is addressed in Section 4.10.2.7.

3.10.3 Recreation Use on Lake Mead and Lake Powell

Both Lake Mead and Lake Powell are major destinations for boaters, fishermen, and campers. Drought in the Southwest has been having a major impact on both reservoirs since 2000 and water levels are continuing to decline.

3.10.3.1 Lake Mead National Recreation Area

Lake Mead resulted from the construction of Hoover Dam (once known as Boulder Dam) in 1932. It is the largest reservoir in the United States and at an elevation of 1,221.4 ft AMSL—the elevation of the top of the spillway gates—the reservoir covers 158,500 ac at an elevation of 1221.4 ft. The reservoir extends approximately 110 mi upstream toward the Grand Canyon and about 35 mi up the Virgin River. The elevation of Lake Mead on March 1, 2014, was 1107.74 ft AMSL (Reclamation 2014a). On average, visitors at Lake Mead total about 6 million annually.

Because of the ongoing drought conditions affecting operations at LMNRA, in October 2005, NPS completed a GMP Amendment for Low Water Conditions and a FONSI (NPS 2005b) that identified the strategy for low-water operations. This amendment articulated the intent to maintain boat-launch capacities established in the original GMP of 1986 and a subsequent amendment in 2003, by either extending or relocating existing launch ramps and marinas to be functional down to an elevation of 1,050-ft AMSL. This amendment reflects the current management direction for low-water operations, and it assumes that NPS and concessionaires will continue to modify launching and marina facilities as necessary and possible, given time and budget to continue providing visitor services.

3.10.3.2 Lake Powell, Glen Canyon National Recreation Area

Reclamation completed construction of Glen Canyon Dam in 1963; Lake Powell, which was created by the dam, is the second largest reservoir in the United States. The total capacity of the reservoir is 27 million ac-ft, and it stretches for 186 mi. At full-pool elevation, 3,700 ft, the reservoir has a surface area of 161,390 ac (NPS 2014e). Lake Powell is subject to the same regional drought conditions as Lake Mead, and the elevation of Lake Powell on March 1, 2014, was 3,575.59 ft AMSL (Reclamation 2014a). Annual visitation varies and has been approximately 2 million visitors annually over the past 10 years.

3.10.4 Park Operations and Management

Related to recreation in GCNRA and GCNP is the level of park staffing needed to support recreation and resource protection. The level of staffing affects the ability of the park units to provide appropriate park infrastructure and services to support river and backcountry operations and address visitor experience, and the administrative use of the Colorado River within GCNRA and GCNP. Issues related to park management and operations were raised in public and internal scoping. Some of these issues have been addressed at GCNP by other

management documents such as the CRMP (NPS 2006b) and the GCNP General Management Plan (NPS 1995). However, some issues specific to Glen Canyon Dam operations are appropriate for considering within the scope of this EIS. Changes in releases from Glen Canyon Dam may affect the number of personnel, level of funding, and staff time needed to adequately maintain park resources. For example, HFEs require increased staffing resources to notify boaters in Glen and Grand Canyons of high flow releases. In addition, NPS management related to changes in dam operations includes planning, coordination with other agencies, concessionaires, and stakeholders, as well as resource monitoring and visitor safety. Park management and operations may also be affected by non-flow actions.

The Superintendent of each park is ultimately responsible for park management and operations. In 2014, GCNP employed 512 employees (of which 313 are permanent) to manage operations, including visitor services and facilities, resource management and preservation, planning and environmental compliance, emergency medical services, law enforcement, search and rescue operations, fire operations, air operations, facilities management and maintenance, and administrative functions. Similarly, GCNRA employed 214 employees to manage areas including Lake Powell, surrounding lands, and the 15-mi stretch of Glen Canyon below the dam. These resources include a historic district, a campground, and designated campsites along the river with bathrooms and fire pits.

Park divisions with river-related responsibilities include facilities management, visitor and resource protection (permits, inner canyon and river rangers, emergency medical services, and search and rescue operations), concessions management (contracts, commercial use authorizations), interpretation and resource education (signage, information, and interpretation), science and resource management (resource protection, inventory, monitoring, research, and research permitting), and the Office of Planning and Compliance (environmental analysis). River recreational and administrative use is currently managed in accordance with the CRMP (NPS 2006b), the GCNP General Management Plan (NPS 1995), the GCNRA General Management Plan (NPS 1979), and applicable NPS laws, policies, and regulations.

3.11 WILDERNESS

There is proposed wilderness in GCNRA and GCNP that is managed as wilderness pursuant to NPS policy as discussed below. The wilderness proposals within GCNRA and GCNP do not address the Glen Canyon Dam or dam operations. Nothing in this EIS modifies the wilderness proposals in any manner.

This section is included in the EIS primarily to address activities conducted or permitted by the NPS (including research as part of the Glen Canyon Dam Adaptive Management Program [GCDAMP]). Approximately 94% of GCNP, or 1,143,918 ac, qualifies as Wilderness as described in the 1964 Wilderness Act and NPS *Management Policies 2006* (NPS 2006d). Grand Canyon Wilderness complements other Designated and Proposed Wilderness Areas north of the Grand Canyon on other NPS, Bureau of Land Management (BLM), and U.S. Forest Service (USFS) lands. Approximately 51% of Glen Canyon, or 588,855 ac, was proposed for

wilderness designation. This includes 6,180 ac in the Paria unit of the Glen Canyon proposed wilderness.

3.11.1 Law and Policy

The Wilderness Act of 1964 required the Secretaries of Agriculture and the Interior to evaluate land under their jurisdiction for possible wilderness classification. Section 4 of the Wilderness Act describes authorized uses of wilderness areas; subsection 4(a) declares, with specific legislative references, that the Wilderness Act shall be supplemental to the purposes for which the national forests, parks, and refuges have been established. Subsection 4(b) states, in part:

> Except as otherwise provided in this Act, each agency administering any area designated as wilderness shall be responsible for preserving the wilderness character of the area and shall so administer such area for such other purposes for which it may have been established as also to preserve its wilderness character. Thus, except for specified provisions in the legislation, wilderness areas shall be devoted to recreational, scenic, scientific, educational, conservation, and historical uses.

Subsection 4(c) prohibits certain uses (unless specifically provided elsewhere in the Act) that are inconsistent with wilderness preservation. With the exception of the minimum actions needed for administrative duties and emergency health and safety procedures, the Act prohibits temporary roads, motor vehicle use, motorized equipment or motorboats, landing of aircraft, mechanical transport, structures, and installations.

Section 4 also addresses special provisions for certain wilderness uses. Subsection 4(d)(1) states, in part:

> Within wilderness areas designated by this Act the use of aircraft or motorboats, where these uses have already become established, may be permitted to continue. These uses are subject to such restrictions as the administering federal official deems desirable. Subsection 4(d)(5) permits the performance of commercial services within wilderness to the extent necessary for activities which are proper for realizing the recreational or other wilderness purposes of this act.

> In addition, NPS Management Policies 2006 (NPS 2006d) includes the following:

> The National Park Service will take no action that would diminish the wilderness suitability of an area possessing wilderness characteristics until the legislative process of wilderness designation has been completed. Until that time, management decision pertaining to lands qualifying as wilderness will be made in expectation of eventual wilderness designation. This policy also applies to potential wilderness, requiring it to be managed as wilderness to the extent that existing non-conforming conditions allow. The National Park Service will seek to

> remove from potential wilderness the temporary, non-conforming conditions that preclude wilderness designation.

NPS will manage proposed wilderness in GCNP and GCNRA in accordance with NPS Management Policies and the Wilderness Act of 1964. This area includes the 277-mi section of the Colorado River within the boundaries of GCNP and portions of the Lees Ferry District, including a 15-mi section of the river downstream of the dam in GCNRA. The Final EIS for the GCNP Colorado River Management Plan (NPS 2005a) clarifies that recreational motorized use does not preclude possible wilderness designation because such use is a temporary or transient disturbance of wilderness values and does not permanently impact wilderness resources. The 2006 CRMP established a 6.5-month no-motor season to enhance opportunities for a wilderness experience (NPS 2006b).

NPS policy requires that its wilderness management decisions be consistent with a minimum requirement concept that evaluates the potential disruptions of wilderness character and resources. The minimum requirement concept applies to all administrative activities, including research and monitoring. Research trips of NPS, USGS, and other agencies are subject to the minimum requirement policy.

3.11.2 Defining Wilderness Character

According to GCNP's GMP, areas proposed for wilderness offer visitors opportunities for solitude and primitive recreation. An important provision in the GMP states:

> The management of these areas should preserve the wilderness values and character. Non-wilderness undeveloped areas should continue to serve primarily as primitive thresholds to wilderness. Visitors traveling through the canyon on the Colorado River should have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able to continue to experience the river corridor with as little influence from the modern world as possible. The river experience should help visitors to intimately relate to the majesty of the canyon (NPS 1995).

Subsection 2(c) of the Wilderness Act defines wilderness as follows:

> A wilderness, in contrast with those areas where man and his works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain.

The same subsection 2(c) further defines wilderness as having the following characteristics:

- Undeveloped land retaining its primeval character in influence without permanent improvements or human habitation

- Generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable

- Has outstanding opportunities for solitude or primitive and unconfined type of recreation

- May contain ecological, geological, scientific, educational, scenic, or historical value

This last quality, recognizing ecological, geological, scientific, educational, scenic, or historical value, is of particular importance when describing the Colorado River and the greater Grand Canyon. To the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, Southern Paiute Tribes, and other American Indian Tribes, the canyon and river represent significant cultural, educational, and historical places that are central to their cultural identity.

Wilderness character is defined in NPS Wilderness Stewardship Reference Manual 41 as, "The combination of biophysical, experiential, and symbolic ideals that distinguishes Wilderness from other lands. The five qualities of Wilderness Character are Untrammeled, Undeveloped, Natural, Solitude or a Primitive and Unconfined Type of Recreation, and Other Features of Value."

All designated wilderness areas, regardless of size, location, or any other feature, are unified by the statutory definition. These four qualities of wilderness are as follows:

1. **Untrammeled**—wilderness is essentially unhindered and free from modern human control or manipulation. This quality pertains to actions that manipulate or control ecological systems.

2. **Natural**—wilderness ecological systems are substantially free from the effects of modern civilization. In the context of managing visitor use on the Colorado River, this quality pertains to the intended and unintended human-caused effects on natural and cultural resources conditions.

3. **Undeveloped**—wilderness is essentially without permanent improvements or modern human occupation. This quality pertains to the presence and development level of trails, campsites, structures, and facilities within the river corridor and areas visited by river users.

4. **Outstanding opportunities for solitude or a primitive and unconfined type of recreation**—wilderness provides outstanding opportunities for people to experience solitude or primitive and unconfined recreation, including the values of inspiration and physical and mental challenge. This quality pertains to visitor opportunities to experience a primitive setting that may include solitude and adventure.

The fifth quality articulated in the definition of wilderness character above is defined as follows:

5. **Other features of scientific, educational, scenic, or historical value**—attributes not required of or found in every wilderness that reflect a wilderness' specific wilderness character, and is based on the Wilderness Act's Section 2(c) that states a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value."

This component captures important wilderness elements not covered in the other four Wilderness Character qualities such as cultural or paleontological resources. The three NPS units within the project area protect important cultural histories, significant traditional cultural resources, and extensive archeological records important to preserving the Wilderness Character of the area. The relationship between these qualities and impacts related to Glen Canyon Dam operations are important components of these analyses and will be further discussed in Chapter 4.

3.12 VISUAL RESOURCES

Visual resources refer to all objects (man-made and natural, moving and stationary) and features (e.g., landforms, night skies, and water bodies) that are visible on a landscape. These resources add to or detract from the scenic quality of the landscape; that is, the visual appeal of the landscape. Visual impacts can be defined as changes to scenic attributes of the landscape brought about by the introduction of visual contrasts and the associated changes in the human visual experience of the landscape. A visual impact can be perceived by an individual or group as either positive or negative, depending on a variety of factors relating to personal circumstances (e.g., personal experience, aesthetic sensitivity, or the activity in which the viewer is engaged) or to viewing circumstances (e.g., viewing distance, time of day, or weather/seasonal conditions).

Visual resources are not only important to visitor enjoyment of GCNRA, GCNP, and LMNRA, they are important to American Indian communities who once resided in and/or visit the area for subsistence or ceremonial purposes. Conservation of visual resources is part of the GCPA of 1992 and an important component of the federal management activities for these areas. Scenic resources found within GCNRA, GCNP, and LMNRA and on Hualapai and Navajo reservations include colorful and unique geological formations; complex geology; sleek canyon walls; towering cliffs, buttes, and mesas; rivers, lakes, and streams; barren deserts; and unique prehistoric and historic cultural sites. The scenic resources of these areas are experienced in a number of ways. The Canyons have a significant place in the traditional cosmology of the indigenous communities of the Southwest. American Indian communities may visually experience the Canyons quite differently than recreational users who experience the Canyons not only during recreational activities but also while gathering natural resources or performing religious ceremonies. Water-based recreational activities such as boating, kayaking, swimming, and fishing allow individuals to view the varied landscapes of the Colorado River, Grand and

Glen Canyons, Lake Powell, and Lake Mead from almost anywhere on the water. Stewart et al. (2000) found that the more valued aspects of a river rafting trip include simply being in a natural setting, having the opportunity to stop in scenic places, and being able to view flora, fauna, and geology. Terrestrial activities such as hiking and camping along the shores of Lake Powell, Lake Mead, and the Colorado River offer spectacular views, as do designated scenic overlooks accessible via boat, car, or hiking trail. For many Tribes, trails that enter the Canyons are sacred and the scenic setting along these trails plays an important part in the travel and ceremonial experience.

Vegetation also plays an important role in the scenic experience along the Colorado River and in Glen Canyon. Vegetation increases the visual interest of many places by adding variety in color and texture and is also a visual cue for Tribes in determining the health of the ecosystem. For example, sandbars and marshes along the river may contain stands of native vegetation which are important for many Tribal communities. For recreational visitors, native vegetation adds variety in color, texture, and form in contrast to the river and surrounding canyon walls, as well as affording the viewer a chance to see native plant life. Stands of nonnative tamarisk that occur along the river are visual evidence of a nonnative plant species. In addition, nonnative plants may have a different texture than native vegetation, and therefore create visual contrast. A full discussion of plant communities can be found in Section 3.6.

Hanging gardens are a unique feature formed when springwater flows through cracks in sandstone and seeps out through canyon walls, allowing plants to grow vertically along the walls and on the canyon floor below (Woods et al. 2001). Where visible to visitors, hanging gardens add visual interest through color and texture contrasts with the surrounding bare rock, and they are visually important to Tribes for various reasons.

3.12.1 Glen Canyon National Recreation Area

The deep, 15-mi long, narrow gorge below the dam provides a glimpse of the high canyon walls, ancient rock art, and a vestige of the riparian and beach terrace environments that were a daily experience for American Indians and first recorded in John Wesley Powell's Colorado River expedition in 1869, providing stark contrast to the impounded canyons of Lake Powell. Portions of this stretch of river are classified as either Class I or Class II scenic areas and are managed as a Natural Zone (NPS 1979). At GCNRA, the Natural Zone is managed for its outstanding scenic resources and relatively undisturbed areas that remain isolated and remote from human activities. Class I scenic areas have outstanding scenic qualities such as "intricately carved landscapes, unique canyons, and unique geological structures," and Class II scenic areas have a "single property of superior quality or a diversity of form and color." This stretch of river also includes unique historic and prehistoric sites such as Lees Ferry and Lonely Dell Ranch (NRHP 1997) and the 9-mi Descending Sheep Panel, as well as features such as Paria Beach, the Glen Canyon Dam, and the popular hiking and photographic destination Horseshoe Bend, an "awe-inspiring bend in the Colorado River" where the rocks and river change color throughout the day (NPS 2007; Hughes 2014b). Examples of these resources are shown in Figures 3.12-1 and 3.12–2. Downstream of the dam, HFEs and fluctuations in daily



FIGURE 3.12-1 Glen Canyon Viewed from the Colorado River



FIGURE 3.12-2 Horseshoe Bend (Photo credit: Massimo Tava)

flow can alter the size and shape of sandbars and scour and erode vegetation along the banks of the river, causing changes in landscape forms, lines, colors, and textures.

3.12.2 Grand Canyon and the Colorado River

Conserving the Grand Canyon's scenic resources is an important part of GCNP management goals. The Colorado River falls within GCNP's Natural Zone which is managed to conserve natural resources and ecological processes while providing for their use by the public, using management techniques that have no adverse effect on scenic quality and natural processes (NPS 1995). Segments of the Colorado River and its tributaries are eligible for Wild and Scenic River status, although an official determination has not yet been made (NPS 1995). The park's Foundation Statement identified the scenic landscape as a primary interpretive theme and further identified "Scenic Qualities and Values" as components of the fundamental resource "Preserving Visitor Experiences in an Outstanding Natural Landscape" (NPS 2010a). In recognition of its outstanding visual landscapes and its biological and cultural significance, the Grand Canyon was designated as a World Heritage Site in 1979 (UNESCO 2012).

The Colorado River flows for 277 mi through the Grand Canyon. As it flows through the canyon, the river offers spectacular views of complex geology, hardened lava flows, waterfalls, sandy beaches, sheer cliffs, towering buttes, hidden caves, and side canyons (NPS 2013l; Belknap and Belknap-Evans 2012).

The Colorado River can be seen from many viewpoints accessible along the rims and inner canyon hiking trails. These vantage points offer spectacular panoramas of the Colorado River as it winds through the Grand Canyon. Of the nearly 5 million annual visitors to the Grand Canyon, most view the Colorado River from the rim. Scenic overlooks on the South Rim along the Hermit Rim Road and Arizona State Route 64 include Mohave, Pima, Hopi, Moran, Lipan, and Desert Viewpoints. North Rim overlooks along the scenic road include Point Imperial, Walhalla Overlook, and Cape Royal. The view from the Toroweap Point overlook is one of the most photographed views of the Colorado River (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin 2010; NPS 2015d; Balsom 2014).

A river trip through the Grand Canyon provides spectacular views of scenic resources along the Colorado River (Figures 3.12-3 and 3.12-4). These include unique cultural sites such as the granaries at Nankoweap (Figure 3.12-4) and Phantom Ranch; exceptionally scenic side canyons and tributaries such as the confluence with the Little Colorado River, Havasu Canyon (Figure 3.12-5), Deer Creek Narrows, Blacktail Canyon, Kanab Creek, and Diamond Creek; and distinctive and colorful geological features caverns, alcoves, grottos, and chasms that range in color from brown, reddish-brown, and orange to light tans and yellows to grays and purples. Redwall Cavern, Elves' Chasm, Vasey's Paradise (Figure 3.12-6), Silver Grotto, Whitmore Wash, Unkar Delta, and Lava Falls are among the most popular scenic geological formations along the river (Belknap and Belknap-Evans 2012; Kaiser 2010; Martin and Whitis 2008).

Campsites are located along the river's edge on sandy beaches or on ledges and alcoves above the high-water mark. Campsites offer the viewer a chance to see native plant and animal



FIGURE 3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip



FIGURE 3.12-4 Colorado River and Granaries at Nankoweap (Photo credit: Mark Lellouch, NPS)



FIGURE 3.12-5 Entrance to Havasu Canyon (Photo credit: Erin Whitaker, NPS)



FIGURE 3.12-6 Vasey's Paradise

life, in addition to offering views of the Colorado River and surrounding landscape. Many trails are accessible only from these campsites and lead visitors to scenic vantage points of the Grand Canyon and Colorado River (NPS 2010a). See Section 3.11 for a more detailed description of campsites.

Dam operations may contribute to effects on visual resources along the Colorado River in the Grand Canyon. Prior to construction of Glen Canyon Dam, the banks of the Colorado River consisted primarily of open sandy beaches and bare talus slopes with native riparian vegetation established above the elevation of annual scouring flows within the Grand Canyon. These beaches and vegetation were depleted and replenished as the Colorado River picked up and deposited debris during seasonal floods (USGS 2007; NPS 2013i). Currently, the size and shape of beaches along the river can change frequently with changing river flows and water levels. Much of the sediment that would otherwise move through the canyon is now trapped behind the dam, and regular seasonal flooding does not occur. Because of this, the river lacks the sediment it needs to build up beaches and sandbars, and the beaches sometimes disappear altogether (NPS 2013i). In addition, beaches that are more stable are no longer scoured by occasional flooding, which allows vegetation, including nonnative species such as tamarisk, to take hold and

spread (GCMRC 2011). The changes to the size and shape of beaches and the amount and types of riparian vegetation create visual contrasts that may affect visitors' scenic experiences.

Prior to construction of Glen Canyon Dam, the Colorado River carried such a large sediment load that it ran a reddish-brown color throughout the canyon. Now, the river downstream from the dam is relatively clear and green in color. During high releases or after large tributary inputs of suspended sediment, water becomes much more reddish-brown; this effect is ephemeral, however, and water quickly returns to a bluish-green color (NPS 2013g; USGS 2007). Calcium carbonate banding resulting from deposition of minerals at the water edge is also visible in some areas along the Colorado River, typically where the river bank consists of bare rock walls, rocky slopes, or boulders. The changes in water color, depth, and texture may affect the scenic experience of river runners.

3.12.3 Lake Mead National Recreation Area

LMNRA is managed for general recreational purposes to enhance visitor use, while recognizing the importance of and preserving its scenic, historic, and scientific resources (NPS 2002c). Pearce Ferry, located in the northeastern end of the park, serves as the boundary between the Grand Canyon and Lake Mead and marks the final destination for rafting trips down the lower Grand Canyon area. This area is mostly managed as a rural natural setting, where man-made features are present, but natural landscape is predominant.

Scenic resources within LMNRA include Lake Mead itself and the low, rocky, volcanic hills; steep canyons; and colorful rock formations that surround the reservoir. The surrounding landscape ranges in color from light tans and yellows to bright reds and browns, and contrasts sharply with the striking blue waters of Lake Mead and the bluish-green waters of the Colorado River.

Sediment deltas resulting from sediment transported through the Grand Canyon have built up in the headwaters of Lake Mead near Peace Ferry (Reclamation 2007a) and Iceberg Canyon (NPS 2015c), areas that are considered rural natural settings. Sediment deltas contribute to changes in form, line, color, and texture that can affect the overall scenic experience of water recreationists and may interfere with management objectives that include the protection of natural-appearing landscapes and pristine views.

3.13 HYDROPOWER

This section describes power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon Powerplant. A description of the seven-state socioeconomic environment in which power from the powerplant is marketed is provided in Section 3.14.

The operation of Glen Canyon Dam and Powerplant directly and indirectly influences the downstream physical environment and aquatic and riparian habitats. For example, the frequency

and magnitude of daily fluctuations (for the purposes of following electrical loads and maximizing the value of hydropower) directly affect sediment transport and deposition downstream, directly or indirectly affect aquatic and riparian habitats, affect the recreational environment (beach areas) and use patterns, and indirectly affect air emissions and water consumption for the region.

Power generation from the dam also financially affects the U.S. Department of Energy's (DOE's) Western Area Power Administration (WAPA) customers. When generation from the powerplant is significantly reduced or not timed to match hourly load patterns and WAPA is unable to fulfill its contractual obligations from existing Salt Lake City Area Integrated Projects (SLCA/IP) resources, WAPA must purchase power from other market sources to meet any contractual obligations. Those alternate sources are typically derived from power-generation sources fueled by natural gas, coal, oil, nuclear, and to a much lesser degree, solar and wind. Each power-generation source has its own characteristic air emissions, water consumption, and economic impacts. In the event customer contractual allocations are reduced, the customers would be required to replace that capacity and energy from an alternate source through a purchase or build-out of new generation.

All of the potential impacts noted above are influenced by hourly, daily, monthly, and annual patterns and variations in how water is released from Glen Canyon Dam to produce electricity, and how those releases are typically timed to enhance the value of power generation. Ramp rates (i.e., the rate, in cfs/hr, at which dam releases rise or fall, referred to hereafter as up-ramp rates and down-ramp rates, respectively), flow rates (in cfs), maximum and minimum daily flows (cfs), daily/monthly release volumes (ac-ft), and reservoir elevation (head) are all factors that influence the extent of impacts of dam operations on electrical power customers, downstream environmental resources, Tribal cultural sites, recreational users, and WAPA's repayment obligations and the ability to fund CRSP operations and important environmental programs in the Upper Basin.

3.13.1 Power Operations

Power operations are the physical operations of a large electrical power system, including hydropower generation, and control (operational flexibility, scheduling, load/generation following, regulation, reserves, and transmission).

3.13.1.1 Hydropower Generation

The Glen Canyon Powerplant has eight generators with a maximum combined capacity of 1,320 MW when the reservoir elevation is 3,700 ft AMSL. The maximum combined discharge (water release) capacity of the eight turbines is approximately 31,500 cfs. Under the current operating regime of MLFF adopted in the 1996 ROD (Reclamation 1996), the maximum release is limited to 25,000 cfs, except in extreme hydrologic or emergency conditions or under approved experimental actions (i.e., HFE protocol). This maximum release restriction limits Glen Canyon Dam power generation capacity to approximately 1,000 MW at a reservoir level of

3,700 ft AMSL, which is 76% of potential usable capacity without restriction. The generators require a minimum Lake Powell elevation of 3,490 ft AMSL to operate. At this elevation, the maximum capacity of the Glen Canyon Powerplant is reduced to approximately 630 MW. Prior to 1991, annual gross generation ranged from a minimum of 1.1 million MWh to a maximum of 8.8 million MWh, with an average of 4.4 million MWh. With the Interim Flows decision in 1990, generation between 1991 and 1996 ranged between 3.6 million MWh and 5.5 million MWh, averaging 4.1 million MWh, and with the adoption of the current operating regime (MLFF), generation from 1997 to 2015 has ranged between 3.1 million MWh and 6.7 million MWh, with an average of 4.2 million MWh (Reclamation 2014b). Since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred from operational restrictions ranged from $38 million to $50 million (Veselka et al. 2010).

Releases that bypass the generators (such as in the case of HFEs) do not generate power, and therefore have no power system economic value. Turbines are operating at maximum capacity during HFEs, which does generate more power than the normal operations; however, there are marketing challenges due to the short-term nature of this generation during the HFE.

Glen Canyon Dam and Powerplant is the largest facility in the CRSP, which also includes other power facilities (e.g., Aspinall Unit [Blue Mesa, Crystal, and Morrow Point dams] in Colorado, and Flaming Gorge Dam in Utah). The power produced at these facilities, which includes both capacity and energy[11] generated at Glen Canyon Dam and other CRSP facilities, is marketed by WAPA. Net winter and summer energy (adding purchases to the combined powerplant resources and subtracting losses and project use) marketed by WAPA is currently 2,558 and 2,394 GWh, respectively, while net winter and summer capacity (subtracting project-use loads, system losses, control area regulation needs, firm-load reserves, and scheduled-outage-assistance-loads from generating capability) are 1,404 MW and 1,318 MW, respectively. Seasonal variation is due to differences in typical reservoir elevations and project-use loads (Reclamation 1995).

To coordinate electric power rate-setting and marketing efforts and ensure the timely repayment of federal project construction and irrigation assistance debt, the Colorado River Storage, Collbran, and Rio Grande Projects were administratively integrated in 1987 into the Salt Lake City Area Integrated Projects (SLCA/IP), which is part of an interconnected generation and transmission system that includes federal, public, and private power generating facilities (Reclamation 1995).

3.13.1.2 Basin Fund

The Upper Colorado River Basin Fund (Basin Fund) was established under Section 5 of CRSPA. CRSPA "authorized a separate fund in the Treasury of the United States to be known as

[11] Energy (typically measured in MWh) is electricity generated and/or used over time; capacity (typically measured in MW) is total powerplant generation capability.

the Upper Colorado River Basin Fund [...] for carrying out provisions of this Act other than Section 8." Money appropriated for construction of CRSP facilities, except recreation and fish and wildlife facilities constructed under Section 8, is transferred to the Basin Fund from the General Fund of the Treasury. Revenues derived from operation of the CRSP and participating projects are deposited in the Basin Fund. Most of the revenues come from sales of hydroelectric power and transmission services. The Basin Fund also receives revenues from municipal and industrial water service sales, rents, salinity funds from the Lower Colorado Basin (as a pass-through for the Colorado River Basin Salinity Control Program), and miscellaneous revenues collected in connection with the operation of the CRSP and participating projects. Revenues and appropriated funds are accounted for separately in the Basin Fund.

3.13.1.3 Operational Flexibility

The operational flexibility of hydroelectric power generation allows WAPA to quickly and efficiently increase or decrease generation in response to customer demand, generating unit or transmission line outages (contingency reserves), unscheduled customer deviation from internally scheduled contracted power usage (regulation and load/generation following) within a specific metered load area known as a Balancing Authority (BA),[12] integrated power system requirements, and requests for emergency assistance from interconnected utilities. Under the water release parameters instituted on an interim basis in 1991 and permanently under the 1996 ROD following the completion of the Glen Canyon Environmental Impact Statement (Reclamation 1995), WAPA currently restricts the scheduling of customer contract allocations to 2-day-ahead prescheduling only. Ramping restrictions, imposed under the 1996 ROD operating criteria, do not allow generation at Glen Canyon Dam to adjust sufficiently each hour to match the power customer demand schedules. These ramping restrictions result in increased use of alternate generating resources to meet power customer demand schedules. Operational conditions are complicated by the frequency, season, and time of day any of these events may occur; physical and environmental operating restrictions at other CRSP generating facilities and within the interconnected electric system; and the availability and price of alternative power resources (Reclamation 1995).

Although there is considerable potential for flexibility in Glen Canyon powerplant operations, current operating criteria have placed multiple restrictions on the variability of water released from the dam, thus restricting operations at the powerplant. Prior to 1991, Reclamation operated the dam and powerplant to maintain a minimum release of 3,000 cfs in summer months, and maintained a 1,000-cfs limit minimum flow for the remainder of the year. There were no restrictions on ramp rates, and daily fluctuations were occasionally as high as 28,500 cfs in the summer months and 30,500 cfs for the rest of the year (Poch et al. 2011). Beginning in August 1991, an Interim Flows decision restricted the operation of the dam for environmental reasons, and the Interim Flows decision was used as the basis for operation until February 1997, when the February 1997 operating criteria, based on the 1996 ROD, restricted dam operational

[12] Note that in this section of the EIS, BA is used as the abbreviation for Balancing Authority. In other sections of the DEIS, BA refers to Biological Assessment.

flexibility. This operating regime, referred to as MLFF, is currently used as the basis of operations at Glen Canyon Dam and requires water release rates to be 8,000 cfs or greater between the hours of 7 a.m. and 7 p.m., and at least 5,000 cfs at night. The criteria also limit ramp rates; the maximum hourly increase (i.e., the up-ramp rate) is 4,000 cfs/hr, and the maximum hourly decrease (i.e., the down-ramp rate) is 1,500 cfs/hr. The 1996 ROD operating criteria also restricted the extent to which releases can fluctuate during a rolling 24-hour period. This change constraint varies between 5,000 cfs/day and 8,000 cfs/day, depending on the monthly volume of water releases. Daily fluctuation is limited to 5,000 cfs in months when less than 600 thousand acre-feet (kaf) is released. The fluctuation limit increases to 6,000 cfs when monthly release volumes are between 600 kaf and 800 kaf. When the monthly water release volume is 800 kaf or higher, the daily allowable fluctuation is 8,000 cfs (Reclamation 1995; Poch et al. 2011). MLFF includes emergency exception criteria.

Under MLFF, the maximum release rate for power generation is limited to 25,000 cfs. Maximum release rate exceptions are allowed if needed to avoid spills or flood releases during high runoff periods or if authorized under approved experimental action (i.e., HFE protocol). Under very wet hydrologic conditions, defined as when the average monthly release rate is greater than 25,000 cfs, the flow rate may be exceeded, but water must be released at a constant rate. Adjustments to MLFF are made to avoid spills, during flood releases, to accommodate experimental releases, and to accommodate electrical emergencies. These adjustments include maximum release rates above 25,000 cfs. Experimental releases may require release rates in excess of the capacity of the powerplant. When this situation occurs, additional water would be released through bypass tubes to achieve the desired high release rate. Bypassing water around the generators produces no energy, which can result in additional purchases of replacement power, and increases the river stage in the tailwater, which reduces elevation, thereby reducing the effective head and power conversion rates for water passing through powerplant turbines (Poch et al. 2011).

3.13.1.4 Scheduling

Power scheduling is the matching of seasonal, daily, and hourly system energy and capacity needs with available generation. At Glen Canyon Dam, power scheduling is affected by the distribution of monthly water release volumes, restrictions in water release patterns (maximum and minimum release limits, allowable daily fluctuation rates, and hourly ramp rates), availability of the eight units in the Glen Canyon Powerplant and other CRSP units (individual units are on a rotating maintenance schedule) in the system, power customer allocations, and peak and off-peak power periods. Weather and runoff forecasts, alternate resource availability, and the market price of electricity also play important roles in how the customers schedule their allocation of CRSP resources (Reclamation 1995).

Scheduling to meet power requirements generally means higher water releases in peak months when the demand for power (load) is higher (December, January, July, and August) and lower water releases when electric power demand is lower.

Prior to 1990, dispatch (the sequence in which SLCA/IP powerplants are utilized to meet the demand for electricity) from powerplants was driven primarily by market prices. A high level of operating flexibility at the SLCA/IP allowed WAPA to purchase energy during off-peak periods to meet customer demand, storing the water for later power generation during on-peak periods when prices were higher. Accordingly, WAPA was able to maximize the economic value of electricity sales from the Glen Canyon Powerplant. Since MLFF operational constraints were imposed on SLCA/IP resources, including those at Glen Canyon Dam, SLCA/IP powerplants have been dispatched independently to meet contractual obligations at the lowest possible cost, with the lowest variable operating costs generally dispatched first, and plants with higher variable operating costs brought online sequentially as electricity demand increases. Hourly differences between loads and resource production are reconciled though market purchases and sales. Within the operational restrictions of MLFF, there are many hourly release patterns and dispatch arrangements that comply with the operating criteria to provide scheduling flexibility to meet power customer demand. However, since the implementation of MLFF, between 1997 and 2005, the average annual cost incurred ranged from $38 million to $50 million, due to operational restrictions (Veselka et al. 2010).

3.13.1.5 Load/Generation Following and Regulation

To ensure interconnected system reliability, WAPA follows mandatory reliability standards enforced by the North American Electric Reliability Corporation (NERC) and the Western Electricity Coordinating Council (WECC). In addition, WAPA follows operational criteria, guidelines, and procedures set in place by the WECC and the contingency Reserve Sharing Group (RSG) applicable to each BA. Each WECC utility is located within such a load control area, and one utility within the BA serves as the BA operator. WAPA is the BA operator for the Western Area Lower Colorado Region (WALC) BA, the Western Area Colorado-Missouri Region (WACM) BA, and the Western Area Upper Great Plains West Region (WAUW) BA, and is responsible for ensuring that each load-serving utility within each BA serves its own internal load while meeting its power and reserve obligations. Operating as a BA, WAPA is the provider of last resort should a load-serving entity not be able to fulfill its obligation to the BA, and it carries all compliance responsibility for the BA function. All CRSP powerplants are within the WACM BA, and the flexibility and load/generation following capability of CRSP hydroelectric powerplants, particularly Glen Canyon Powerplant, are important in meeting NERC/WECC reliability standards and criteria.

Hydropower generation is valuable because it can react instantaneously to changes in load or unanticipated changes in generation resources within the BA. This ability to respond to rapidly changing load conditions is called load and/or generation following regulation. As a BA operator, WAPA utilizes its hydrogeneration resources, and hydropower is typically used to balance instantaneous changes to loads and/or generation within the metered transmission and generation BA system. By comparison, coal- and nuclear-based resources have a very slow response time, and consequently have limited load/generation following regulation capability. Load/generation following regulation capability at Glen Canyon Dam is limited to $\pm$ 40 MW and is outside the 1996 ROD operating criteria ramping restrictions.

In general, power demand increases during the daylight hours as residences, commercial establishments, agriculture, and industrial electrical demands increase. Under normal conditions, the system load pattern throughout the region is similar from Monday through Friday, but load often drops considerably on Saturday and Sunday as companies with a heavy commercial or industrial load shut down. System load also varies seasonally with increases in the conditions load in December, January, July, and August, and lower demand for power in the remaining months (Reclamation 1995).

Implementation of the 1996 ROD operating criteria has reduced the ability of power generation at Glen Canyon Dam to follow hourly changes in customer load. Prior to the 1990s, power generation from CRSP powerplants, including Glen Canyon Dam, was driven primarily to meet daily and seasonal power demands. A high level of operating flexibility at these federal facilities allowed power generation to closely follow on- and off-peak electrical loads which made these federal facilities valuable assets in developing the economies of the Western United States. For example, during the 1978 energy crisis, Glen Canyon Dam was operated under an executive order that required federal agencies to exercise their authorities to increase domestic energy production and reduce U.S dependence on foreign oil. Accordingly, WAPA was able to increase the economic value of electricity deliveries to its electrical customers using generation at Glen Canyon Dam and its other facilities in the CRSP system to meet this directive. Beginning in the 1990s, however, operations at each of the CRSP powerplants (Glen Canyon Dam in 1996, Flaming Gorge Dam in 2005, and the Aspinall Unit in 2012) have been restricted for environmental reasons. Although WAPA continues to dispatch these units to maximize load-following capabilities within the constraints each unit operates under, these restrictions have substantially reduced the usable generation capacity of these facilities to meet the daily and seasonal energy needs of its customers.

In addition to load/generation-following and regulation responsibilities, dispatchers follow other practices that are specific to Glen Canyon Dam Powerplant operations. These practices fall within MLFF constraints but are not ROD requirements and may be altered or abandoned by WAPA at any time. One practice involves reducing generation at Glen Canyon Dam to the same minimum level every night during low-price, off-peak hours. WAPA also avoids large changes to total daily water volume releases when they occur over successive days. This increases the efficiency of producing and marketing power at the dam and reduces downstream environmental impacts. In addition, weekend releases are generally not less than 85% of the average weekday release and, during the summer season, one cycle of raising and lowering Glen Canyon Dam Powerplant output, increasing to a maximum of two cycles during other seasons of the year as dictated by the hourly load pattern provided by customer preschedules (Poch et al. 2011).

Changes in WAPA's scheduling guidelines typically occur slowly over a period of months, not only because of the operational constraints imposed by the ROD, but also due to changing market conditions, such as persistent drought, electricity market disruptions in 2000 and 2001, and extended experimental releases that have large daily flow rate fluctuations (Poch et al. 2011).

3.13.1.6 Capacity Reserves

Each BA, or RSG utility applicable to it, is required to maintain sufficient generating capacity to continue serving its customer load, even if the BA or RSG utility loses all or part of its own largest generating unit or largest capacity transmission line. This is done to ensure electrical service reliability and uninterrupted power supply. Reserve requirements for the generation resources of the SLCA/IP are based on a formula which considers the loss of the largest single generator within the Rocky Mountain RSG and allocates a reserve quota to each member based on their relative size within the group. Total available capacity, in turn, is determined by the minimum and maximum allowable releases from these powerplants. Spinning reserves (generating units that are operating online but not generating electricity) are used to quickly replace lost electrical generation resulting from a forced outage, such as the sudden loss of a major transmission line or generating unit. Additional offline reserves (offline idle units that are ready to begin generating electricity) can be used to replace generation shortages, but they cannot respond as quickly as spinning reserves (Reclamation 1995). SLCA/IP generation resources are located within the Rocky Mountain RSG. A portion of that generation is set aside by the Rocky Mountain RSG to be utilized during contingency reserve activation periods. Capacity for this reserve obligation is held on Glen Canyon generation resources by WAPA whenever possible. (Reserve activations and subsequent water releases through the generators are not subject to the 1996 ROD release criteria.)

3.13.1.7 Disturbances and Emergencies and Outage Assistance

In the event of a widespread sudden loss of generation resource power outage, or an imbalance in the transmission system element causing a load/resource imbalance requiring an immediate response (i.e. disturbance), NERC contingency reserve standards require that available generation capacity be utilized to return the electric generation and transmission system to normal operating conditions within load/generation balance within 10 minutes following the disturbance. Generally, emergency operations contingency reserves are needed only for periods of an hour or less, but can and frequently are activated several times a day. WAPA also has existing contractual agreements to use capacity at Glen Canyon Dam to restart traditional thermal powerplants and provide emergency shutdown power to nuclear powerplants. It is especially important for generation resources at Glen Canyon Dam to be available for safe shutdown of nuclear facilities in the area in the unlikely event of a widespread power outage. WAPA's ability to supply emergency assistance is limited by available transmission capacity and available generation capability, while the ability to deliver emergency assistance varies on an hourly basis, depending on firm load obligations and available generation from project resources. With a full reservoir and average loads, Glen Canyon Dam and Powerplant has been able to provide emergency assistance beyond its required reserves by utilizing its remaining unloaded capacity after serving load, regulation, frequency response, and contingency reserve obligations. Due to the flexibility of hydroelectric resources, the SLCA/IP has often provided scheduled outage assistance. This ability will continue into the future under all potentially selected alternatives of the LTEMP DEIS. Responding to electrical emergencies also is not subject to the 1996 ROD operating constraints.

3.13.1.8 Transmission System

The CRSP/WACM transmission system is used to transmit electricity from Glen Canyon Dam and other generating sources to customer utilities that serve end users such as municipal, residential, Tribal, irrigation district, and commercial and industrial consumers. Both hydroelectric generation and other generation resources are affected by transmission limitations when lines do not have enough capacity to transmit electricity from the point of generation to the point of demand. The amount of power scheduled for transmission varies from season to season, day to day, and hour to hour. Scheduling limits are derived from physical limits and determine how many transactions may occur. Actual transmission refers to the measured flow of power on the line. NERC requires monitoring of the actual and scheduled power flow for system operation (Reclamation 1995).

3.13.2 Power Marketing

Electricity generated at Glen Canyon Dam and Powerplant and other SLCA/IP facilities in the Upper Colorado Region is marketed by WAPA under statutory criteria in the Reclamation Project Act of 1939, the Flood Control Act of 1944, CRSPA, and the Department of Energy Organization Act of 1977, along with associated marketing plans and contractual obligations. Requirements stemming from these criteria include:

- Preference in the sale of capacity and energy must be given to municipalities, public corporations, cooperatives, and other nonprofit organizations.

- Capacity and energy must be marketed at the lowest possible rates consistent with sound business practices.

- Revenues generated from capacity and energy sales must pay for power generation and transmission facility costs (including operations, maintenance, replacements, and firming purchases and emergency power) and all allocated investment costs under the CRSPA, including interest and irrigation project expenses and investment costs related to regulating water deliveries, flood control, and water storage beyond the ability of the irrigators to repay, as well as certain environmental costs as provided under the GCPA 1992.

- Projects must generate the greatest practicable amount of capacity and energy that can be sold at firm power and energy rates.

- WAPA is responsible for the construction, operation, and maintenance of transmission lines and attendant facilities.

WAPA markets wholesale CRSP power to preference entities serving approximately 5.8 million retail customers in Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers are small and medium-sized municipalities that operate publicly owned electrical systems; irrigation cooperatives and water conservation districts; rural

electrical associations or generation and transmission co-operatives who often act as wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and Indian Tribes (Reclamation 2012d).

For WAPA's eight largest customers in 2013, the SLCA/IP provided 6.1% of energy and 4.7% of capacity requirements; the remaining 93.9% of energy and 95.3% of capacity being provided by customer utility-owned generation facilities, or purchased from investor-owned or other utility systems, as well as other federal hydropower projects marketed by WAPA. Reliance on SLCA/IP capacity and energy varies considerably among customers; Navajo Tribal Utility Authority (27.4%) and Utah Municipal Power Agency (25.7%) received more than 25% of their energy from SLCA/IP in 2009, while three utilities, Navajo Tribal Utility Authority (19.1%), Utah Municipal Power Agency (17.8%), and Deseret Generation and Transmission Cooperative (17.8%), relied on WAPA for more than 15% of their capacity (Table 3.13-1). Other utilities, such as Tri-State G&T (1,537 GWh and 235 MW), received larger energy and capacity allocations but relied on WAPA for only a small portion of their total capacity and energy requirements.

WAPA markets long-term firm capacity and energy, short-term firm capacity and energy, and non-firm energy. Firm power is capacity and energy that are guaranteed to be available to the customer. Loads are made up of firm load, non-firm sales, and interchanges out of the control area. Firm load and capacity obligations include long- and short-term firm sales, Reclamation project use loads, system losses, BA control area regulation, firm load contingency reserves, and scheduled outage assistance. Capacity is reserved to provide regulation, contingency reserves, frequency support and response, meet CRSP contractual obligations, participating project capacity, and serve Reclamation's irrigation and drainage pumping plant loads before being marketed as long-term firm capacity. WAPA's ability to make non-firm energy sales with hydrogeneration resources after all firm power obligations have been met, and there are generation resources available for marketing purposes as water release requirements dictate, depends on SLCA/IP's flexibility to take advantage of on-peak and off-peak spot energy markets (Reclamation 1995).

The majority of CRSP power is sold under long-term firm electric service contracts. If WAPA is unable to supply contracted amounts of firm capacity or energy from Reclamation hydroelectric resources, it must purchase the deficit from other (primarily non-hydropower) resources for delivery. The expense for this purchased power is shared by all SLCA/IP customers.

Non-firm sales are short-duration energy transactions that are always less than 1 year. Normally scheduled 1 day in advance, although transactions can occur hourly, they can be determined up to the hour of transaction. These non-firm sales occur when generation patterns associated with the 1996 operating criteria do not match customer load schedules and cannot be used for firm electricity deliveries. WAPA sells the excess generation on the non-firm market to accommodate release obligations. The flexibility of hydropower operations allows actual deliveries to be modified hourly, as system conditions warrant. WAPA may market non-firm energy and arrange for interchange transactions, depending on revised water release estimates. Non-firm capacity and energy are capacity and energy that are not guaranteed to be available to

TABLE 3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013[a]

Customer Utility	Energy Required (GWh)	Energy from WAPA (GWh)	Percentage of Energy from WAPA	System Peak Load (MW)	WAPA Allocation (MW)	Percentage of Load from WAPA
Colorado Springs Utilities	4,968	140	2.8	908	22	2.4
Deseret Generation and Transmission Cooperative	2,497	447	17.9	391	70	17.8
Navajo Tribal Utility Authority	718	197[b]	27.4	140[b]	27	19.1
Platte River Power Authority	3,196	536	16.8	659	71	10.7
Salt River Project	32,452	290	0.9	6,663	42	0.6
Tri-State G&T	15,313	1,537	10.0	2,666	235	8.8
Utah Municipal Power Agency	1,216	312	25.7	265	47	17.8
Utah Associated Municipal Power Systems	3,884	477	12.3	943	75	8.0
All eight customers	64,243	3,937	6.1	12,635	588	4.7

[a] Data on energy requirements and system peak load are actual values for 2013, except data for Deseret Generation and Transmission Cooperative and Navajo Tribal Utility Authority, which are forecasts for 2013.

[b] Does not include allocations received by Navajo Tribal Utility Authority from WAPA on behalf of 13 other Tribal groups.

Sources: Colorado Springs Utilities (2015); Deseret Power Cooperative (2012); Navajo Tribal Utility Authority (2012); Platte River Power Authority (2015); Salt River Project (2015); Tri-State G&T (2015); Utah Municipal Power Agency (2015); Utah Associated Municipal Power Systems (2015); Osiek (2015).

the customer, and are purchased by wholesale customers that prefer non-firm energy that is less expensive than power generated at their own powerplants or by alternative supply sources. Non-firm energy is usually sold with the caveat that the sale can be stopped on short notice and the buyer must have the resources available to meet its own load. Non-firm energy is sold at a negotiated price and delivery point based on market conditions. Rates for non-firm energy only include a charge for the energy delivered, since the customer has the capacity to meet its loads if necessary. WAPA does not sell non-firm energy on a long-term basis. The price for non-firm energy is based on market conditions (Reclamation 1995).

WAPA also offers both firm and non-firm transmission service. Firm transmission service is contractually guaranteed for the term of the agreement. Non-firm transmission service

is provided as available and is not guaranteed. WAPA participates in electricity transfers, which occurs when two indirectly connected utilities agree to purchase or sell power to each other. The purchaser or seller must make arrangements to use the transmission system that connects them. WAPA offers wheeling transmission service over particular CRSP transmission paths, including lines carrying power from Glen Canyon Dam. Non-firm transmission service, like non-firm power sales, can be interrupted on short notice (Reclamation 1995).

3.13.2.1 Wholesale Rates

WAPA has long-term firm electric service contracts for SLCA/IP power with 138 Tribal entities and wholesale customers (including municipal utilities, federal and state public power facilities, and rural electric cooperatives). Power rates are established in order that revenues will be sufficient to pay all costs assigned to power within required time periods. Power revenues also pay annual power operation and maintenance, purchased power, transmission service, and interest expenses on Treasury loans used to finance construction of WAPA hydropower projects, as well as irrigation assistance beyond the ability of the irrigators to repay, along with various environmental costs, including costs of the GCDAMP and the Upper Colorado River and San Juan River Endangered Fish Recovery Implementation Programs. CRSP power revenues also must contribute toward salinity control costs under the Colorado River Basin Salinity Control Act and construction costs (with interest) of CRSP participating projects, as well as certain environmental costs as provided under the GCPA. Any remaining annual revenues are used to pay off investment costs assigned to power, so that each investment can be paid within the time allowed (Reclamation 1995).

3.13.2.2 Retail Rates

Retail rates are those paid by end users (residential, commercial, and industrial customers of WAPA's wholesale customers). The retail rates charged by not-for-profit entities normally are set to cover system operation and capital costs. As costs of these individual components change, the retail rates are adjusted to ensure enough revenue is collected to meet the utility's financial obligations.

3.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section provides a brief socioeconomic background for two regions of influence: a six-county region in which the majority of recreation in the Grand Canyon area occurs and a seven-state region in which power from the Glen Canyon Powerplant is marketed. Five standard measures of economic development are described in the following sections: (1) population, (2) income, (3) total employment, (4) employment by sector, and (5) unemployment. A brief description of the numbers and locations of minority and low-income populations, including Tribal populations, in an 11-county region is also provided.

3.14.1 The Six-County Region of Influence

The six-county region is composed of Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Additional socioeconomic background information on these counties can be found in DOI (2012a). Clark County, Nevada, was not included in the recreational economics analysis presented here. Although it is likely that there is some recreational expenditure in Clark County associated with recreation in Lake Mead, the share of these expenditures occurring in Clark County is not known. Expenditures were assumed to occur only in the six counties included in the analysis.

3.14.1.1 Population

Table 3.14-1 presents recent and projected populations in the region and states as a whole. The population in the region stood at 511,435 in 2012, having grown at an average annual rate of 2.4% since 2000. Washington County (4.0%), Mojave County (2.3%), and Kane County (1.5%) experienced higher growth rates than the remainder of the region, with lower growth rates in Garfield County (0.6%) and San Juan County (0.3%). The population growth rate for the region (2.4%) was slightly higher than the rates for both Arizona and Utah (2.1%) between 2000 and 2012.

TABLE 3.14-1 Population in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012	2020	2030
Coconino County, Arizona	116,320	136,011	1.3	144,300	154,400
Garfield County, Utah	4,735	5,095	0.6	6,063	6,821
Kane County, Utah	6,046	7,221	1.5	8,357	10,259
Mohave County, Arizona	155,032	203,334	2.3	241,000	285,600
San Juan County, Utah	14,413	14,965	0.3	15,644	15,486
Washington County, Utah	90,534	144,809	4.0	196,762	280,558
Six-County Region	386,900	511,435	2.4	612,126	753,124
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Governor's Office of Planning and Budget (2013).

The population in the region is expected to increase to 612,126 by 2020 and 753,124 by 2030.

3.14.1.2 Income

Personal income in the region stood at $15.1 billion in 2011 and grew at an annual average rate of 3.1% over the period from 2000 to 2011 (Table 3.14-2). Personal income per capita in the region also rose over the same period at a rate of 0.6%, increasing from $27,990 to $29,842. Per-capita incomes were higher in Coconino County ($35,685) and Kane County ($32,989) in 2011 than the average for the region as a whole. The rate of growth in personal income in the region (3.1%) was higher than the rates for Arizona (2.3%) and the same as that for Utah (2.5%) as a whole.

Average per-capita incomes in 2012 in the six-county region were lower than the averages for Arizona ($36,397) and Utah ($34,738).

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period 2008 to 2012 varied between $42,074 (in 2013 dollars) in Mohave County and $51,622 in Coconino County (U.S. Census Bureau 2013a). Median household incomes were $50,101 for Arizona and $60,576 for Utah over the same period.

3.14.1.3 Employment

In 2012, employment in the region stood at 207,673 (Table 3.14-3). Over the period from 2000 to 2012, annual average employment growth rates were higher in Washington County (3.0%) and Mohave County (1.3%) than elsewhere in the region. At 1.6%, growth rates in the region as a whole were slightly higher than the average rates for Arizona (1.2%) and Utah (1.3%).

In 2011, the service sector provided the highest percentage of employment in the region at 53.9%, followed by wholesale and retail trade (22.3%) (Table 3.14-4). Smaller employment shares were held by manufacturing (6.6%) and construction (5.6%). Within the region, county-level employment varied somewhat across sectors compared with the region as a whole. Garfield County had a higher percentage of employment in agriculture (18.7%) and services (64.4%) than the region as a whole, while manufacturing in Coconino County (8.3%), wholesale and retail trade in Mohave County (26.6%), and services in Kane County (76.2%) were more important as employment sources than in the region as a whole.

TABLE 3.14-2 Income[a] in the Six-County Region

Location	2000	2011	Average Annual Growth Rate (%), 2000–2011
Coconino County, Arizona			
Income (billions of 2013$)	3.8	4.8	2.2
Per-capita income (2013$)	32,298	35,685	0.9
Garfield County, Utah			
Income (billions of 2013$)	0.1	0.1	1.6
Per-capita income (2013$)	25,680	28,007	0.8
Kane County, Utah			
Income (billions of 2013$)	0.2	0.2	2.5
Per-capita income (2013$)	30,195	32,989	0.8
Mohave County, Arizona			
Income (billions of 2013$)	4.1	5.5	2.7
Per-capita income (2013$)	26,249	27,045	0.3
San Juan County, Utah			
Income (billions of 2013$)	0.3	0.3	2.6
Per-capita income (2013$)	17,866	23,148	2.4
Washington County, Utah			
Income (billions of 2013$)	2.4	4.1	4.8
Per-capita income (2013$)	27,019	28,915	0.6
Six-County Region			
Income (billions of 2013$)	10.8	15.1	3.1
Per-capita income (2013$)	27,990	29,842	0.6
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4

[a] Per-capita income is income per person.

Source: U.S. Department of Commerce (2013).

TABLE 3.14-3 Employment in the Six-County Region

Location	2000	2012	Average Annual Growth Rate (%), 2000–2012
Coconino County	59,739	67,052	1.0
Garfield County	2,301	2,454	0.5
Kane County	2,896	3,098	0.6
Mohave County	65,589	76,733	1.3
San Juan County	4,324	4,449	0.2
Washington County	37,771	53,887	3.0
Six-County Region	172,620	207,673	1.6
Arizona	2,404,916	2,778,579	1.2
Utah	1,097,915	1,276,249	1.3

Source: U.S. Department of Labor (2013).

3.14.1.4 Unemployment

Unemployment rates varied across the five counties in the region. Between 2000 and 2012, the average rate in San Juan County was 8.9% and 8.3% in Garfield County, with a relatively high rate of 6.8% in Mohave County (Table 3.14-5). The average rate in the region over this period was 6.4%, which was higher than the average rates for Arizona (5.2%) and Utah (4.0%). Unemployment rates were higher in 2012 than the average rates for the period from 2000 to 2012, with higher rates of 10.7% in San Juan County, 10.5% in Garfield County, and 9.9% in Mohave County. The average rates in 2012 for the region (8.6%) and for Arizona (8.3%) and Utah (5.7%) were also higher than the corresponding average rates for 2000 to 2012.

3.14.1.5 Environmental Justice

E.O. 12898, "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations" (59 FR 7629, Feb. 11; U.S. President 1994b), formally requires federal agencies to incorporate environmental justice as part of their missions. Specifically, it directs them to address, as appropriate, any disproportionately high and adverse human health or environmental effects of their actions, programs, or policies on minority and low-income populations.

The analysis of the impacts of changes in the operation of hydropower facilities on environmental justice issues follows guidelines described in the CEQ's *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). The analysis method has three parts: (1) the geographic distribution of low-income and minority populations in the

TABLE 3.14-4 Employment by Sector in 2011[a]

Employment Sector	Coconino County Employment	Coconino County % of Total	Garfield County Employment	Garfield County % of Total	Kane County Employment	Kane County % of Total	Mohave County Employment	Mohave County % of Total
Agriculture[a]	628	1.4	260	18.7	141	6.3	265	0.7
Mining	60	0.1	10	0.7	10	0.4	556	1.4
Construction	1,932	4.3	60	4.3	76	3.4	1,932	4.8
Manufacturing	3,750	8.3	60	4.3	60	2.7	2,552	6.4
Transportation and public utilities	1,658	3.7	20	1.4	70	3.1	1,551	3.9
Wholesale and retail trade	8,563	19.0	176	12.6	369	16.5	10,645	26.6
Finance, insurance, and real estate	1,628	3.6	23	1.7	70	3.1	1,724	4.3
Services	25,722	57.0	896	64.4	1,702	76.2	20,744	51.9
Other	10	0.0	0	0.0	0	0.0	12	0.0
Total	45,143		1,392		2,234		39,998	

Employment Sector	San Juan County Employment	San Juan County % of Total	Washington County Employment	Washington County % of Total	Six-County Region Employment	Six-County Region % of Total
Agriculture[a]	226	8.3	381	1.0	1,901	1.5
Mining	110	4.0	60	0.2	806	0.6
Construction	164	6.0	2,953	8.1	7,117	5.6
Manufacturing	175	6.4	1,896	5.2	8,493	6.6
Transportation and public utilities	75	2.7	2,624	7.2	5,998	4.7
Wholesale and retail trade	492	18.0	8,236	22.6	28,481	22.3
Finance, insurance, and real estate	99	3.6	1,830	5.0	5,374	4.2
Services	1,475	53.9	18,511	50.7	69,050	53.9
Other	0	0.0	1	0.0	23	0.0
Total	2,738		36,485		127,990	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

TABLE 3.14-5 Unemployment Rates (%) in the Six-County Region

Location	Average Growth Rate (%), 2000–2012	2012
Coconino County, Arizona	6.1	8.1
Garfield County, Utah	8.3	10.5
Kane County, Utah	5.5	7.2
Mohave County, Arizona	6.8	9.9
San Juan County, Utah	8.9	10.7
Washington County, Utah	5.7	7.0
Six-County Region	6.4	8.6
Arizona	5.2	8.3
Utah	4.0	5.7

Source: U.S. Department of Labor (2013).

affected area is described; (2) an assessment is conducted to determine whether the impacts of changes in operation would produce impacts that are high and adverse; and (3) if impacts are high and adverse, a determination is made as to whether these impacts disproportionately affect minority and low-income populations.

Changes in the operation of hydropower facilities and in hydropower costs could affect environmental justice if any adverse impacts on health, environmental conditions, economics, or Tribal values resulting from operational changes are determined to be high, and if these impacts would disproportionately affect minority and low-income populations, including impacts on Tribal groups. If the analysis determines that impacts on health, environmental conditions, economics, and Tribal values are not significant, there can be no disproportionate impacts on minority and low-income populations. In the event impacts are significant, disproportionality would be determined by comparing the proximity of any high and adverse impacts with the location of low-income and minority populations, including Tribal groups.

Environmental justice impacts on Tribes could occur through impacts on Tribal values or through impacts on Tribal economics. Impacts on values could result from temporary changes in access to culturally important Tribal resources associated with dam operations, and there may be an adverse impact on Tribal values from trout management actions. In addition, Tribal economics may be affected by alternative-specific differences in impacts on recreation in Glen Canyon and Grand Canyon and in the surrounding area.

The affected environment related to environmental justice issues is the 11-county region in the vicinity of the reservoirs and river corridor, and in eastern Arizona and northwestern New Mexico, which corresponds to the area in which the majority of impacts on recreation of

changes in dam operations would likely occur. A description of the geographic distribution of minority and low-income groups in the affected area was based on demographic data from the 2010 Census (U.S. Census Bureau 2013b) and the 2008–2012 American Community Survey (U.S. Census Bureau 2013a). The following definitions were used to define minority and low-income population groups:

- **Minority.** Persons are included in the minority category if they identify themselves as belonging to any of the following racial groups: (1) Hispanic, (2) Black (not of Hispanic origin) or African American, (3) American Indian or Alaska Native, (4) Asian, or (5) Native Hawaiian or Other Pacific Islander.

  Beginning with the 2000 Census, where appropriate, the census form allows individuals to designate multiple population group categories to reflect their ethnic or racial origin. In addition, persons who classify themselves as being of multiple racial origins may choose up to six racial groups as the basis of their racial origins. The term "minority" includes all persons, including those classifying themselves in multiple racial categories, except those who classify themselves as not of Hispanic origin and as White or Other Race (U.S. Census Bureau 2013b).

- **Low-Income.** Individuals who fall below the poverty line. The poverty line takes into account family size and age of individuals in the family. In 2013, for example, the poverty line for a family of five with three children below the age of 18 was $27,400. For any given family below the poverty line, all family members are considered as being below the poverty line for the purposes of analysis (U.S. Census Bureau 2013b).

The CEQ guidance states that minority or low-income populations should be identified where either (1) the minority or low-income population of the affected area exceeds 50%, or (2) the minority or low-income population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis. The LTEMP EIS applies both criteria in using the Census Bureau data for census block groups, wherein consideration is given to the minority or low-income population in a census block group where the relevant population is either 50% or more of the total block group population, or where the relevant population is 20 percentage points higher than the state average (the reference geographic unit) for the relevant population.

The data in Table 3.14-6 show the minority and low-income composition of the total population located in the region, based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals additionally identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-6 Minority and Low-Income Populations in the 11-County Area

Population Type	Apache County, Arizona	Coconino County, Arizona	Mohave County, Arizona	Navajo County, Arizona	Cibola County, New Mexico	McKinley County, New Mexico	San Juan County, New Mexico	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	11-County Region
Total population	71,518	134,421	200,186	107,449	27,213	71,492	130,044	5,172	7,125	14,746	138,115	5,730,547
White, non-Hispanic	14,568	74,231	159,378	47,181	5,857	7,384	55,254	4,740	6,639	6,474	118,282	3,555,517
Hispanic or Latino	4,113	18,166	29,569	11,571	9,934	9,473	24,776	234	263	649	13,486	1,433,977
Non-Hispanic or Latino minorities	52,837	42,024	11,239	48,697	11,422	54,635	50,014	198	223	7,623	6,347	741,051
One race	51,753	39,222	7,985	47,047	11,077	53,329	47,564	161	153	7,371	4,161	646,795
Black or African American	157	1,495	1,715	842	221	317	617	13	15	21	632	67,458
American Indian or Alaskan Native	51,360	35,610	3,793	45,551	10,680	52,402	46,321	75	103	7,308	1,460	457,112
Asian	185	1,787	2,016	542	136	542	445	61	31	35	954	87,215
Native Hawaiian or other Pacific Islander	24	138	316	68	19	17	64	10	1	5	1,022	26,839
Some other race	27	192	145	44	21	51	117	2	3	2	93	8,171
Two or more races	1,087	2,802	3,254	1,650	345	1,306	2,450	37	70	252	2,186	94,256
Total minority	56,950	60,190	40,808	60,268	21,356	64,108	74,790	432	486	8,272	19,833	2,175,028
Low-income	19,838	23,050	37,426	24,061	6,468	19,985	20,576	628	539	4,103	20,225	729,333
Percent minority	76.9	44.8	20.4	56.1	78.5	89.7	57.5	8.4	6.8	56.1	14.4	38.0
State percent minority	42.2	42.2	42.2	42.2	59.5	59.5	59.5	19.6	19.6	19.6	19.6	–[a]
Percent low-income	27.7	17.2	18.6	22.4	23.7	27.8	16.0	12.3	7.6	27.9	14.5	12.7
State percent low-income	12.4	12.4	12.4	12.4	14.9	14.9	14.9	12.1	12.1	12.1	12.1	–

[a] A dash indicates not applicable.

A large number of minority and low-income individuals are located in the 11-county area around the Glen Canyon and Grand Canyon. Within the area, 38.0% of the population is classified as minority, while 12.7% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in a state, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority individuals exceeds the state average by 20 percentage points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan County, Utah; and exceeds 50% of the total population in Apache County and Navajo County, Arizona; in Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah; meaning that there are minority populations in each of these counties based on CEQ guidelines and on county-level data in the 2010 Census and 2008–2012 American Community Survey data. As the number of low-income individuals does not exceed the state average by more than 20 percentage points, or does not exceed 50% of the total population in any of the 11 counties, there are no low-income populations based on county-level data in the 11-county region.

Within each county, there are block groups with minority and low-income populations. Figures 3.14-1 and 3.14-2 show the locations of the minority and low-income population groups in the 11-county area.

A large number of block groups in the 11-county area have populations whose percentage of minority individuals is more than 20 percentage points higher than the state average. In the Arizona counties, these block groups are located in the eastern part of Coconino County on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; in the western part of Coconino County, which includes the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County. The Navajo Nation Indian Reservation and the Hopi Indian Reservation are also located in the central and northern part of Apache County, which also contains the Fort Apache Indian Reservation in the southern part of the county. The Navajo Nation Indian Reservation is also located in the central and northern part of Navajo County, Arizona, and in the western part of San Juan County, New Mexico. In all census block groups in these areas, the number of minority individuals is higher than the state average by 20 percentage points or more. Elsewhere in New Mexico, eastern San Juan County, a large majority of McKinley County, which contains part of the Navajo Nation Indian Reservation, part of the Zuni and Ramah Navajo Indian Reservations, and parts of Cibola County, which contains parts of the Ramah Navajo Indian Reservations, and the Acoma, Canoncito and Laguna Indian Reservations, all have block groups whose percentage of minorities is more than 20 percentage points higher than the state average.

There are a number of census block groups in the 11-county area in which more than 50% of the total population is minority. These are located in the southern portion of San Juan County, Utah, which includes the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; the western part of Cibola County, which includes the Zuni Indian Reservation; and the eastern part of the Cibola County, which includes the Acoma, Canoncito and Laguna Indian Reservations. Census block groups in Page, Winslow, and Holbrook,

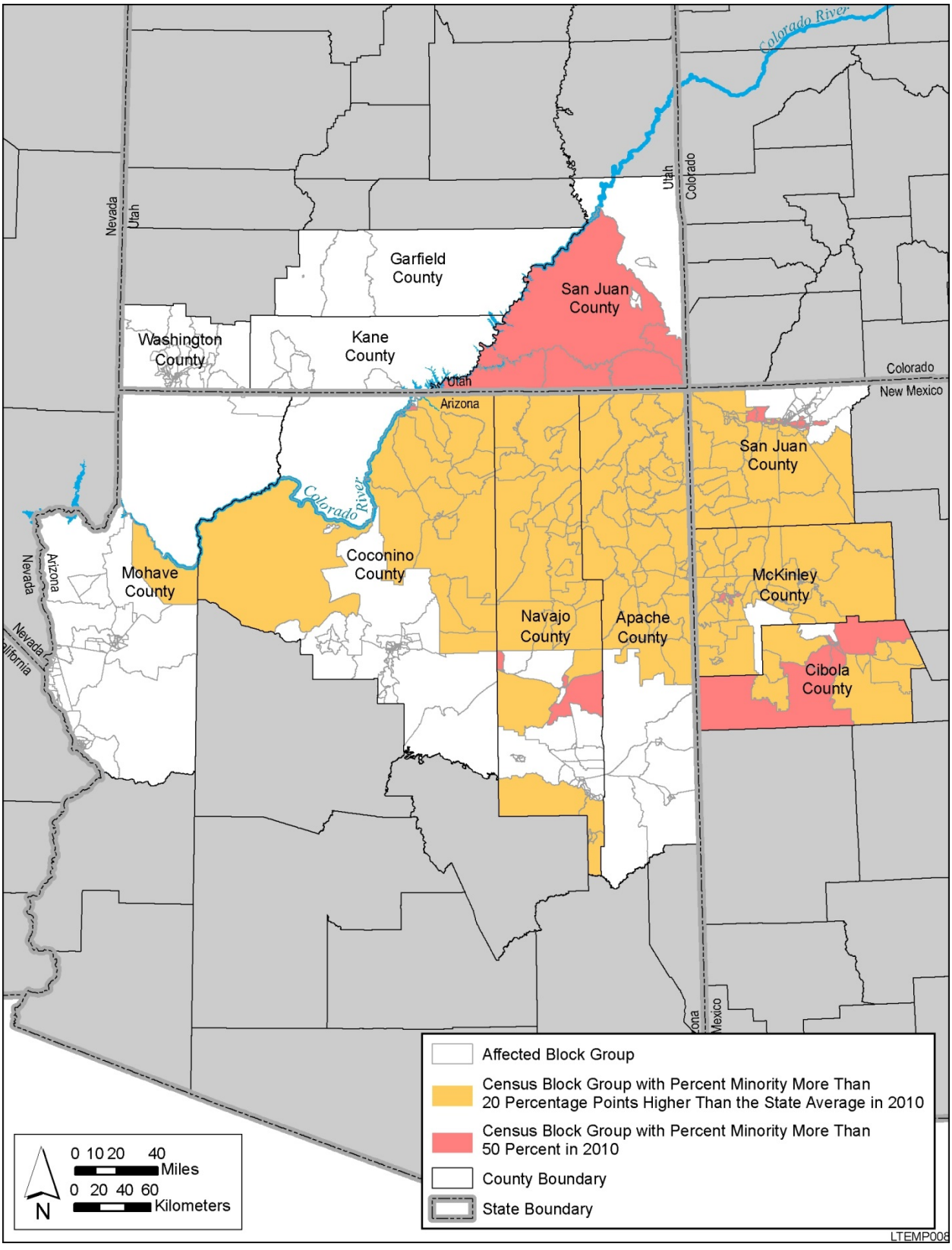

FIGURE 3.14-1 Minority Population Groups in the 11-County Area

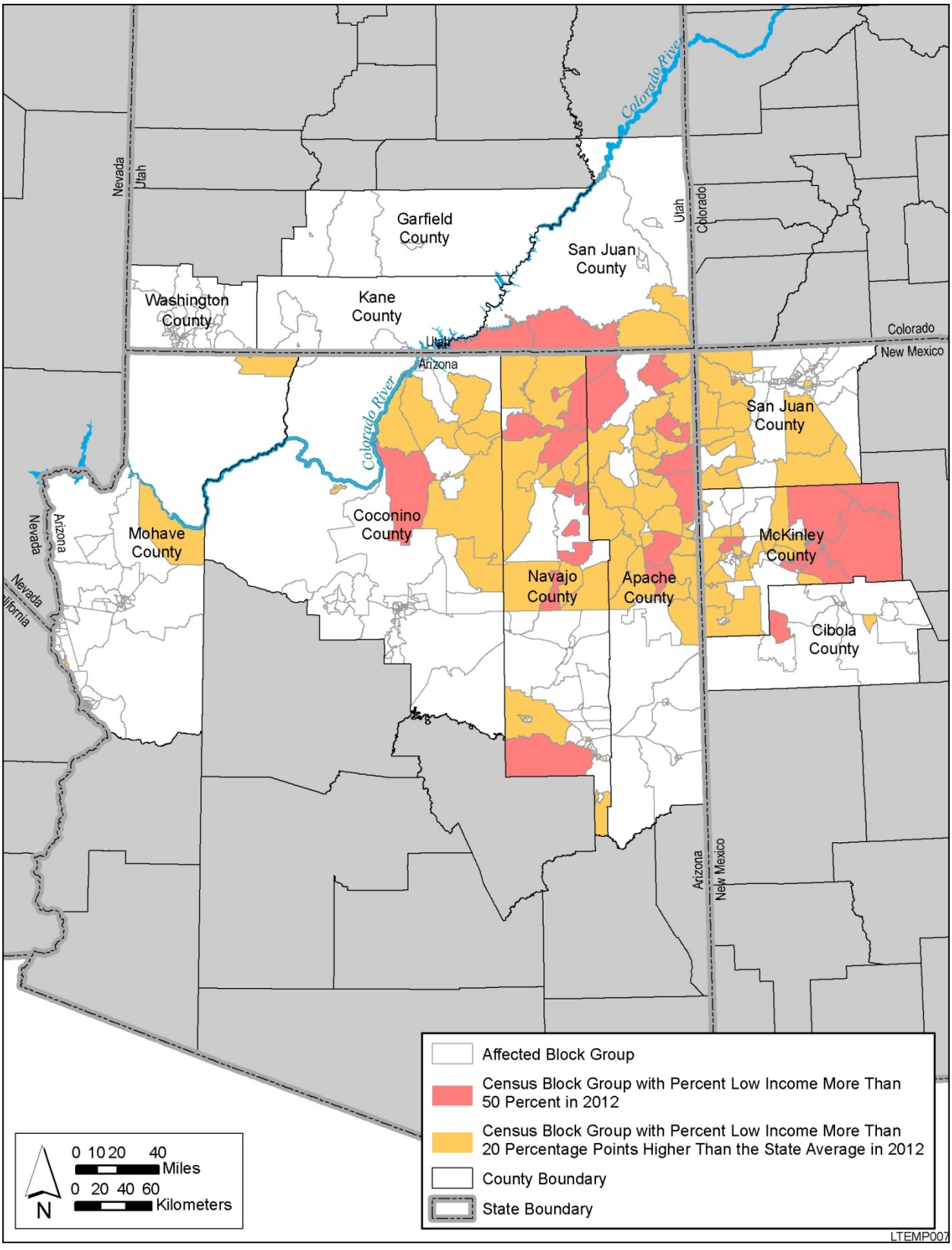

FIGURE 3.14-2 Low-Income Population Groups in the 11-County Area

Arizona, also have minority populations that are more than 50% of the total, as do census block groups in, and in the vicinity of, Farmington and Shiprock, New Mexico

There are a large number of census block groups in the 11-county area in which the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located on the Navajo Nation Indian Reservation and the Hopi Indian Reservation in Coconino County and on the Navajo Nation Indian Reservation in Navajo County, Arizona, which also contains the Fort Apache Indian Reservation; and in Apache County, Arizona, and San Juan County, New Mexico, on the Navajo Nation Indian Reservation. There are also block groups in McKinley County, New Mexico, on the Zuni Indian Reservation and in the vicinity of Gallup; in southeastern San Juan County, New Mexico; in eastern Mohave County, Arizona, on the Hualapai Indian Reservation; in southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation, where the percentage of low-income individuals is more than 20 percentage points higher than the state average.

There are also a number of census block groups in the 11-county area in which more than 50% of the total population is below the poverty level. These are located in the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; in southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; in the northern parts of Navajo County and Apache County, Arizona; in southwestern Navajo County on the Fort Apache Indian Reservation; in New Mexico, in the eastern part of McKinley County, in the vicinity of Gallup, and on the Ramah Navajo Indian Reservation in Cibola County, New Mexico.

3.14.2 The Seven-State Region of Influence

This section describes current socioeconomic conditions within the seven-state region, the area in which electricity from Glen Canyon Dam is marketed, including Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming.

3.14.2.1 Population

Total population in the seven-state region was 21.9 million people in 2012, an increase from 17.7 million in 2000 (Table 3.14-7). Population in the region is concentrated in Arizona and Colorado, which, at 11.7 million people, had almost 54% of the total regional population in 2012.

Population in the seven-state study area grew at an annual average rate of 1.8% from 2000 to 2012. Growth within the region was uneven over the period, with higher than average annual growth rates in Nevada (2.7%), Arizona (2.1%), and Utah (2.1%). Growth rates in Colorado (1.6%) were closer to the average for the region, with lower than average rates in Wyoming (1.3%), New Mexico (1.1%), and Nebraska (0.7%).

TABLE 3.14-7 Population in the Seven-State Region of Influence

State	2000	2012	Annual Growth Rate (%), 2000–2012	2020	2030
Arizona	5,130,632	6,553,255	2.1	7,485,000	8,852,800
Colorado	4,301,261	5,187,582	1.6	5,915,922	6,888,181
Nebraska	1,711,263	1,855,525	0.7	1,940,114	2,054,752
Nevada	1,998,257	2,798,931	2.7	2,959,641	3,222,107
New Mexico	1,819,046	2,085,538	1.1	2,351,724	2,613,332
Utah	2,233,169	2,855,287	2.1	3,309,234	3,914,984
Wyoming	493,782	576,412	1.3	622,360	668,830
Total	17,687,410	21,872,530	1.8	24,583,995	28,214,986

Sources: U.S. Census Bureau (2013a); Arizona Department of Administration (2013); Colorado Department of Local Affairs (2013); Nebraska Department of Economic Development (2013); Nevada State Demographer's Office (2013); University of New Mexico (2013); Governor's Office of Planning and Budget (2013); Wyoming Department of Administration and Information (2013).

The regional population is projected to reach 24.6 million in 2020 and 28.2 million 2030.

3.14.2.2 Income

Arizona and Colorado generated almost 55% of the income in the seven-state region, together producing almost $469 billion in 2011 (Table 3.14-8). Personal income grew at an annual average rate of 2.0% over the period from 2000 to 2011, with higher than average growth rates in Wyoming (3.4%), New Mexico (2.5%), Utah (2.5%), and Arizona (2.3%). Income per capita rose slightly over the same period at a rate of 0.2%, resulting in an increase from $38,640 to $39,509. Per capita incomes were higher in 2011 in Wyoming ($49,676), Colorado ($45,628), and Nebraska ($43,973) than the average for the region as a whole.

Median household incomes (the income level at which exactly half of all households earn more than the level, and half earn less) over the period from 2008 to 2012 varied between $45,542 in New Mexico and $59,096 in Colorado (U.S. Census Bureau 2013a). Median household income in the United States was $53,832 over the same period.

TABLE 3.14-8 Income in the Seven-State Region of Influence

State	2000	2011	Average Annual Growth Rate (%), 2000–2011
Arizona			
Income (billions of 2013$)	183.6	235.4	2.3
Per-capita income (2013$)	35,778	36,397	0.2
Colorado			
Income (billions of 2013$)	198.9	233.4	1.5
Per-capita income (2013$)	46,252	45,628	–0.1
Nebraska			
Income (billions of 2013$)	66.3	81.0	1.8
Per-capita income (2013$)	38,735	43,973	1.2
Nevada			
Income (billions of 2013$)	84.6	104.3	1.9
Per-capita income (2013$)	42,337	38,328	-0.9
New Mexico			
Income (billions of 2013$)	56.0	73.6	2.5
Per-capita income (2013$)	30,808	35,410	1.3
Utah			
Income (billions of 2013$)	74.4	97.8	2.5
Per-capita income (2013$)	33,333	34,738	0.4
Wyoming			
Income (billions of 2013$)	19.6	28.2	3.4
Per-capita income (2013$)	39,626	49,676	2.1
Total			
Income (billions of 2013$)	683.4	853.7	2.0
Per-capita income (2013$)	38,640	39,509	0.2

Source: U.S. Department of Commerce (2013).

3.14.2.3 Employment

In 2012, more than 53% (5.3 million) of all employment in the seven-state power marketing service territory (9.9 million) was concentrated in Arizona and Colorado (Table 3.14-9). Employment in Utah was 1.3 million and 1.2 million in Nevada, the remaining states supporting 2.1 million jobs. Over the period from 2000 to 2012, annual employment growth rates were higher in Nevada (1.6%) and Utah (1.3%) than elsewhere in the seven-state study area, with rates in Colorado (0.8%), New Mexico (0.6%), and Nebraska (0.5%) lower than the average rate of 1.0%.

In 2011, the service sector provided the highest percentage of employment in the seven-state region at almost 56%, followed by wholesale and retail trade (17.5%) (Table 3.14-10). Smaller employment shares were held by finance, insurance, and real estate (6.9%), and both construction and manufacturing (6.7%). Within the region, the distribution of employment across sectors varied somewhat compared to the region as a whole. Nebraska (5.7%) and Wyoming (4.6%) have a higher percentage of employment in agriculture than the region as a whole (2.2%), and these states have lower shares of employment in services compared with the region as a whole. Service sector employment in Nevada (62.9%) and Colorado (58.6%) is higher than in the region as a whole. Nebraska (10.8%) and Utah (10.2%) have larger than average shares of manufacturing sector employment, while mining is a more significant employer in Wyoming (12.4%) than elsewhere in the region.

TABLE 3.14-9 Employment in the Seven-State Region of Influence

State	2000	2012	Average Annual Growth Rate (%), 2000–2012
Arizona	2,404,916	2,778,579	1.2
Colorado	2,300,192	2,523,535	0.8
Nebraska	923,198	980,668	0.5
Nevada	1,015,221	1,226,408	1.6
New Mexico	810,024	871,299	0.6
Utah	1,097,915	1,276,249	1.3
Wyoming	256,685	289,621	1.0
Total	8,808,151	9,946,359	1.0

Source: U.S. Department of Labor (2013).

TABLE 3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence[a]

Sector	Arizona		Colorado		Nebraska		Nevada	
	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	30,113	1.4	40,673	2.0	48,061	5.7	4,603	0.5
Mining	11,160	0.5	25,006	1.2	963	0.1	11,484	1.1
Construction	116,992	5.5	115,615	5.7	37,196	4.4	50,140	5.0
Manufacturing	137,532	6.4	117,810	5.9	91,190	10.8	39,277	3.9
Transportation and public utilities	87,613	4.1	68,901	3.4	38,583	4.6	48,147	4.8
Wholesale and retail trade	398,228	18.6	332,919	16.6	146,784	17.4	163,369	16.3
Finance, insurance, and real estate	168,747	7.9	132,273	6.6	68,097	8.1	57,788	5.7
Services	1,186,730	55.5	1,177,687	58.6	413,514	49.0	632,580	62.9
Other	175	0.0	375	0.0	60	0,0	175	0.0
Total	2,137,315		2,011,186		844,678		1,005,038	

Sector	New Mexico		Utah		Wyoming		Total	
	Employment	% of Total	Employment	% of Total	Employment	% of Total	Employment	% of Total
Agriculture[a]	23,426	3.8	20,175	1.9	10,029	4.6	177,080	2.2
Mining	16,643	2.7	10,755	1.0	27,001	12.4	103,012	1.3
Construction	39,441	6.4	56,030	5.3	17,350	8.0	432,764	5.5
Manufacturing	27,434	4.4	106,865	10.2	9,644	4.4	529,752	6.7
Transportation and public utilities	21,385	3.4	50,294	4.8	13,861	6.4	328,784	4.2
Wholesale and retail trade	115,071	18.5	187,284	17.9	37,926	17.4	1,381,581	17.5
Finance, insurance, and real estate	31,848	5.1	76,448	7.3	10,925	5.0	546,126	6.9
Services	345,254	55.6	540,136	51.5	92,500	42.4	4,388,401	55.6
Other	62	0.0	60	0.0	75	0.0	982	0.0
Total	620,564		1,048,851		218,211		7,885,843	

[a] Agricultural employment includes 2007 data for hired farmworkers.

Sources: U.S. Census Bureau (2013c); USDA (2013).

3.14.2.4 Unemployment

Between 2000 and 2011, average unemployment rates have varied across the seven-state region, from 7.7% in Nevada and 6.5% in Arizona to lower rates elsewhere in the region, particularly in Nebraska (3.8%) (Table 3.14-11). The average rate in the region over this period was 6.2%. Rates were higher in 2012 than average rates for the period from 2000 to 2011, unemployment standing at 11.1% in Nevada and 8.3% in Arizona, with lower rates in the other five states; the average rate for the region as a whole (7.6%) was also higher during this period than the corresponding average rate for 2000 to 2011.

3.14.2.5 Environmental Justice

The data in Table 3.14-12 show the minority and low-income composition of total population located in the seven-state region based on 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines. Individuals identifying themselves as Hispanic or Latino are included in the table as a separate entry. However, because Hispanics can be of any race, this number also includes individuals also identifying themselves as being part of one or more of the population groups listed in the table.

TABLE 3.14-11 Unemployment in the Seven-State Region of Influence[a]

State	Average Rate (%), 2000–2011	2012 (%)
Arizona	6.5	8.3
Colorado	6.0	8.0
Nebraska	3.8	3.9
Nevada	7.7	11.1
New Mexico	5.7	6.9
Utah	5.0	5.7
Wyoming	4.5	5.4
Total	6.2	7.6

Source: U.S. Department of Labor (2013).

TABLE 3.14-12 State Minority and Low-Income Populations, 2010

Category	Arizona	Colorado	Nebraska	Nevada	New Mexico	Utah	Wyoming	Region Total
Total population	6,392,017	5,029,196	1,826,341	2,700,551	2,059,179	2,763,885	563,626	21,334,795
White, Non-Hispanic	3,695,647	3,520,793	1,499,753	1,462,081	833,810	2,221,719	483,874	13,717,677
Hispanic or Latino	1,895,149	1,038,687	167,405	716,501	953,403	358,340	50,231	5,179,716
Non-Hispanic or Latino minorities	801,221	469,716	159,183	521,969	271,966	183,826	29,521	2,437,402
One race	686,590	368,869	130,757	442,837	242,131	134,841	21,216	2,027,241
Black or African American	239,101	188,778	80,959	208,058	35,462	25,951	4,351	782,660
American Indian or Alaska Native	257,426	31,244	14,797	23,536	175,368	27,081	11,784	541,236
Asian	170,509	135,564	31,919	191,047	26,305	54,176	4,279	613,799
Native Hawaiian or other Pacific Islander	10,959	5,661	966	15,456	1,246	23,909	365	58,562
Some other race	8,595	7,622	2,116	4,740	3,750	3,724	437	30,984
Two or more races	114,631	100,847	28,426	79,132	29,835	48,985	8,305	410,161
Total minority	2,696,370	1,508,403	326,588	1,238,470	1,225,369	542,166	79,752	7,617,118
Low-income	1,094,249	659,786	229,923	398,027	413,851	359,242	61,577	3,216,655
Percent minority	42.2	30.0	17.9	45.9	59.5	19.6	14.1	35.7
U.S. Percent	35.3	35.3	35.3	35.3	35.3	35.3	35.3	35.3
Percent low-income	17.4	13.4	12.9	14.9	20.4	13.2	11.2	15.1
U.S. percent	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8

Sources: U.S. Census Bureau (2013a,b).

A large number of minority and low-income individuals are located in the seven-state region in which electricity from Glen Canyon dam is marketed. In the region as whole, 35.7% of the population is classified as minority, while 15.1% is classified as low-income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in the nation, for example), rather than only on the number of minority and low-income individuals present in a geographic area. The number of minority or low-income individuals in the seven-state region does not exceed the respective national averages by 20 percentage points or more, and does not exceed 50% of the total population in the area, meaning that for the region as a whole, there are no minority or low-income populations based on CEQ guidelines and on 2010 Census and 2008–2012 American Community Survey data. However, within one state in the region, New Mexico, 59.5% of the total population is minority, meaning that according to 2010 Census and 2008–2012 American Community Survey data, there is a minority population in the state.

Although there are no minority populations in any of the seven states, except for New Mexico, and no low-income populations, there are a large number of Native American individuals in the seven-state area, many of whom reside on Tribal Reservations. Section 3.9 provides more information on the location and Tribal population associated with Reservations. Many of these individuals are low-income in status.

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from the SLCA/IP system, which includes power from Glen Canyon Dam. Nine of these Tribes operate electric utilities and receive power directly from WAPA, while the remaining 48 Tribes can often benefit from cheaper federal hydropower through "benefit crediting" arrangements with SLCA/IP customers or other electric utilities. Benefit credits are provided to a Tribe by the utility that serves the area in which the Tribe is located in lieu of direct electric service by WAPA, and are intended to be the financial equivalent of a direct allocation. When the SLCA/IP rate is lower than the rate charged for electrical power by the utility, the difference between the two rates is paid to each Tribe by subtracting the amount of the benefit credit, pro-rated by the amount of electricity consumed, from the monthly electric bill.

3.14.3 Non-Use Value

Non-use values are economic values that may be placed on the status of the natural or physical environment by non-users, or individuals who may never visit or otherwise use a natural resource that might still be affected by changes in its status or quality, who may assign a non-use or passive-use economic value to a resource.

Welsh et al. (1995) estimated the willingness to pay to improve native vegetation, native fishes, game fish, river recreation, and cultural sites in Glen Canyon National Recreation Area

and Grand Canyon National Park. Value estimates varied between $17.74 and $26.91 for a U.S. household, and between $29.05 and $38.02 for a western U.S. household.

Understanding non-market values affected by proposed operational changes at Glen Canyon Dam, for both recreational use and environmental non-use values, has been the topic of considerable prior investigations (e.g., Bishop et al. 1987; Welsh et al. 1995). These studies have been important in bringing non-market values into consideration for managing the resources of the Colorado River Basin (Harpman et al. 1995; Loomis et al. 2005). In that regard, two additional studies (Loomis 2014; Jones et al. 2016) have been conducted regarding non-market values.

Loomis (2014) concluded that there is a theoretical basis for non-market values associated with hydropower and water. He used the example of how people can place value on maintaining the ranching and farming way of life associated with western rural communities as irrigated agriculture landscapes are correlated with open space. In addition, people may place value on the existence and well-being of farming communities. Indirect empirical support for altruism toward farmers is cited in Loomis (2014). Non-market values associated with hydropower and water resources may also exist to the extent hydropower and developed water assist in the maintenance of Tribal values and social well-being.

3.15 AIR QUALITY

Air quality is primarily affected by air emission sources, both natural (e.g., wildfires and windblown dust) and man-made (e.g., power generation from fossil fuel–fired plants, such as the nearby Navajo Generating Station, and potentially other plants in the 11-state area, as well as onroad and offroad mobile sources such as vehicles).

Changes in operations at Glen Canyon Dam can create either more or less hydroelectricity at certain times of the day to meet regional electricity demand. If less electricity is available at Glen Canyon Dam, demand must be met by other means, which may include powerplants fueled by fossil fuels (including coal, oil, and gas turbine plants) and nuclear, other hydroelectric, wind, and solar energy sources, or by demand-side management. Changes in the operation of Glen Canyon Dam, therefore, may indirectly affect air quality by potentially changing the degree to which electricity demand is met within the region, with either non-emission hydropower, wind, or solar powerplants, or emission-producing powerplants, such as fossil fuel–fired powerplants that can directly affect air quality and related resources. These air quality changes can also affect greenhouse gas (GHG) emissions that can influence climate change. Local and regional GHG information is presented here, while climate change is discussed in Section 3.16.

3.15.1 Local Air Quality

The Clean Air Act (CAA), as amended (42 USC 7401) established Prevention of Significant Deterioration (PSD) provisions for use in protecting the nation's air quality and

visibility. The PSD provisions apply to new or modified major stationary sources and are designed to keep an attainment area in continued compliance with the National Ambient Air Quality Standards (NAAQS). Major stationary sources are industrial-type facilities and include powerplants and manufacturing facilities that emit more than 100 tons per year of a regulated pollutant. No major stationary sources are being proposed for construction or modification by the proposed federal action; therefore the statutory provisions specific to PSD are not applicable. However, there are criteria pollutants for which thresholds for increases in pollution concentrations have been established. These include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM), which are often analyzed. The PSD standards are most stringent in Class I areas and are progressively less stringent in the Class II and Class III areas (Table 3.15-1). GCNRA and LMNRA are designated as Class II areas, while GCNP is designated as a Class I area.

Table 3.15-2 presents criteria pollutant and volatile organic compound (VOC) emission totals in 2011 for Coconino and Mohave Counties (EPA 2013a), which encompass the GCNP. The data represent 13 source categories (e.g., fuel combustion by power generation and industry, highway vehicles, off-highway vehicles, and miscellaneous sources). Miscellaneous sources, including prescribed/structural fires, wildfires, fugitive dust, and agricultural production, account for a predominant portion of the two-county totals of PM with an aerodynamic diameter less than or equal to 2.5 μm ($PM_{2.5}$), particulate matter with an aerodynamic diameter less than or equal to 10 μm (PM_{10}), and SO_2. In addition, miscellaneous sources are primary contributors to carbon monoxide (CO) and VOC emissions, which account for more than 50% of their respective total emissions. Highway vehicles are primary contributors to total NO_x emissions and secondary contributors to total CO emissions. Off-highway vehicles are secondary contributors to total NO_x and VOC emissions. In these counties, fuel combustion and industrial activities are minor contributors to any criteria pollutant and VOC emissions.

TABLE 3.15-1 Clean Air Act Prevention of Significant Deterioration Designations

Designation	Definition
Class I Area	Visibility is protected more stringently than under the NAAQS; includes national parks, wilderness areas, monuments, and other areas of special national and cultural significance.
Class II Area	Moderate change is allowed, but stringent air quality constraints are nevertheless desired.
Class III Area	Substantial industrial or other growth is allowed, and increases in concentration up to the national standards would be considered insignificant.

TABLE 3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011

	Annual Emissions (10^3 tons)[a]					
County/Facility	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2
Coconino	117.41	14.24	26.17	8.98	17.76	0.67
Mohave	48.77	12.79	10.97	2.55	12.65	0.13
Two-county total	166.19	27.03	37.13	11.52	30.41	0.80
Navajo Generating Station[b]	1.96	19.84	0.03	2.83	4.11	4.64

[a] CO = carbon monoxide; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤ 2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤ 10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

[b] The 2,250-MW coal-fired powerplant is located on the Navajo Indian Reservation near Page, Arizona, which is within Coconino County. Emissions from the Navajo Generating Station are not included in Coconino County emission totals.

Source: EPA (2013a).

Data on emissions from Tribal lands in Coconino and Mohave Counties are hard to find because the emission data are given in total emissions for Tribal lands which straddle many counties and even many states. One important point source within the area is the Navajo Generating Station, a 2,250-MW coal-fired powerplant located on the Navajo Indian Reservation near Page, Arizona (within Coconino County). NO_x emissions from this powerplant are about three-fourths of the two-county emissions combined, while SO_2 emissions are much larger (Table 3.15-2). There are three natural gas–fired powerplants in southwestern Mohave County but none in Coconino County.

3.15.2 Regional Air Quality

Changes in operations at Glen Canyon Dam can affect regional air quality if these changes result in corresponding increases or decreases in power generation at other facilities in the Western Interconnection grid. Under the CAA, the U.S. Environmental Protection Agency (EPA) has established the NAAQS for six criteria pollutants considered harmful to public health and the environment (40 CFR Part 50): SO_2, NO_2, CO, ozone (O_3), $PM_{2.5}$, PM_{10}, and lead (Pb) (EPA 2015a). Each state in this 11-state area can have its own State Ambient Air Quality Standards (SAAQS) for criteria pollutants. If a state has no standard corresponding to one of the NAAQS or a standard less stringent than NAAQS, the NAAQS apply. In addition, any state can establish standards for pollutants other than criteria pollutants. Several states have adopted standards for additional pollutants: visibility-reducing particles, sulfates, hydrogen sulfide (H_2S), and vinyl chloride for California; fluorides for Idaho; H_2S, settled PM, and fluoride in forage for Montana;

H_2S for Nevada; total suspended particulates, H_2S, and total reduced sulfur for New Mexico; particle fallout for Oregon; radionuclides and fluorides for Washington; and H_2S, suspended sulfates, fluorides, and odors for Wyoming.

Parts of the 11-state area have not yet attained the NAAQS for SO_2, 8-hour O_3, $PM_{2.5}$, PM_{10}, and Pb, as shown in Figure 3.15-1 (EPA 2015b). Currently, there are no nonattainment areas for NO_2 and CO in the United States, and thus in the 11-state area. Except for Washington, each state has one or more nonattainment areas. Arizona has nonattainment areas for all five air pollutants, while California and Montana have nonattainment areas for four air pollutants. In contrast, Washington has no nonattainment areas. Utah has nonattainment areas for three air pollutants. Three states (Idaho, Oregon, and Wyoming) have nonattainment areas for two air pollutants, while three states (Colorado, Nevada, and New Mexico) have nonattainment areas for one air pollutant. Nonattainment areas are mostly located in urban areas, except for the rural environment of the Upper Green River Basin in southwestern Wyoming, due to high wintertime ozone.

There are many regional air pollution problems such as O_3, acid deposition, and visibility degradation in the western United States. Ozone issues are most prevalent around urban centers, with the exception of elevated wintertime O_3 at higher elevations near oil and gas fields in Utah, Wyoming, and Colorado, where snow cover is prevalent. Impacts of acid deposition have been observed in the Desert Southwest, where excess nitrogen deposition facilitates invasion of nonnative grass species that compete with native plant species and increase fire risk due to increased biomass fuel loading. Acid deposition may also affect high-elevation lakes where excess nitrogen deposition can alter aquatic species composition. Visibility impairment is a widespread and pervasive problem throughout the country, and, in particular, in many national parks and wilderness areas where the CAA specifically requires visibility protection.

Visibility degradation is caused by cumulative emissions of air pollutants from a myriad of sources scattered over a wide geographical area. In general, the primary cause of visibility degradation is the scattering and absorption of light by fine particles, with a secondary contribution provided by gases. In general, visibility conditions in the western United States are substantially better than those in the eastern United States because of the higher pollutant loads and humidity levels in the East (EPA 2006). The typical visual range (defined as the farthest distance at which a large black object can be seen and recognized against the background sky) in most of the western United States is about 60 to 90 mi, while that in most of the eastern United States is about 15 to 30 mi. Most visibility degradation is associated with combustion-related sources, while fugitive dust sources contribute to some extent. In particular, smaller particles such as $PM_{2.5}$ scatter light more efficiently, which includes ammonium sulfate, ammonium nitrate, particulate organic matter, light-absorbing carbon (or soot), mineral fine soil, and sea salt. Ammonium sulfate and ammonium nitrate are formed by chemical reactions in the atmosphere that include emissions of SO_2 and NO_x, respectively. Particulate organic matter (POM) can be emitted directly from vegetation or can form in the atmosphere from a variety of gaseous organic compounds. At the GCNP, POM has the greatest impact on visibility, followed by ammonium sulfate (Hand et al. 2011).

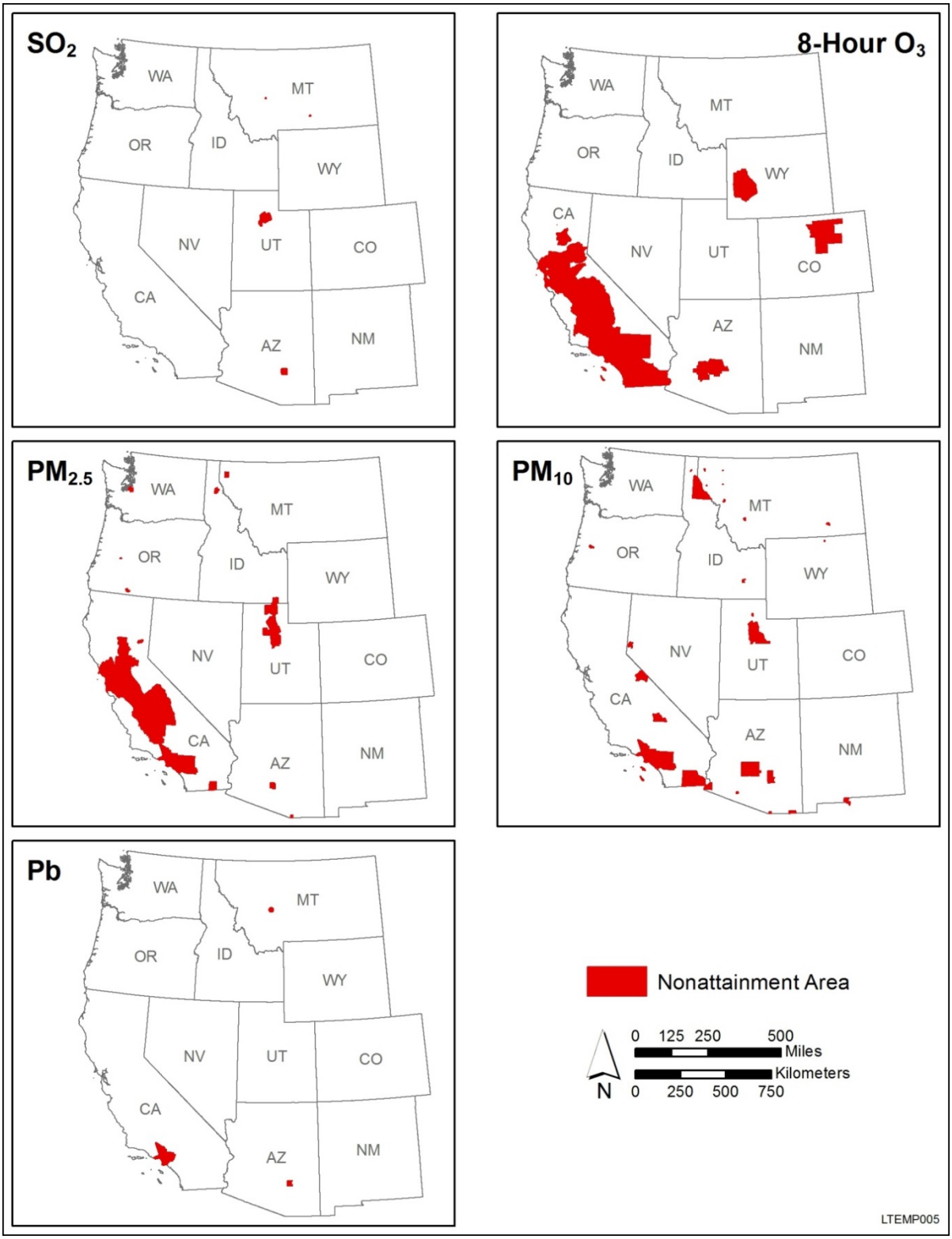

FIGURE 3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area (Note that currently there are no nonattainment areas for NO_2 and CO in the United States and thus in the 11-state area.) (Source: EPA 2015b)

Visibility was singled out for particular emphasis in the CAA Amendments (CAAA) of 1977. Visibility in a Class I area is protected under two sections of the CAAA. Section 165 provides for the PSD program (described in Section 3.15.2) for new sources. Section 169(A), for older sources, describes requirements for both reasonably attributable single sources and regional haze, which address multiple sources. Federal land managers have a particular responsibility to protect visibility in Class I areas. There are 158 mandatory federal Class I areas in the United States, and those in the 11-state area are illustrated in Figure 3.15-2 (EPA 2013b).

In 1999, the EPA issued the final Regional Haze Rule (64 FR 35714, July 1, 1999) which sets a national visibility goal for preventing future and remedying existing impairment to visibility in Class I areas. The rule is designed to reduce visibility impairment from existing sources and limit visibility impairment from new sources. States with Class I areas or states affecting visibility in Class I areas must revise their state implementation plans, prepare emission-reduction strategies to reduce regional haze, and establish glide paths for each Class I area. States are required to periodically review whether they are making reasonable progress toward meeting the goal of achieving natural conditions by 2064. Wildfires and windblown dust storms can significantly degrade visibility at Class I areas in the 11-state area. Emissions of SO_2 and NO_X from fossil fuel combustion are the major man-made causes of visibility impairment; these emissions have been substantially reduced in the 11-state area in the past decade in response to state and federal requirements (ARS 2013).

3.15.3 Regional Air Emissions

Table 3.15-3 presents statewide criteria pollutants and VOC emissions for the 11-state area within the Western Interconnection in 2011 (EPA 2013a). As discussed in Section 3.15.2, emission data are given in 13 source categories. Overall, miscellaneous sources are primary contributors to CO, $PM_{2.5}$, PM_{10}, and VOCs for the 11-state totals. Highway vehicles and fuel combustion for electricity generation are primary contributors to NO_x and SO_2, which account for about 45% and 41% of the 11-state total emissions, respectively. Among the 11 states in the region, all criteria pollutants and VOC emissions, except PM_{10} and SO_2, are highest in California. PM_{10} emissions are highest in New Mexico. SO_2 emissions are highest in Wyoming, which burns large quantities of fossil fuel (notably coal) for power generation and industrial activities. Total criteria pollutant and VOC emissions combined are highest in California followed by Arizona, and lowest in Nevada.

Table 3.15-3 also shows total statewide gross[13] GHG emissions on a consumption basis in terms of carbon dioxide equivalent (CO_2e).[14] GHG emissions for California are the highest at 453.1 million metric tons (MMt) (499.5 million tons) CO_2e, followed by Colorado, while those

[13] Excluding GHG emissions removed due to forestry and other land uses.

[14] The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs on the basis of their global warming potential (GWP), which is defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period. For example, GWP is 21 for CH_4, 310 for N_2O, and 23,900 for SF_6. Accordingly, CO_2e emissions are estimated by multiplying the mass of a gas by the GWP.

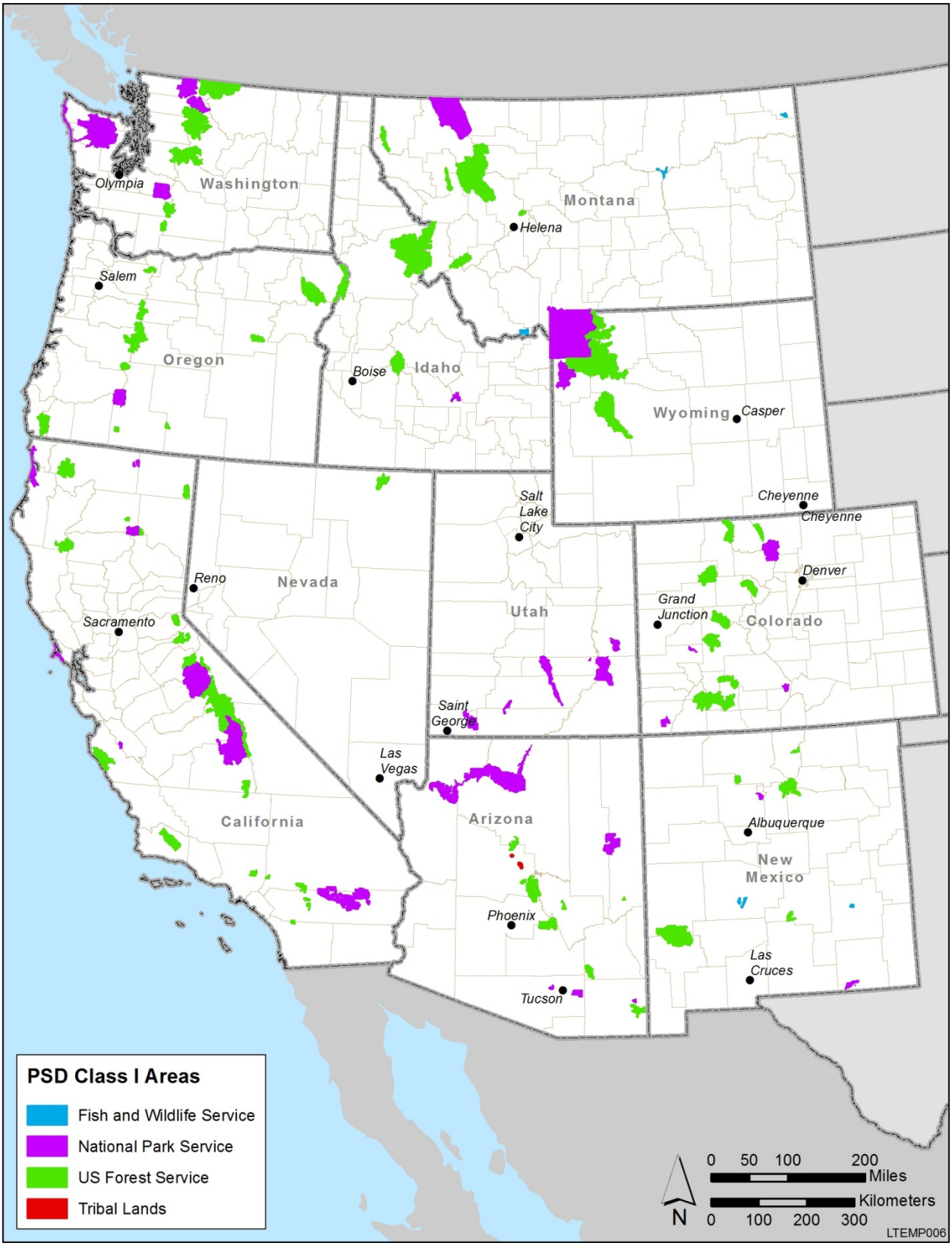

FIGURE 3.15-2 PSD Class I Areas in the 11-State Affected Area (Source: EPA 2013b)

TABLE 3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection

	Annual Emissions (10^3 tons; million metric tons for CO_2e)[a]						
State	CO	NO_x	VOCs	$PM_{2.5}$	PM_{10}	SO_2	CO_2e[b]
Arizona	2,357	251	508	178	405	77	116.6
California	3,674	736	836	208	475	36	453.1
Colorado	1,340	282	500	103	332	57	129.3
Idaho	1,111	98	258	116	431	14	39.6
Montana	1,321	119	342	141	437	29	38.5
Nevada	509	99	87	37	169	13	58.1
New Mexico	1,392	208	440	180	916	30	77.5
Oregon	2,285	161	495	183	372	30	74.7
Utah	595	185	241	39	184	28	75.7
Washington	1,648	278	307	92	249	30	103.0
Wyoming	1,106	196	296	130	483	80	60.3
11-State Total	17,338	2,614	4,311	1,407	4,454	425	1,226.4

a CO = carbon monoxide; CO_2e = carbon dioxide equivalent; NO_x = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of ≤2.5 μm; PM_{10} = particulate matter with an aerodynamic diameter of ≤10 μm; SO_2 = sulfur dioxide; and VOC = volatile organic compound.

b Total gross emissions on the consumption basis. To convert from metric ton to ton, multiply by 1.1023.

Sources: ADEQ (2006b); ARB (2014); Bailie et al. (2006), Bailie, Roe, et al. (2007); Bailie, Strait, et al. (2007); CCS (2007); EPA (2013a); NDEP (2008); ODEQ, ODOE, and ODOT (2013); Roe et al. (2007); Strait et al. (2007, 2008).

for Montana are the lowest at 38.5 MMt (42.4 million tons) CO_2e. Wyoming also produces a relatively large amount of CO_2e, but about one-third of the state's CO_2e emissions result from the production of electricity that is exported out of state. Total emissions from the 11-state area are about 1,226.4 MMt (1,351.9 million tons) CO_2e. This equates to about 18.0% of total GHG emissions in the United States during 2010, at 6,810.3 MMt (7,507.0 million tons) CO_2e (EPA 2013c).

3.16 CLIMATE CHANGE

Climate change may affect resources that are also affected by LTEMP alternatives. As explained in the air quality discussion (Section 3.15), changes in operations at Glen Canyon Dam have the potential to alter emissions from other sources of electricity, sources that can produce more GHGs than hydroelectric power. Glen Canyon dam reduces CO_2 emissions by about 1.4 to 3.5 MMt (1.5–3.9 million tons) in an average year (EPA 2014a; Reclamation 2015), which

equates to about 0.11 to 0.29% of 11-state total emission. Climate change is also predicted to affect climate and hydrology in the region, which could affect resources in the project area.

As discussed above, dam operations can affect air quality, including the concentration of GHGs in the atmosphere. GHGs are transparent to incoming short-wave radiation from the sun but opaque to outgoing long-wave (infrared) radiation from the earth's surface. The net effect over time is a trapping of absorbed radiation and a tendency to warm the earth's atmosphere, which together constitute the "greenhouse effect." The principal GHGs that enter the atmosphere due to human activities, including fossil fuel power generation, include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Some GHGs such as CO_2, CH_4, and N_2O occur naturally and are emitted to the atmosphere through natural processes as well.

In the arid/semiarid western states, climate change is already having serious consequences on the region's scarce water supplies; this particularly applies to the snow that makes up most of the region's precipitation and that, when melted, provides 70% of its water. To date, decreases in snowpack, less snowfall, earlier snowmelt, more winter rain events, increased peak winter flows, and reduced summer flows have been documented (Saunders et al. 2008). Another potential effect of climate change is that more dust will be produced as vegetative cover decreases and as soils become dry (Mormon 2010). It is widely understood that impurities in snow, such as dust or soot, decrease snow albedo[15] and enhance solar radiation absorption and melt rates. Dust may shorten snow-cover duration by as much as a month (Painter et al. 2007). Earlier spring snowmelt and higher spring/summer temperatures have broad implications with regard to water resources in southwestern states that are already strapped for water, especially during the summer when peak demand is higher, and these factors also lead to increased numbers of forest fires (USGCRP 2014). It is likely that most dust on snowpack at high mountains is coming both from nearby lands where soil-disturbing activity has made the land susceptible to wind erosion and dust from the deserts of Colorado Plateau along with prevailing westerlies, and to dust from other southwestern deserts to some extent. Activities such as exploration and development of energy resources, offroad vehicle use, agriculture, and grazing serve to destabilize soils, making them more susceptible to wind erosion (Belnap et al. 2009).

In December 2012, Reclamation and agencies representing the seven Colorado River Basin States completed the Colorado River Basin Water Supply and Demand Study (Reclamation 2012e). The purpose of the Study was to define future imbalances in water supply and demand in the Basin through the year 2060, and to develop and analyze options and strategies to resolve those imbalances. The study used several different scenarios for both supply and demand to capture a range in potential future conditions. The supply conditions included the downscaled general circulation model (GCM) projected trends and variability (downscaled GCM) scenario. This scenario was developed as one plausible projection of the future based on recent studies of future changes in climate variability and climate trends, and their influence on streamflow and Basin water supply, which indicate that the climate will continue to warm, and

15 The fraction of solar radiation reflected from an object or surface, often expressed as a percentage.

that there will be corresponding changes in regional precipitation and temperature trends beyond what has occurred historically. Comparing the median of the water supply projections against the median of the water demand projections, the long-term projected imbalance in future supply and demand is about 3.2 million ac-ft by 2060 (Figure 3.16-1).

Another key Reclamation document that provides information regarding climate change is the 2011 SECURE Water Act Report (Reclamation 2011e). It identifies climate challenges the Colorado River Basin could likely face:

- On average, Colorado River Basin temperature is projected to increase by 5 to 6°F during the 21st century, with slightly larger increases projected in the upper Colorado Basin.
- Precipitation is projected to increase by 2.1% in the upper basin while declining by 1.6% in the lower basin by 2050.
- Mean annual runoff is projected to decrease by 3.5 to 8.5% by 2050.
- Warmer conditions will likely transition snowfall to rainfall, producing more December to March runoff and less April to July runoff.

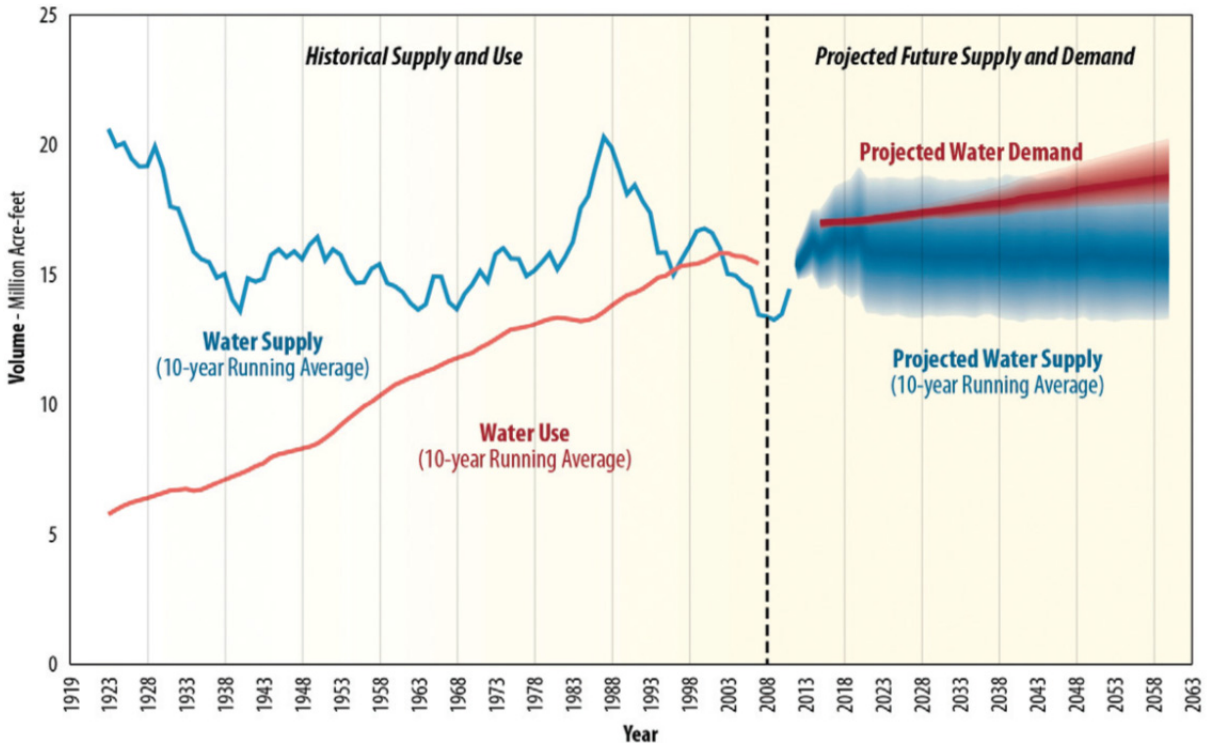

FIGURE 3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand (medians of projections are indicated by the darker shading) (Source: Reclamation 2012e)

Historical and projected climate changes have potential impacts for the basin:

- Spring and early summer runoff reductions could translate to a drop in water supply for meeting irrigation demands, resulting in lower reservoir levels, which adversely impact energy production from hydropower operations at the Glen Canyon Dam.

- Increased winter runoff may require infrastructure modification or flood control rule changes to preserve flood protection, which could further reduce warm-season water supplies.

- Warmer conditions might cause changes in fisheries habitat, shifts in species geographic ranges, increased water demands for instream ecosystems and thermoelectric power production, increased power demands for municipal uses (including cooling), and increased likelihood of invasive species infestations. Endangered species issues might be exacerbated.

The extent to which climate change could affect future water supply is considered in the hydrology modeling for the proposed action and all alternatives. See Section 3.2.1 for an explanation of the methodology for hydrology modeling.

Although no studies specifically evaluate the potential effects of climate change on Lake Powell or the Colorado River between Lake Powell and Lake Mead, decreases in Lake Powell elevation and corresponding increases in temperatures of water releases from Glen Canyon Dam and in water temperature of the Colorado River downstream (as well as to tributaries of the Colorado River) are important potential effects of climate change on the project area. Projections of future supply and demand in the basin indicate that inflows into Lake Powell may decrease, and the effect of climate change is likely to exacerbate this effect (Reclamation 2012e). Climate-induced changes in inflow, evaporation, and evapotranspiration all have the potential to influence water quality. For example, increased temperatures will increase metabolic rates of aquatic biota, increasing the demand for nutrients and oxygen, and potentially changing the quality of habitat for various organisms (Wrona et al. 2006; Heino et al. 2009; Woodward et al. 2010). Increases in the water temperature of the Colorado River mainstem and its tributaries in the Grand Canyon due to climate change could expand the distribution of warmwater-adapted nonnative fishes (Eaton and Scheller 1996; Rahel and Olden 2008), which can prey on and compete with native fishes such as endangered humpback chub or disadvantaged coldwater nonnative species. Climate-change-driven warmer water temperatures across the contiguous United States are predicted to expand the distribution of existing aquatic nonnative species by providing 31% more suitable habitat for aquatic nonnative species, based upon studies that compared the thermal tolerances of 57 fish species with predictions made from climate change temperature models (Mohseni et al. 2003). Climate change also may facilitate expansion of nonnative parasites such as Asian tapeworm (Rahel et al. 2008), another threat to native fishes such as humpback chub. Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have so far prevented these warmwater fishes and parasites from expanding their distribution in the project area. Warmer climate trends could result in warmer

overall water temperatures, increasing the prevalence of these species and threating native fish populations.

Climate change effects on Lake Powell's elevation could also affect the amount of electric energy produced by the Glen Canyon Dam Powerplant over the study period, as well as the electric capacity of the Glen Canyon Dam. The hydraulic head (water pressure) on the turbines in the Glen Canyon Dam Powerplant is directly proportional to the elevation in Lake Powell. Thus, when Lake Powell's elevation drops, the amount of hydropower generated by a given release volume also decreases. Ultimately, if Lake Powell drops low enough, no power can be produced at Glen Canyon Dam (at a Lake Powell elevation of 3,490 ft).

In addition to water temperature, other aspects of water quality are also affected by Lake Powell's elevation. Dissolved oxygen concentrations in the tailwater are usually slightly below saturation but have not dropped to concentrations low enough to affect the aquatic ecosystem in the Grand Canyon. However, climate-change driven decreases in the elevation of Lake Powell could increase the chances of water that is low in DO being released from Glen Canyon Dam (Vernieu et al. 2005). Low DO in the tailwater could adversely affect the rainbow trout fishery in Glen Canyon. Similarly, an increase in water temperatures of the Colorado River driven by climate change could cause low levels of DO in Lake Mead that could adversely affect native and nonnative fish (Tietjen 2014).

Climate change could have mixed effects on sediment supply and retention in the Colorado River in the project area. For example, reduced precipitation under climate change could lower sediment input from tributaries to the mainstem of the Colorado River. In addition, higher variability in flows under climate change may require higher flows in equalization years, which could lead to a large erosive effect. Conversely, lower average flows in the Colorado River could positively affect overall sediment retention.

4 ENVIRONMENTAL CONSEQUENCES

Environmental effects are analyzed for resources that could be affected by the proposed action, to adopt and implement an LTEMP for Glen Canyon Dam over the next 20 years. The affected resources are described in Chapter 3. Affected natural resources include water, sediment, aquatic ecology, vegetation, wildlife, special status species, and air quality. Affected socioeconomic resources include cultural resources, visual resources, recreational resources, wilderness, park management and operations, hydropower, regional socioeconomics, resources of importance to Indian Tribes, and environmental justice.

Six action alternatives are compared to the No Action Alternative (Alternative A), which describes how the dam is currently operated. Operations under Alternative A employ a release pattern established in the 1996 Record of Decision (ROD) (Reclamation 1996) associated with the 1995 EIS on operations of Glen Canyon Dam (Reclamation 1995). This operational release pattern, referred to as Modified Low Fluctuating Flows (MLFFs), moderated the releases relative to operations practiced in the 1960s through 1980s. As described in Chapter 2, Alternative A also includes various practices and operational decisions that have been established since the 1996 ROD.

The effects of alternatives result primarily from the patterns of water release from Glen Canyon Dam that are characteristic of each alternative. Monthly, daily, and hourly release rates directly and primarily affect flows and sediment distribution in the river channel and corridor, as well as intraannual water levels in Lake Powell and Lake Mead. These primary effects drive secondary effects on aquatic and terrestrial resources, historic properties, Tribal resources and values, and recreational resources. Hydropower generation and capacity are additional primary effects of release patterns, particularly the ability to adjust releases in response to changes in the demand for electric power. Alternatives also include non-flow actions such as mechanical trout removal and vegetation treatments, which would be undertaken as part of the alternative.

In the following sections, the effects of the alternatives are presented for each resource. Discussions begin with an identification of the resource issues being analyzed and a description of the indicators that are evaluated to assess the related issues. The analysis methodology is presented next, describing both the quantitative and qualitative methods used to assess effects. A summary of effects follows, focusing on the general effects of various flow conditions on resource indicators. An alternative-specific analysis is then presented wherein the effects of the various alternatives are presented individually and compared. Finally, in Section 4.17, an analysis is presented of the cumulative impacts of the alternatives on resources in combination with other past, present, and reasonably foreseeable future actions.

4.1 OVERALL ANALYSIS AND ASSESSMENT APPROACH

Operational characteristics and experimental actions of each alternative are likely to affect resources in different ways. These environmental effects were modeled using historically observed resource responses to flow conditions and relationships derived from experimental

results obtained since dam operations were last reviewed in 1995. Information sources used for this analysis included a large quantity of observational and research data collected since the start of dam operations and resulting from research programs originating under the Glen Canyon Adaptive Management Program (GCDAMP) established under the 1996 ROD and carried out by the Grand Canyon Monitoring and Research Center (GCMRC) and other researchers. The geographic region of interest and the topics and issues analyzed as determined from project scoping are described in Section 1.5.

The quantitative analyses in this chapter employed an integrated multiple-resource modeling framework that incorporated a series of linked models that explicitly account for the effects of dam operations and the linkages among resources. The discussion of effects by resource acknowledges these linkages under a common conceptual model. This conceptual model is central to the construction of the LTEMP alternatives as described in Chapter 2. The modeling approach used for this Environmental Impact Statement (EIS) is presented in technical appendices provided in this EIS.

Responses of resources to operations and non-flow actions were predicted using linked models (e.g., reservoir operations model, hydropower operations models, sand budget model, and others, as depicted in Figure 4-1). The magnitude of effects was estimated using quantifiable metrics for indicators of the condition of a resource. The environmental effects of alternatives are compared quantitatively whenever possible, on the basis of the estimated effect on resource condition as measured by a set of resource metrics (see Appendix B for details); these quantitative predictions are supported when possible by published observations and findings. Note that the models used here are mainly intended to allow for relative comparisons among alternatives and not necessarily to be predicitive.

The Department of the Interior (DOI) considered an adaptive management approach when developing its models. This included, but was not limited to, developing models for use in a Structured Decision Analysis (see Appendix C for a full description). Because several of the alternatives use a condition or information-dependent approach to experimentation that would adapt to new information gathered as the alternative is implemented (e.g., Alternatives B, C, D, and E), we developed a set of "long-term strategies" that represented possible ways the alternative might be implemented if uncertainties were resolved. With this approach, we established versions of these alternatives (the long-term strategies) that implemented subsets of the proposed experiments being considered in the alternative. Because there are many possible combinations of experiments within any alternative, we chose sets that would be representative of certain conditions related to uncertainties; there were 19 of these long-term strategies (Table 4.1-1). For example, if under Alternative D the effect of trout on humpback chub was determined to be more important than temperature, and trout management flows (TMFs) proved to be effective at controlling trout numbers, a long-term strategy that included spring and fall high-flow experiments (HFEs) and TMFs would be implemented. Under this scenario, there would be no need for low summer flows to warm water for chub. Long-term strategy D4 represents this scenario. A benefit of the long-term strategies approach is that it allowed for analysis of the combinations of various alternative-specific condition-dependent flow and non-flow actions that would occur if uncertainties were resolved through experimentation and learning. Thus, each long-term strategy represented a possible future implementation of actions

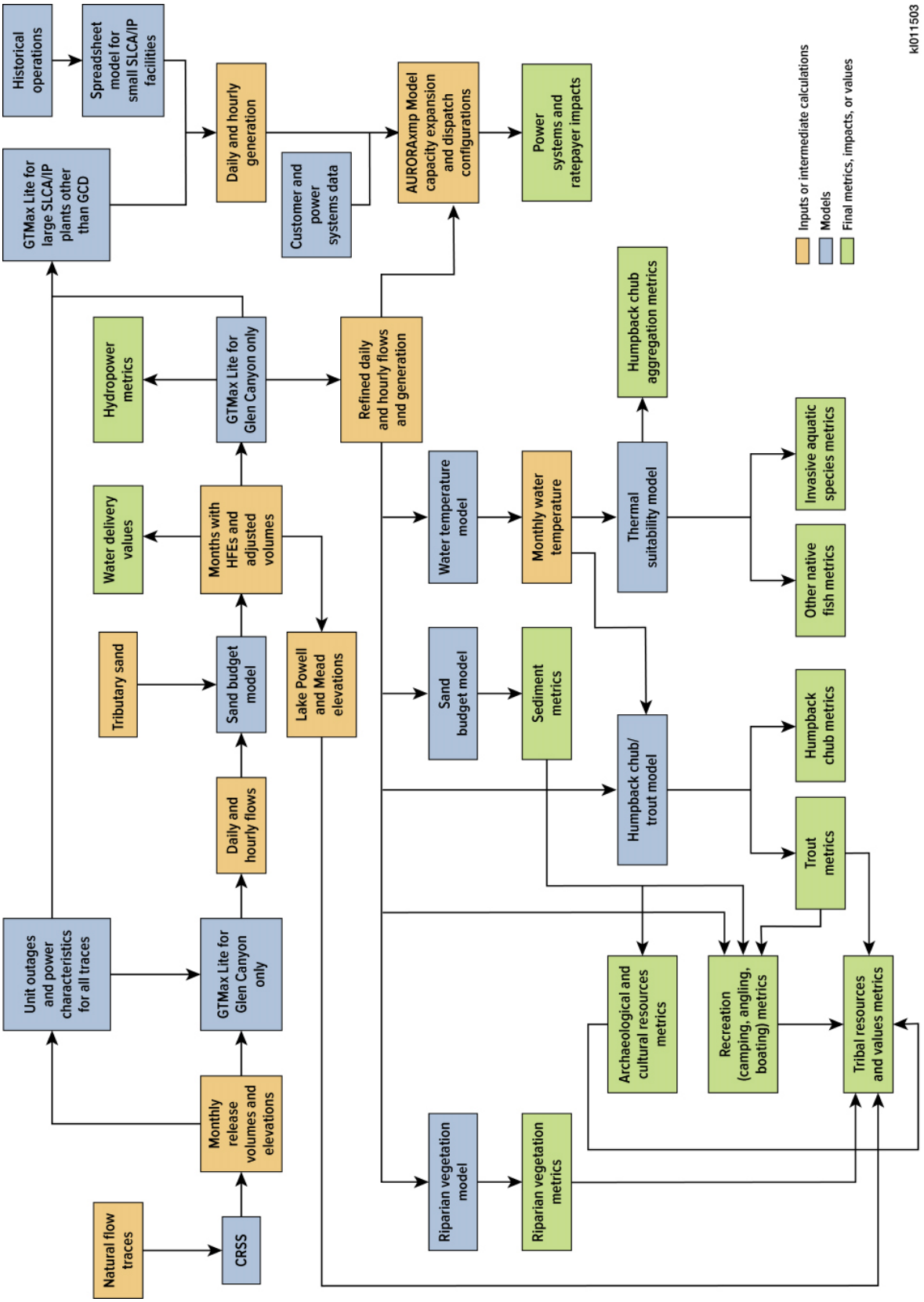

FIGURE 4-1 Integrated Multiple-Resource Modeling Framework Showing Inputs, Intermediate Calculations, and Output

TABLE 4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative (Letters depict alternative, numbers depict long-term strategy.)

	Alternative and Associated Long-Term Strategy[a]																		
Experimental Element	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
Spring HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	N	Y[d]	Y[d]	Y[d]	Y[d]	Y[e]	Y[e]	N	N	N	N	Y	Y
Fall HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y
Spring proactive HFE	N	N	N	Y[f]	Y[f]	N	N	Y[f]	Y[f]	Y[f]	Y[f]	N	N	N	N	N	N	N	Y[f]
Extended-duration HFE	N	N	N	Y[g]	Y[g]	N	Y[g]	Y[h]	Y[h]	Y[h]	Y[h]	N	N	N	N	N	N	N	Y[i]
Load-following curtailment (steady flows)	N	N	N	Y[j]	Y[j]	N	Y[j]	N[k]	N[k]	N[k]	N[k]	Y[l]	Y[l]	N	Y[l]	N	N	N	N
Low summer flows	N	N	N	N	Y[m]	N	N	Y[n]	Y[n]	Y[n]	N	N	Y[o]	N	N	Y[o]	N	N	N
Macroinvertebrate production flows	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Mechanical trout removal	Y[b]	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	Y
Trout management flows	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y
Hydropower improvement flows	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

[a] Y = element included; N = element not included. Long-term strategies that include the element are shaded gray.

[b] Activity ends after 2020.

[c] Not to exceed one HFE (spring and fall) every other year.

[d] Not to occur in first 2 years of LTEMP. Would not be conducted in the same water year as an extended-duration fall HFE.

[e] Not to occur in first 10 years of LTEMP.

[f] Triggered in years with annual release volume ≥10 maf. Not implemented in the same water year as a sediment-triggered spring HFE or an extended-duration fall HFE.

[g] Volume limited to that of a 96-hr, 45,000-cfs release.

[h] Fall only, limited to four HFEs up to 250 hr if sediment will support, first implementation limited to 192 hr.

[i] Spring and fall HFEs, no limit in number, up to 336 hr long if sediment will support.

[j] Before and after spring and fall HFEs.

[k] This experiment was dropped from Alternative D in the Final EIS based on comments on the Draft EIS from stakeholders and GCMRC. GCMRC scientists indicated that the effects of this experiment could be too small to measure with current monitoring methods. The potential importance of load-following curtailment is also expected to be small because, under current practice, the volume of released water and fluctuations are reduced in the remaining days of the month in which HFEs occur to compensate for the large volume released during the HFE.

[l] Before fall HFEs only.

[m] Target 13°C.

[n] Target 14°C, second 10 years only.

[o] Target 16°C, second 10 years only.

under the overall constraints of each alternative. Not all possible combinations were evaluated; instead, a set of long-term strategies that represented the expected range of combined flow and non-flow actions were chosen for analysis. These combinations allowed for examination of the effects of specific experiments when they were included in a long-term strategy. This approach is described more fully in Appendix C.

To facilitate comparisons of alternatives in the text, we chose a single-long-term strategy for each alternative—A, B1, C1, D4, E1, F, and G. Long-term strategies C1, D4, and E1 were chosen because they included a comparable set of experimental elements (spring and fall HFEs and TMFs). Long-term strategy B1 was chosen because it did not include hydropower improvement flows, and was thus comparable to other long-term strategies. The analytical results for the full suite of long-term strategies enabled a determination of the effects of experiments, and these effects are described in the individual resource sections of this chapter. The quantitative results for all 19 long-term strategies are presented in Appendix C and the resource-specific Appendices E, F, G, H, I, and J.

For those resource metrics that could be modeled quantitatively, a range of potential hydrologic conditions and sediment conditions were modeled for a 20-year period that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell inflow scenarios (known as hydrology traces) for the 20-year LTEMP were sampled from the 105-year historic record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth sequence of 20 years. Using this approach, the first 20-year period considered was 1906–1925, the second was 1911–1930, and so forth. As the start of traces reach the end of the historic record, the years needed to complete a 20-year period are obtained by wrapping back to the beginning of the historical record. For instance, the trace beginning in 1996 consists of the years 1996–2010 and 1906–1910, in that order. This method produced 21 hydrology traces for analysis that represented a range of possible traces from dry to wet. Although these hydrology traces represent the range of hydrologic conditions that occurred during the period of record, they may not fully capture the driest years that could occur with climate change (see Section 4.17).

In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record (water years 1964 to 2013) were analyzed that represented low (water years 1982 to 2001), medium (water year 1996 to 1965), and high (water years 2012 to 1981) amounts of sediment. In combination, the 21 hydrology traces and three sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions.

Models depicted in Figure 4-1 were used to generate resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. The values generated represent a range of possible outcomes that in many cases were graphed using box-and-whisker plots (Figure 4-2), which show the full distribution of values obtained as characterized by the minimum, maximum, mean (average of all values), median (50% of the values are less than this value), 25th percentile (25% of the values are less than this value), and 75th percentile (75% of the values are less than this value).

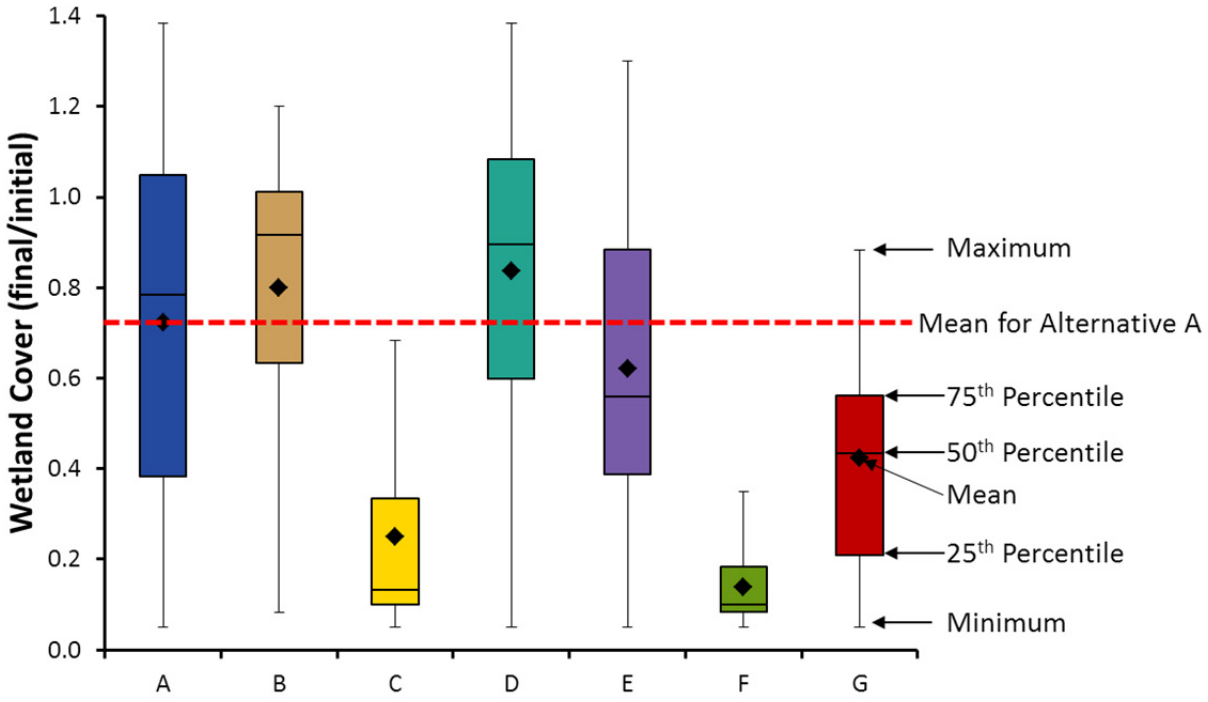

FIGURE 4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values

Some resources or environmental attributes do not lend themselves to quantification because there are insufficient data or understanding to support development of a model. In these cases, the assessment presented in this chapter includes qualitative assessments of the likely impacts on these resources and attributes. Qualitative analysis was particularly important for effects related to personal and cultural values, as well as for an assessment of impacts on resources not directly affected by river flow. In all cases, multiple lines of evidence, including consultation with subject matter experts, were used to assess impacts on resources.

The analytical results presented in this chapter represent, in part, the results of integrated multiple-resource modeling completed in March 2015. After this modeling was completed, several adjustments were made to specific operational and experimental characteristics of Alternative D (the preferred alternative) based on discussions with Cooperating Agencies and stakeholders. These adjustments included (1) an increase in release volume in August with corresponding decreases in May and June (in an 8.23-maf year, the increase was 50 kaf in August, i.e., from 750 to 800 kaf; and a reduction of 25 kaf each in May and June; these changes were applied proportionally to monthly volumes in drier and wetter years); (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE—previously, it lasted from the HFE until December 1, but after the adjustment it lasts from the HFE until the end of the month in which the HFE occurred; and (4) a prohibition on sediment-triggered spring HFEs in the same water year as an extended-duration fall HFE. Adjustments made to Alternative D after the Draft EIS (DEIS) was published, and based on comments received from Cooperating Agencies and

stakeholders on the DEIS, included (1) elimination of load-following curtailment after a fall HFE and (2) a prohibition on proactive spring HFEs in the same water year as an extended-duration fall HFE. The description of Alternative D provided in Section 2.2.4 represents the final version of the alternative that resulted from these changes.

Once the adjustments to Alternative D were made, analyzing them using multiple-resource modeling would have taken many months and incurred significant additional cost. Therefore, instead of performing multiple-resource modeling on the effects of these adjustments, the joint-leads chose to perform streamlined modeling using the screening tool (described in Section 2.1) and additional analysis to assess the magnitude and direction of these effects of the adjustments. As described in the following paragraphs, for most resources, these adjustments to Alternative D are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D. However, the streamlined analysis did show that the adjustments could result in some changes to the expected impacts on sediment and hydropower resources, and that for all resources but hydropower these changes would not affect the relative performance of Alternative D compared to other alternatives. Because the adjustments to Alternative D would not change Alternative D's relative performance for most resources, and the changes to hydropower impacts would be reductions in impact rather than increases, the agencies chose not to perform additional multiple-resource modeling. In addition to presenting the original multiple-resource modeling results, the results of the streamlined modeling evaluating the effects of these adjustments on sediment and hydropower are presented in Sections 4.3.3.4 and 4.13.3.4, respectively. Because, for resources other than sediment and hydropower, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D, the only quantitative analysis results presented in those sections of the EIS are those from the original multiple-resource modeling.

Modeling of the effects of load-following curtailment determined that this experimental treatment would have a very small effect on sediment resources, the intended beneficiary of this treatment. Modeling indicated that there would be a very small effect of load-following curtailment on the sand load index (a measure of sandbar-building potential; see Section 4.3.1 for a description) immediately following the treatment, but that any difference in this index between HFEs with and without load-following curtailment would disappear by the end of the water year (see Section E.3.5 of Appendix E). In addition, the treatment had a small effect on sediment mass balance (estimated conservation of about 9,000 metric tons, or 0.04%, of the average annual sediment input from the Paria River). This decrease would represent a 0.6% decrease in the sand mass balance index (a measure of the amount of sand retained in the Marble Canyon reach of the Colorado River; see Section 4.3.1 for a description of the index). GCMRC scientists indicated that the effects of this experiment could be too small to measure with current monitoring methods. The potential importance of load-following curtailment is also expected to be small because, under current practice, the volume of released water and fluctuations are reduced in the remaining days of the month in which HFEs occur to compensate for the large volume released during the HFE.

Since load-following curtailment has an adverse effect on hydropower generation, the value of generation without this experiment is expected to be slightly higher than with the experiment (i.e., impacts on hydropower would be reduced under the revised Alternative D). Streamlined modeling using the screening tool indicated that, without load-following curtailment, there would be a reduction in the NPV of the cost of Alternative D of about $4.0 million. This adjustment would have no effect on hydropower capacity because August release volume, from which capacity is estimated, would be unaffected. The impacts of this change on all other resources are expected to be negligible.

Prohibition of sediment-triggered and proactive spring HFEs after extended-duration fall HFEs is expected to have relatively little effect on the impact of Alternative D because of the relatively low probability of these combinations being triggered in any water year. Without the prohibition, an average of 5.2 sediment-triggered spring HFEs and 1.6 proactive spring HFEs would occur over the 20-year LTEMP period. With the prohibition, there would be 4.1 sediment-triggered spring HFEs (1.1 fewer) and 1.4 proactive spring HFEs (0.2 fewer). In total, this prohibition on spring HFEs after an extended-duration fall HFE would result in an average of 1.3 fewer HFEs over the LTEMP period, and a potential slight reduction in sandbar building potential (sand load index) and slight increase in sand mass balance. The slight reduction in the number of HFEs would reduce the cost of the alternative on hydropower generation by about $2.1 million in a 20-year period, based on the average cost of an HFE of $1.64 million presented in Section 4.13.2.3. The impacts of this change on all other resources are expected to be negligible.

The change in August volume in an 8.23-maf year from 750 to 800 kaf, with proportional adjustments in drier and wetter years, is expected to have relatively minor effects and potentially undetectable changes on most downstream resources because the change in mean daily flow would be small (about an 800 cfs increase in August and a 400 cfs decrease in May and June, when volumes would be reduced by 25 kaf in each month to offset the increase in August volume), and the adjusted August monthly volume is below the 900 kaf of Alternative A (the no-action alternative). This adjustment in monthly volumes could, however, affect the alternative's impacts on hydropower and sediment resources. As estimated using the screening tool, the adjustments in monthly volume are expected to reduce the NPV of the cost of generation and capacity by about $5.3 million and $27.6 million, respectively, over the 20-year period. The effect on sediment would be a slight increase in sediment transport (about 1.2%), resulting in a lower SLI and a lower sand mass balance index. For resources other than sediment and hydropower, these adjustments are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D.

Note that the technical appendices of the EIS describe the original modeling results developed before Alternative D adjustments were made, and do not discuss the effects these adjustments would have on anticipated impacts.

4.2 WATER RESOURCES

This section presents an analysis of impacts on water resources of the Colorado River between Glen Canyon Dam and Lake Mead, and in Lake Powell and Lake Mead. This section is organized into two broad topics—hydrology and water quality. The hydrology section encompasses those topics related to the pattern and volume of monthly, daily, and hourly releases from Lake Powell. The water quality section relates to non-flow characteristics of the water, including temperature, salinity, dissolved oxygen (DO), turbidity, nutrients, metals, organics, and bacteria and other pathogens. Analysis methods, a summary of impacts, and alternative-specific impacts are presented in Sections 4.2.1, 4.2.2, and 4.2.3, respectively.

Issue: How do the alternatives affect water resources in the project area?

Impact Indicators:

- Lake Powell releases (annual, monthly, daily, and hourly)
- Lake Powell and Lake Mead reservoir elevations
- Lake Powell annual Operating Tier and Lake Mead operating conditions
- Monthly, hourly, and daily patterns in Colorado River flows downstream of Glen Canyon Dam

The water resources objective was developed to ensure the LTEMP does not affect fulfillment of water delivery obligations to the communities and agriculture that depend on Colorado River water and remains consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC) for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

A primary aspect of reservoir operations that potentially affects water resources is related to the monthly distribution of the Lake Powell annual release volume and its resulting impact on reservoir elevations, operating tiers, and annual release volumes. Changes to monthly release volumes have the potential to, in critical time periods, affect reservoir elevations for operating tier determinations, which could in rare circumstances affect annual release volumes. The impact analysis for water resources reflects the 20-year LTEMP period, which, for modeling purposes, was from October 1, 2013, to September 30, 2033. Analyses of the alternatives have been performed in order to avoid changes in annual volume releases and thereby ensure operations are consistent with the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines.

Quantitative analysis of the effects of reservoir operations was performed using Reclamation's official basin-wide long-term planning model, Colorado River Simulation System (CRSS). Model results provide a range of potential future system conditions such as reservoir releases and storage, as well as operating tiers for Lake Powell and Lake Mead.

4.2.1 Analysis Methods

4.2.1.1 Hydrology

Annual and Monthly Operations

Modeling of the Colorado River system was conducted to determine whether there were potential effects of LTEMP alternatives on annual and monthly operations on Colorado River system conditions (e.g., reservoir elevations, reservoir releases, and river flows) as compared to Alternative A (the No Action Alternative). Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each alternative in order to quantify the uncertainties in future conditions, and the modeling results are expressed in probabilistic terms.

Future Colorado River system conditions under the LTEMP alternatives were simulated using CRSS. The model framework used for this process is the commercial software RiverWare™ (Zagona et al. 2001), a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers. CRSS was originally developed by Reclamation in the early 1970s, was converted to RiverWare™ in 1996, and has been used as Reclamation's primary Colorado River Basin–wide planning model since that time. Previous studies that used CRSS include the 1996 Glen Canyon Operations EIS (Reclamation 1995), the 2007 Interim Guidelines EIS (Reclamation 2007a), and the Colorado River Basin Water Supply and Demand Study, referred to as the Basin Study (Reclamation 2012a).

CRSS simulates the operation of 12 major reservoirs on the Colorado River system and provides information regarding the projected future state of the system on a monthly basis; the model simulates the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and diversions to and return flows from water users throughout the system. The basis of the simulation is a mass balance (or water budget) calculation that accounts for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, and evaporation), and water moving through the system (e.g., either stored in reservoirs or flowing in river reaches). Further explanation of the model is provided in Appendix D. CRSS was used to project the future conditions of the Colorado River system for the 20-year LTEMP period, which for modeling purposes was water years 2013 through 2033.[1]

The input data for the model includes monthly natural inflows; various physical process parameters such as the evaporation rates for each reservoir; initial reservoir conditions on

[1] The water year is defined as October 1 through September 30 of the following calendar year.

January 1, 2013[2]; and the future projected diversion and depletion schedules for entities in the seven Basin States (Appendix D) and for Mexico. These future schedules are based on demand and depletion projections prepared and submitted by the Basin States for the Basin Study, and assume the Current Projected demand scenario (Schedule A) from the Basin Study. For purposes of this EIS, depletions (or water consumptive uses) are defined as diversions from the river less return flows.

For each alternative, the rules of operation of the Colorado River mainstem reservoirs, including Lake Powell and Lake Mead, were developed as input to the model. These sets of operating rules describe how water would be released and delivered under various hydrologic conditions. In the modeling of all alternatives, the operations of Lake Powell and Lake Mead are assumed to revert back in 2027 to the assumptions used to represent the No Action Alternative in the 2007 Interim Guidelines. Because CRSS is a monthly model, reservoir operations at sub-monthly intervals (e.g., daily release fluctuations, ramp rates, HFEs, and TMFs) were not explicitly modeled in CRSS, but they were modeled using other modeling software. Further explanation of the operating rules for each alternative is provided in Section 2.2.

Long-term planning models, such as CRSS, are typically used to project future river and reservoir conditions over a period of years or decades into the future. There are numerous inputs to, and assumptions made by, these models. As the period of analysis increases (for this EIS the analysis period is 20 years), the uncertainty in those inputs and assumptions also increases. Consequently, these models are not used to predict future river and reservoir conditions, but rather to project the range of possible effects. When analyzing the potential hydrologic impacts from operational alternatives, most inputs, as well as other key modeling assumptions, are held constant for each alternative to isolate the differences due to each alternative. In this manner, the analyses for each alternative may be compared, and thus a relative comparison of the impacts of alternatives can be made.

Uncertainties in CRSS output are due to assumptions in input, including parameterization of physical processes such as reservoir evaporation and bank storage, the future diversion and depletion schedules for the entities throughout the Colorado River Basin, and the future inflows into the system. In addition, much of the input data are derived from actual measurements that have uncertainties associated with them. For example, natural flows (i.e., those flows that would occur in the absence of dams, reservoirs, diversions, and withdrawals) are partially based on data acquired from streamflow gages, which, when calibrated properly, have uncertainties of about 5 to 10%. Although these data are generally the best available, all of these uncertainties limit the absolute accuracy of the model. However, by holding most inputs constant, the relative comparisons among modeled conditions are still valid.

Despite the differences in the LTEMP alternatives, the future conditions of the Colorado River system (e.g., future Lake Mead and Lake Powell elevations) are most sensitive to future

[2] Initial reservoir conditions as of January 1, 2013, were used in conjunction with the CRSS modeling, which started at the beginning of water year 2013 (October 1, 2012). However, since the hydrology is not intended to be predictive of conditions in a given year, but rather to show how the alternatives vary in response to a variety of hydrological conditions, the actual starting year does not affect the relative comparison of alternatives.

inflows. Observations over the period of historical record (1906 through 2010) show that inflow into the system has been highly variable from year to year and over decades. Because it is impossible to predict the actual future inflows for the next 20 years, a range of possible future inflows are analyzed and used to quantify the probability of occurrences of particular events (e.g., higher or lower reservoir elevations). This technique, performed for the hydrologic analysis presented here, involves multiple simulations for each alternative, one for each future hydrologic sequence.

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-year period from 1906 through 2010 from 29 individual inflow points (or nodes) on the system. The locations of the inflow nodes are described in Appendix D.

Typically, CRSS is run with the full suite of available natural flow traces created using a resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997). Using the ISM on a 105-year record (1906–2010) results in 105 inflow traces (i.e., plausible inflow sequences). For this EIS, every fifth trace from the 105 natural flow traces was selected, resulting in 21 traces that are considered representative of the full period of record (Appendix D). For the climate change analysis described in Section 4.26, CRSS was run with 112 natural flow traces developed from downscaled general circulation model projected hydrologic traces (Reclamation 2011f).

As shown in Figure 4-1, a full set of resource models was used to analyze resource impacts, and CRSS output served as input for most of these models. Reservoir operations under each alternative were explicitly modeled in CRSS. Each alternative was modeled in CRSS with 21 different potential hydrology scenarios to account for uncertainty in future hydrologic conditions. Comparisons between alternatives are made on these 21 simulations per alternative. The interquartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

Daily and Hourly Operations

Monthly volumes under each alternative, as predicted by CRSS and described in the previous section, were used as input to determine daily and hourly patterns of releases using GTMax-Lite, a program developed by Argonne National Laboratory for hydropower modeling (see Appendix K for technical information and analysis related to the hydropower systems modeling). Within each month, this program determines the pattern of daily and hourly releases that would maximize hydropower value based on CRSS-predicted monthly volume, reservoir elevation, hourly electricity market prices, and the operational constraints of each alternative, including maximum and minimum flows, ramping rates, and allowable daily range.

Hourly flows were generated using the GTmax-Lite model for the 20-year LTEMP period under each of the 21 hydrology scenarios and three sediment scenarios that were analyzed for each alternative. This resulted in 63 unique 20-year simulations for each alternative. Daily and hourly flow data were statistically analyzed to generate values of mean daily flow, mean

daily change (maximum flow minus the minimum flow for each day), and monthly volume for each alternative, and to show the variation in these variables over the range of scenarios analyzed.

4.2.1.2 Water Quality

This section describes the methods used to determine the potential effects on water quality associated with the LTEMP alternatives. Details of the methodologies used are presented in Appendix F of this EIS.

Using the hydrologic output from the CRSS RiverWare™ model (see Section 4.2.1.1), the CE-QUAL-W2 model (Cole and Wells 2003) was used to simulate water temperatures of Lake Powell (including dam releases).

Temperature exerts a major influence on biological and chemical processes. Aquatic organisms have preferred temperature ranges that influence their abundance and distribution. DO concentrations are generally lower, while salinity levels, nutrient, and pathogen concentrations are higher in warmer water. Temperature modeling for the Colorado River below Glen Canyon Dam was performed using the method described in Wright, Anderson et al. (2008). This model computes gains and losses of heat as water moves down the river. In general, predicted downstream temperatures are driven by the release temperature from Glen Canyon Dam, equilibrium water temperature (i.e., the temperature the water would eventually reach if it did not flow; dependent on air temperature, direct insolation, wind patterns, and evaporation), temperature and volumes of tributary inflows, and a heat exchange coefficient, which are all complex functions of environmental conditions (Walters et al. 2000).

The salinity module of the CRSS RiverWare™ model was used to analyze changes in salinity concentration for Colorado River reaches from Lake Powell to Imperial Dam, which is located downstream of Hoover Dam and Lake Mead. The Salinity Control Act sets numerical criteria for salinity concentrations on the Colorado River. Monthly salinity estimates were aggregated to annual values because the salinity criteria/standards set for Colorado are based on flow-weighted average annual salinity (mg/L). Other water quality parameters (e.g., DO, turbidity, nutrients, metals, organics, and bacteria/pathogens) were not modeled quantitatively. Qualitative assessments of these parameters in the Colorado River between Lake Powell and Lake Mead were based on previous scientific studies and historical data, including published research, related EISs, and Environmental Assessments (EAs).

Detailed modeling for Lake Mead was conducted by the Southern Nevada Water Authority because of concerns related to the potential effects of LTEMP alternatives on the quality of municipal water supplies. The temperature modeling was performed using the model described in Flow Science (2011). The Lake Mead Model (LMM) uses the ELCOM (Estuary, Lake and Coastal Ocean Model) code to simulate hydrology and conservative constituents, and CAEDYM (Computational Aquatic Ecosystem Dynamics Model) code for simulating biogeochemical processes.

Ten 2-year model scenarios were chosen to represent a subset of LTEMP alternatives that could result in important water quality impacts (Tietjen 2015). The goal of modeling was to indicate the possibility of effects that could occur. The 10 selected scenarios were separated into three general elevation-based scenarios. The first scenario covers water years 2014–2015, which have higher relative reservoir surface elevations (1,080–1,110 ft AMSL), and models hydrology trace 8, sediment trace 1, and Alternatives A, E (represented by two long-term strategies, E1 and E5), and F. The second scenario looks at water years 2018–2019, with lower relative reservoir surface elevations (1,040–1,060 ft AMSL), and models hydrology trace 11, sediment trace 1, and Alternatives A, E (long-term strategy E1), and F. The third scenario covers water years 2019–2020, which displays a high starting reservoir surface elevation that decreases significantly (1,125–1,070 ft AMSL), and hydrology trace 18, sediment trace 1, and models Alternatives A, E (long-term strategy E6), and F.

4.2.2 Summary of Impacts

The overall impacts of the seven LTEMP alternatives on the hydrology and water quality of Lake Powell, the Colorado River below Glen Canyon Dam, and Lake Mead are presented in this section and summarized in Table 4.2-1. A discussion of alternative-specific impacts is provided in Section 4.2.3. Impacts on seeps and springs are discussed in Section 4.9.1.2.

4.2.2.1 Hydrology

Impacts on annual, monthly, daily, and hourly reservoir releases, elevations, and annual operating tiers, as well as consistency with water delivery considerations, are discussed in the subsections below.

Lake Powell Operating Tier and Annual Release Volume

The Lake Powell annual operating tier and annual release volume are driven by hydrological conditions in a given year, and by the LROC as currently implemented through the 2007 Interim Guidelines. The modeled Lake Powell annual release volumes range from 7.0 maf to 19.2 maf, with a median value of 8.23 maf, across all years, traces, and alternatives.

The Lake Powell annual release volume is driven by the annual operating tier, which is set based on projections of end-of-calendar-year and end-of-water-year elevations in Lake Powell and Lake Mead. Under the 2007 Interim Guidelines, Lake Powell operates under four operating tiers. Each operating tier has a specific logic for determining the required annual release within that tier. Depending on the operating tier, the annual release is either a set volume determined at the beginning of the water year, or a variable volume based on projected and actual inflows and resulting Lake Powell and Lake Mead elevations and storages. LTEMP actions will be implemented consistent with these operations.

TABLE 4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology							
Overall summary of impacts	No change from current condition in reservoir elevations, annual operating tiers, monthly release volumes, mean daily flows, or mean daily changes in flow (up to 8,000 cfs).	Compared to Alternative A, no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months (up to 12,000 cfs). Hydropower improvement flows would cause even greater mean daily flow changes.	Compared to Alternative A, some change from current condition related to reservoir elevations (<2 ft difference for each reservoir at end of Dec.), annual operating tiers (2.1% of years), monthly release volumes and mean daily flows (lower in Aug. and Sept.); lower mean daily changes in flow in all months (up to 6,200 cfs).	Compared to Alternative A, some change from current condition related to reservoir elevations (0.2 ft difference for Lake Powell, no difference for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months (up to 8,000 cfs).	Compared to Alternative A, negligible change from current condition related to reservoir elevations (0.3 ft difference for Lake Powell, 0.1 ft for Lake Mead at end of Dec.); no change in annual operating tiers; more even monthly release volumes and mean daily flows (lower in Aug. and Sept.); higher mean daily changes in flow in all but Sept. and Oct. (up to 9,600 cfs).	Compared to Alternative A, some change from current condition related to reservoir elevations (about 3 ft difference for each reservoir at end of Dec.) and annual operating tiers (2.1% of years); large changes in monthly release volumes and mean daily flows (high volume in May and Jun., low in other months); steady flows throughout the year.	Compared to Alternative A, some change from current condition related to reservoir elevations (0.4 ft difference for Lake Powell, 1.4 ft for Lake Mead at end of Dec.) and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year.
Lake Powell and Lake Mead Reservoir elevations	No change from current condition; reservoir elevations vary significantly with inflow hydrology; Lake Powell and Lake Mead operate at times within the full range of operating elevations.	Same as Alternative A for end-of-Dec. elevations for Lake Powell and Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 1.5 ft higher at Lake Powell and 0.6 ft lower at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.2 ft higher at Lake Powell but the same at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.3 ft higher at Lake Powell and 0.1 ft lower at Lake Mead.	Compared to Alternative A, end-of-Dec. elevations would be on average 3.2 ft higher at Lake Powell and 2.9 ft lower at Lake Mead, the largest difference of all alternatives.	Compared to Alternative A, end-of-Dec. elevations would be on average 0.4 ft lower at Lake Powell and 1.4 ft higher at Lake Mead.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Lake Powell annual operating tier	No change from current condition; Alternative A would operate at times within each of the four operating tiers during the period 2013–2026 and at times within both operating tiers during the period 2027–2033.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Compared to Alternative A, would operate in a different tier an average of 0.7% of years; there would be the same frequency of operating tiers, but different timing during the analysis period.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Monthly release volume	No change from current condition; monthly volumes would be highest in Dec., Jan., Jun., Jul., Aug., and Sept. (670,000 to 1,500,000 ac-ft; 570,000 to 1,200,000 ac-ft in other months).	Same as Alternative A.	Compared to Alternative A, higher volumes in Feb. through May (by 82,000 to 157,000 ac-ft); lower in Aug., Sept., and Oct. (by 111,000 to 200,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 43,000 to 98,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 60,000 to 127,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 45,000 to 128,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 30,000 to 242,000 ac-ft).	Compared to Alternative A, much higher volume in Apr., May, and Jun. (by 439,000 to 651,000 ac-ft); much lower in Dec., Jan., Jul., Aug, and Sept. (by 214,000 to 433,00 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Mar., and Apr. (by 71,000 to 286,000 ac-ft); lower in Dec., Jan., Jul., and Aug. (by 139,000 to 196,000 ac-ft).
Mean daily flow	No change from current condition; mean daily flows are highest in Dec., Jan., Jun., Jul., Aug., and Sept. (11,200 to 24,600 cfs; 9,400 to 14,400 cfs in other months).	Same as Alternative A.	Compared to Alternative A, higher mean daily flow in Feb. through May (by 1,300 to 2,500 cfs); lower in Aug., Sept., and Oct. (by 1,800 to 3,300 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 3,000 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 1,000 to 2,100 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 2,100 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 500 to 4,000 cfs).	Compared to Alternative A, much higher mean daily flow in Apr. through Jun. (by 7,400 to 10,600 cfs); much lower in Dec. and Jan. and Jul. through Sept. (by 3,600 to 7,000 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Mar., Apr. (by 1,200 to 4,800 cfs); lower in Dec., Jan., Jul., and Aug. (by 2,300 to 3,200 cfs).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Mean daily change in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs in Dec., Jan., Jun., Jul., Aug., and Sept.; 2,600 to 6,400 cfs in other months.	Compared to Alternative A, mean daily change higher in all months (range about 2,500 to 12,000 cfs).	Compared to Alternative A, mean daily change lower in all months (about 1,300 to 6,200 cfs).	Compared to Alternative A, mean daily change slightly higher in Oct. through Jun., same or less in Jul. through Aug. (range about 2,700 to 7,600 cfs).	Compared to Alternative A, mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs).	Mean daily change is zero except for ramping up and down from spring and fall HFEs.	Mean daily change is zero except for ramping up and down from spring and fall HFEs.
Water Quality							
Overall summary of impacts	No change in temperature or other water quality indicators from current conditions.	Compared to Alternative A, negligible differences in temperature or other water quality indicators.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A and the other alternatives, greatest increase in summer water temperature and potential for bacteria and pathogens.	Compared to Alternative A, some increase in summer water temperature and potential for bacteria and pathogens.
Water temperature (change from Lees Ferry to Diamond Creek)	No change from current conditions; summer warming would be lowest among alternatives (average 5.6°C).	Same as Alternative A.	Summer warming would be higher than under Alternative A (average 5.8°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be highest among alternatives (average 6.8°C).	Summer warming would be higher than under Alternative A (average 6.2°C).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Water Quality (Cont.)							
Salinity	Negligible change from current condition. Negligible alternative-specific differences (<2.5%) expected because, regardless of operating conditions, salinity would not increase over time or exceed control criteria.						
Turbidity	Negligible change from current condition. No alternative-specific differences expected because potential turbidity increases due to scouring during HFEs are expected to be temporary and any observed fluctuations recover quickly when lower flows return. Effects of operational changes related to tributaries are currently unknown.						
Bacteria and pathogens	No change from current condition.	Compared to Alternative A, slightly lower probability of the occurrence of bacteria and pathogens because of higher within-day fluctuations.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during low summer flow experiments.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during annual low steady flows.	Compared to Alternative A, increased probability of the occurrence of bacteria and pathogens during year-round steady flows.
Nutrients	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, waters are expected to remain relatively low in nutrients.						
Dissolved oxygen	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, DO concentrations are expected to remain within the accepted healthy range for fish.						
Metals/ radionuclides	Negligible change from current condition. No alternative-specific differences expected because operational changes will not affect metal/radionuclide concentrations. There are no concerns related to these substances because levels do not exceed any enforceable human-health-based standards or guidance values.						
Organic/other contaminants	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, organic and other contaminant concentrations are expected to remain below those considered toxic.						

Modeling incorporated the elevation-based triggers from the 2007 Interim Guidelines through 2026 regarding annual release volumes from Glen Canyon Dam. The selection of the annual operating tier at Lake Powell and Lake Mead and the annual release volumes can, in some instances, be affected by the differing monthly release patterns of the LTEMP alternatives. The differences regarding operating tier selections and annual volumes among alternatives occur only in rare circumstances (see Appendix D for more detail). Two pimary causes contribute to the identified model results showing differences in operating tier or different annual release volumes: (1) October to December release ratio; and (2) differences in equalization releases when maximum release is a constraining factor.

October to December Release Ratio. Alternatives that release proportionally different volume during October through December, relative to the rest of the water year, result in a slightly different end-of-year Lake Powell elevation (and slightly different end-of-year Lake Mead elevation), and can, accordingly in those circumstances, when Lake Powell elevation is projected to be close to an operating tier threshold, result in a different operating tier selection, potentially impacting the implementation of a different operating tier at Lake Powell and Lake Mead, as well as different annual volumes. This effect (a changed operating tier) is projected to occur very infrequently (0 to 2.1 % of years, depending on the alternative) and constituted all occurrences of operating tier differences from Alternative A in this modeling. Alternatives with the same October through December volume as Alternative A (2,000 kaf in an 8.23-maf year) did not result in a different operating tier. Alternatives B, D, and E also have October–December volumes of 2,000 kaf, but Alternatives C, F, and G have October–December volumes of 1,790 kaf, 1,466 kaf, and 2,075 kaf, respectively.

Effects Due to Differences in Equalization Releases when Maximum Release Is a Constraining Factor. Modeling assumptions for equalization operations are needed for a full analysis of monthly and annual operations in this LTEMP EIS. These assumptions are for analytical purposes only and do not, and cannot, modify the Secretary's approach to operations of equalization releases, which are made pursuant to the Colorado River Basin Project Act of 1968. Modeled equalization release volumes can be affected by the annual pattern of monthly volumes. Alternatives that have higher releases earlier in the water year are able to release more water in years when the maximum release through the powerplant becomes a potential limiting factor to equalizing within the water year, which is consistent with the objectives of applicable federal law. A limitation of the current modeling assumptions is that they cannot fully mimic or predict operator judgment or actions to achieve full equalization within the relevant timeframe. Reclamation will continue to operate Glen Canyon Dam to achieve equalization releases in a manner fully consistent with the Law of the River and in consultation with the Colorado River Basin States. As hydrologic conditions change throughout the water year, the annual release volume also shifts. In years when the annual release volume increases throughout the year, it may not be possible to release the entire volume in the remaining months of the water year through the powerplant turbines; thus, some must be released the following water year. Generally, the action alternatives pass more water earlier in the water year (through July) and thus have less potential for annual releases extending beyond the water year than Alternative A (0 to 200 kaf less, depending on the alternative). This can result in different modeled annual

volumes, but that difference is made up in the following water year. This effect does not result in different operating tiers.

Monthly Releases

Although annual release volumes would be nearly the same under each of the LTEMP alternatives, the monthly patterning of that annual volume varies significantly among the alternatives. Monthly release patterns for each of the alternatives in years with different annual release volumes are shown in Figure 4.2-1. Monthly releases were shaped for each alternative in an 8.23-maf year and then generally scaled proportionally to the 8.23-maf pattern relative to the annual volume.[3] For example, 763 kaf in January for Alternative D in an 8.23-maf year scaled to 1,104 kaf in January for an 11-maf year. For years when the annual volume reaches the maximum release capacity of Glen Canyon Dam, the monthly distribution of releases became more similar across alternatives (Figure 4.2-1). Monthly release volumes for different annual releases are included in Appendix D.

Monthly releases sometimes would be limited by the minimum or maximum release constraints at Glen Canyon Dam. In low annual volume release years, monthly volumes sometimes would be increased to ensure that the minimum hourly release objective of each alternative could be maintained throughout the month. In high annual release years, monthly volumes sometimes would be decreased because they were capped at the maximum release capacity (45,000 cfs), and the remaining volume was released in the following month(s). See Appendix D for further detail.

Operationally, annual releases and the associated monthly releases are affected by hydrologic uncertainty. In some cases, Lake Powell's annual release target changes throughout the water year because the actual inflow volume is not known until the end of the water year. Reservoir operators utilize inflow forecasts throughout the year to project the expected annual release volume and allocate the monthly releases accordingly in order to make releases consistent with the LROC as currently implemented through the 2007 Interim Guidelines. This effect of hydrologic uncertainty is captured, in part, through a forecasting algorithm in CRSS. However, due to modeling limitations, monthly release patterns under actual operating conditions are likely to differ from the modeling results.

[3] Note that adjustments to Alternative D made after modeling was completed resulted in a 50-kaf increase in August (changed from 750 kaf to 800 kaf) and a corresponding 25-kaf decrease in both May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

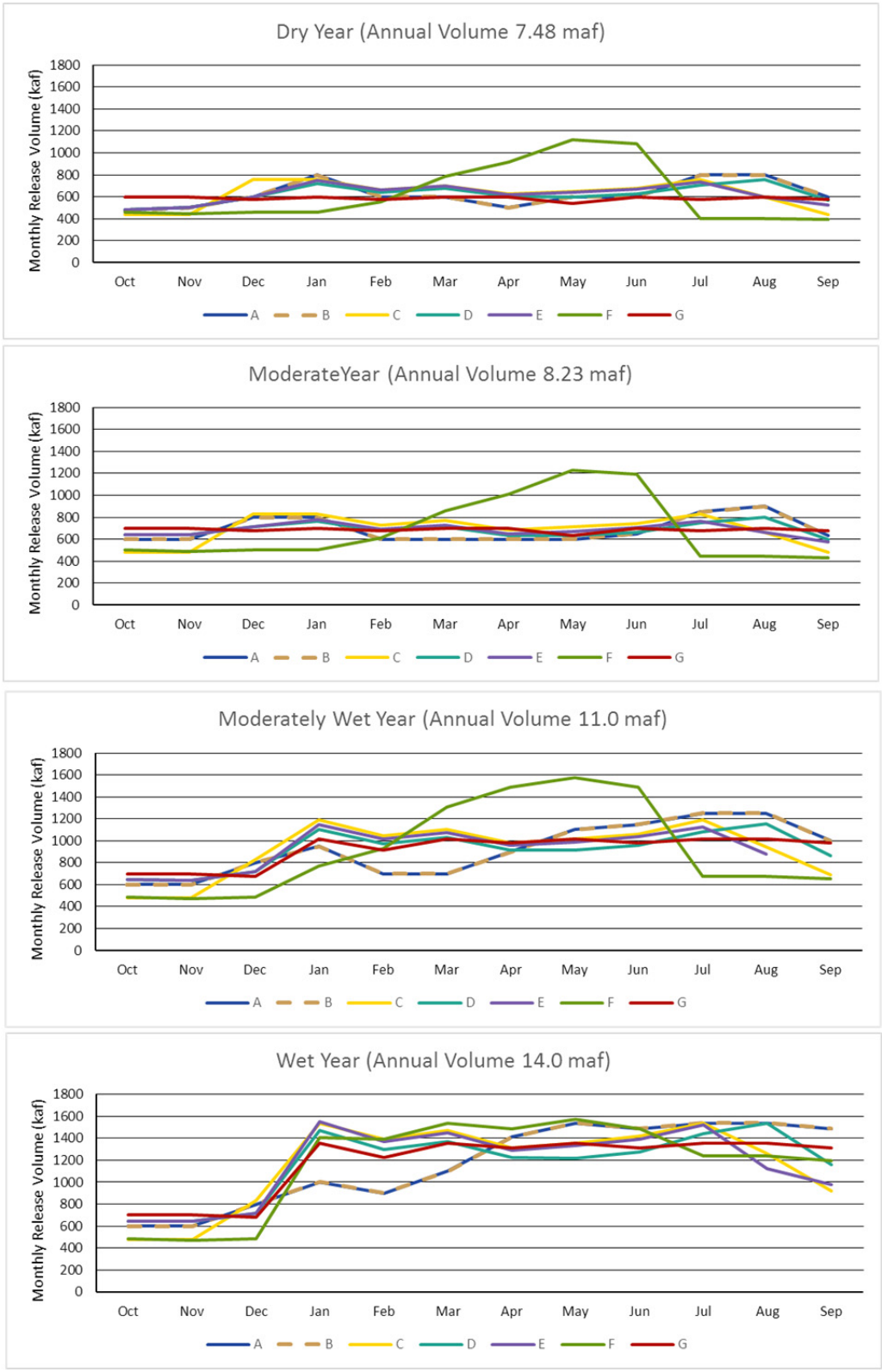

FIGURE 4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes

Monthly release volume can also be affected by HFEs. For HFEs that require more water than was already allocated for the given month of the HFE, water is reallocated from later months to ensure the water year release volume remains the same. The monthly reallocation of releases to support a HFE does not affect the Lake Powell operating tier. See Appendix D for further detail.

Monthly releases can also be affected by low summer flows. Low summer flows could be implemented as an experimental component under Alternatives C, D, and E. During years with low summer flows, releases would be lower than typical in July, August, and September, and proportionally higher in May and June, in order to maintain the same annual release volume. Subject to the decision-making process outlined in Section 2.2.4.3, low summer flows may be implemented if three conditions are met: (1) the projected annual release was less than 10 maf; (2) the projected temperature at the confluence with the Little Colorado River in July, August, or September was less than 13°C (Alternatives C and E) or less than 14°C (Alternative D); and (3) switching to the low summer flow pattern resulted in temperatures of at least 13°C (Alternatives C and E) or at least14°C (Alternative D) in those months. For those alternatives with low summer flows, the number of those flows in the 20-year period was estimated to range from zero to four occurrences. Depending on the alternative, the average ranges from 0.7 to 1.8 low summer flows per 20-year run. See Appendix D for further detail.

Mean monthly release volumes averaged over all years within each run are shown in Figure 4.2-2. The variability in these values reflects the effect on operations of natural variability in inflows observed in the historical record. The differences among alternatives in mean monthly release volumes are a function of the monthly volume patterns established in the definition of each alternative (see Chapter 2 for a description of these operational constraints).

Within alternatives, mean monthly volumes would vary the most among the scenarios in the months of June through September (Figure 4.2-2). This pattern of variability is a result of adjustments in operations in the latter half of the water year in response to forecasts that become more certain after June 1. During the first half of the water year, operations tend to be more conservative (less variable) to ensure sufficient water remains for the remainder of the year to meet minimum flows.

Mean monthly volumes under Alternative F are consistently the most different from other alternatives, with volume being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

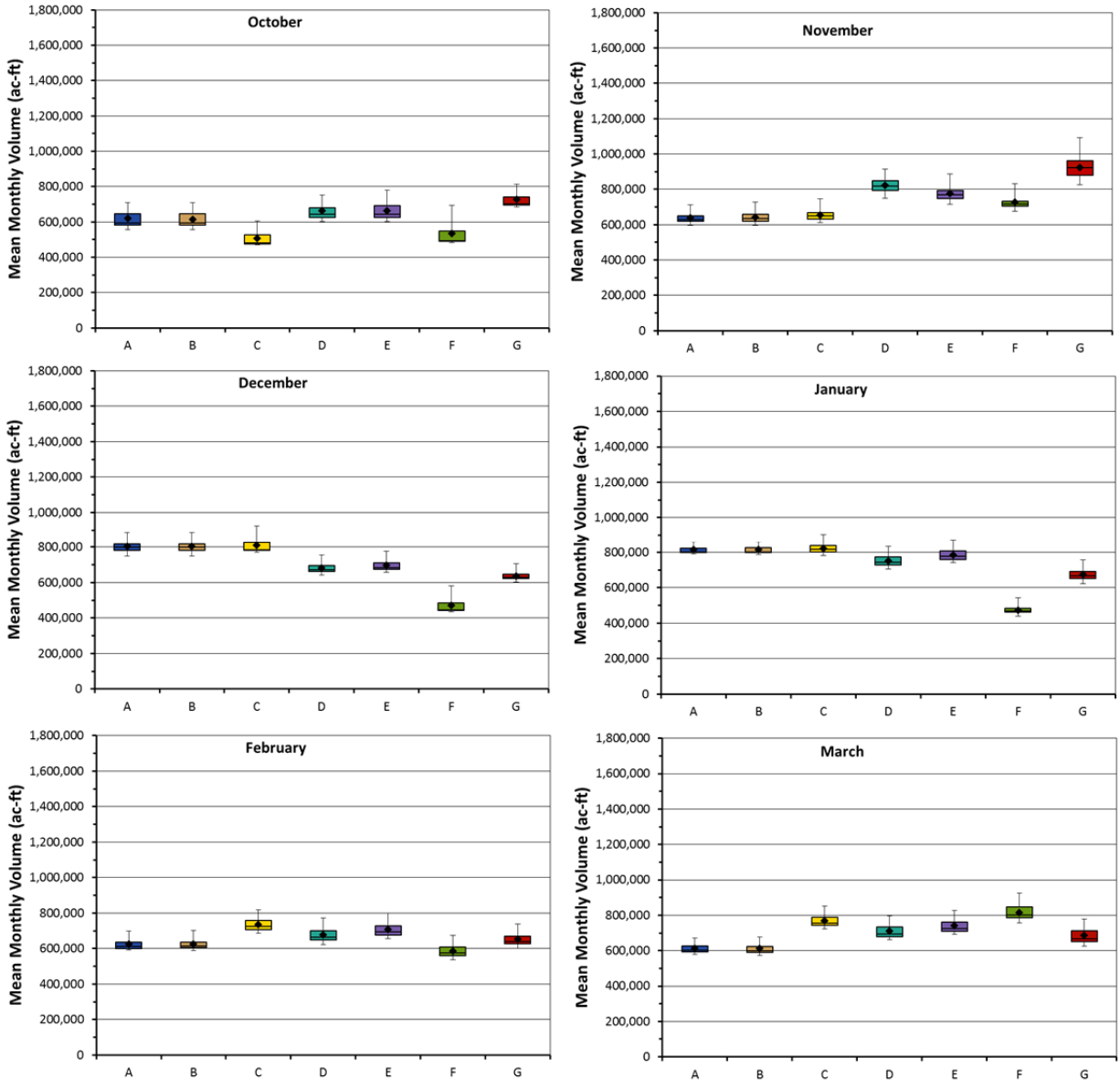

FIGURE 4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

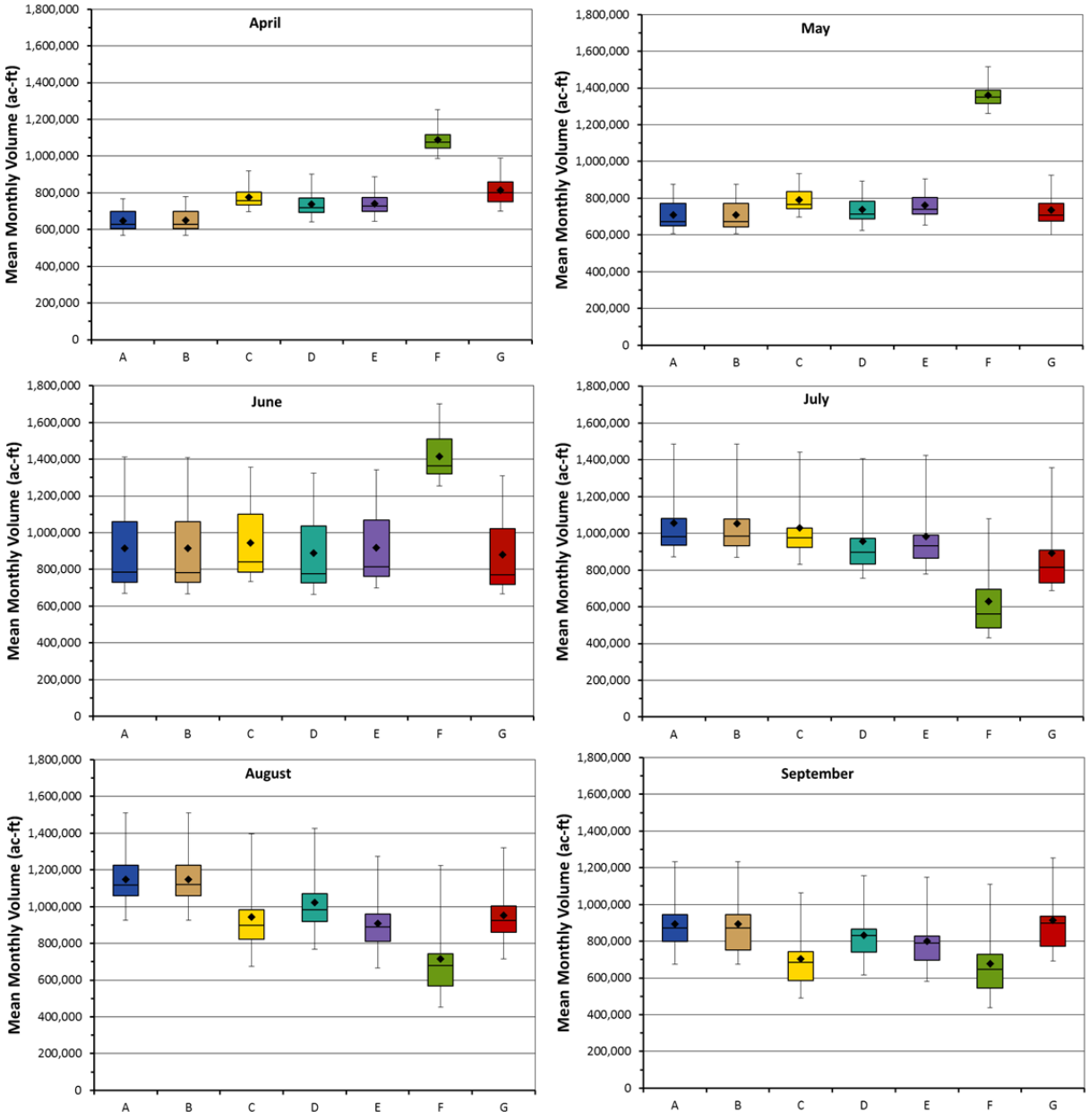

FIGURE 4.2-2 (Cont.)

Daily and Hourly Releases and Ramp Rates

For most alternatives, releases from Glen Canyon Dam fluctuate throughout the day in response to hydropower demand. Releases are generally higher during the day when there is a higher demand for hydropower, and lower during the night when the demand is lower. The fluctuation within a day (i.e., from nighttime low to daytime high) varies by alternative and is typically relative to the monthly release volume. For example, months with a higher release volume typically have a larger daily range of releases. Two alternatives, Alternatives F and G, do not have daily or hourly release fluctuations.

The range of daily releases is further defined by a required minimum release and is alternative specific. The scheduled hourly release rate must be equal to or greater than the prescribed minimum release. The minimum release during the daytime is typically higher than the minimum release during the nighttime.

The peak release in a day is determined by the maximum allowable daily fluctuation, and the daily and monthly release volume. In cases when the required monthly release is very large, the peak daily release could be limited by reservoir outlet works capacity, which is a function of reservoir head. Generally speaking, the maximum possible release without using the spillway was computed as 45,000 cfs. The actual maximum release may be lower, depending on reservoir elevation and the number of available hydropower units.

Ramp rates, the change in release from one hour to the next, are also specific to each alternative (Chapter 2). Ramp rates down vary by alternative; ramp rates up are the same for all alternatives (Chapter 2, Table 2-1). For all alternatives, the ramp rate up is faster than the ramp rate down.

Daily release volumes vary throughout the week relative to hydropower demand. Release volumes are typically larger during weekdays, when the demand for hydropower is higher, and release volumes are lower during the weekends and holidays.

Mean daily flow and mean daily change vary among alternatives, in part due to differences in the monthly volume patterns established for each alternative, but also as a result of operational constraints characteristic of each alternative (see Chapter 2 for a description of these operational constraints) (Figures 4.2-3 and 4.2-4).

Within alternatives, mean daily flows would vary the most among the scenarios in the months of June through September (Figure 4.2-3). This pattern can be attributed to increased variability in monthly volume, as described in the previous section.

Mean daily flows under Alternative F are consistently the most different from other alternatives, with mean daily flows being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-3). These differences are a result of the monthly release pattern of this alternative, as described in the previous section. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

Similar to the pattern discussed above for mean daily flows, mean daily change would vary the most among the scenarios in the months of June through September (Figure 4.2-4). This pattern reflects the variability in monthly volume, which determines the level of amount of daily change allowed under each alternative.

Mean daily change varies among the alternatives, ranging from 0 cfs (in all but the months with HFEs) in the two steady flow alternatives (Alternatives F and G), to up to 12,000 cfs in Alternative B. Of the fluctuating flow alternatives (Alternatives A–E), Alternative C has the lowest mean daily change. Relative to Alternative A, mean daily change

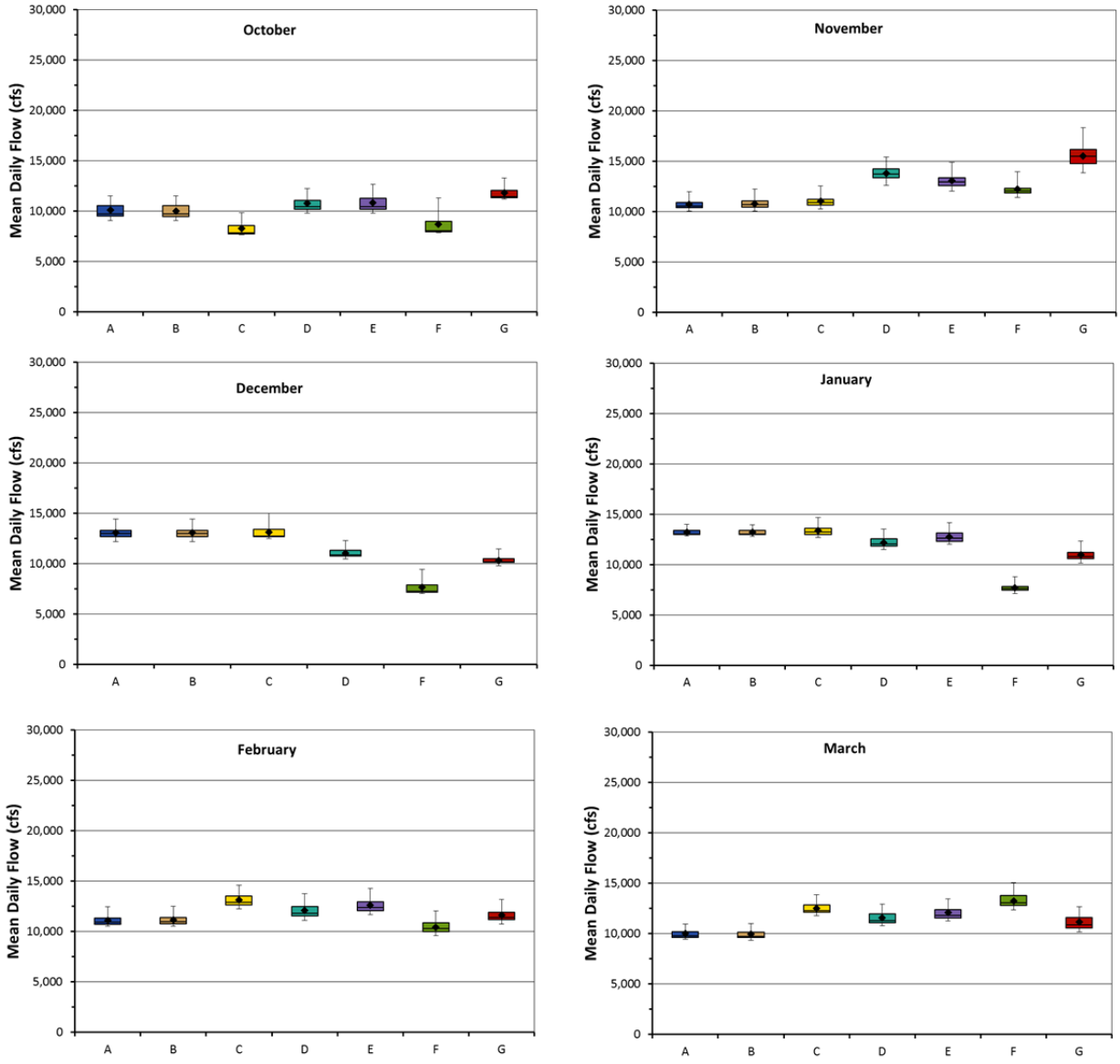

FIGURE 4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

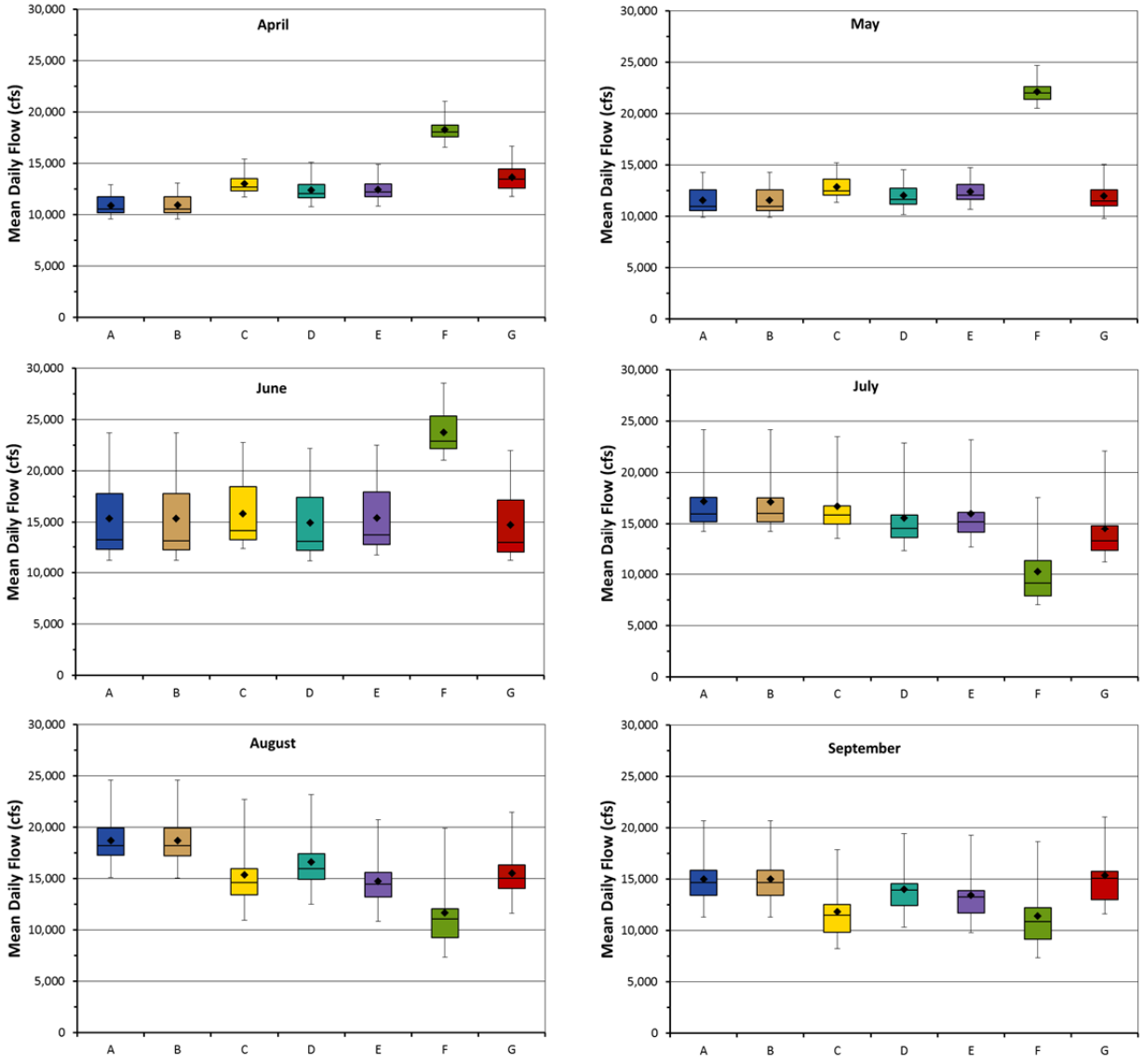

FIGURE 4.2-3 (Cont.)

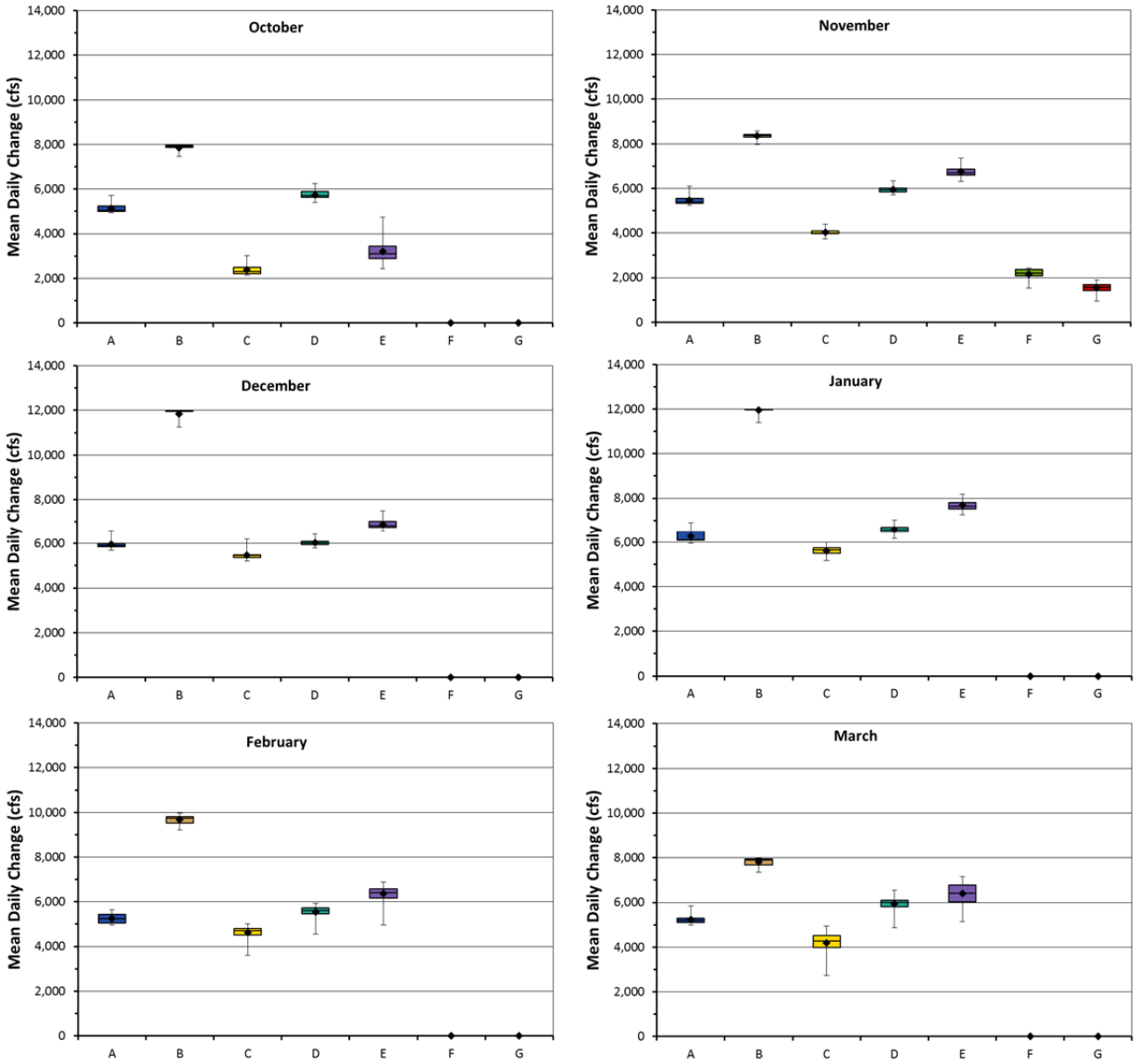

FIGURE 4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

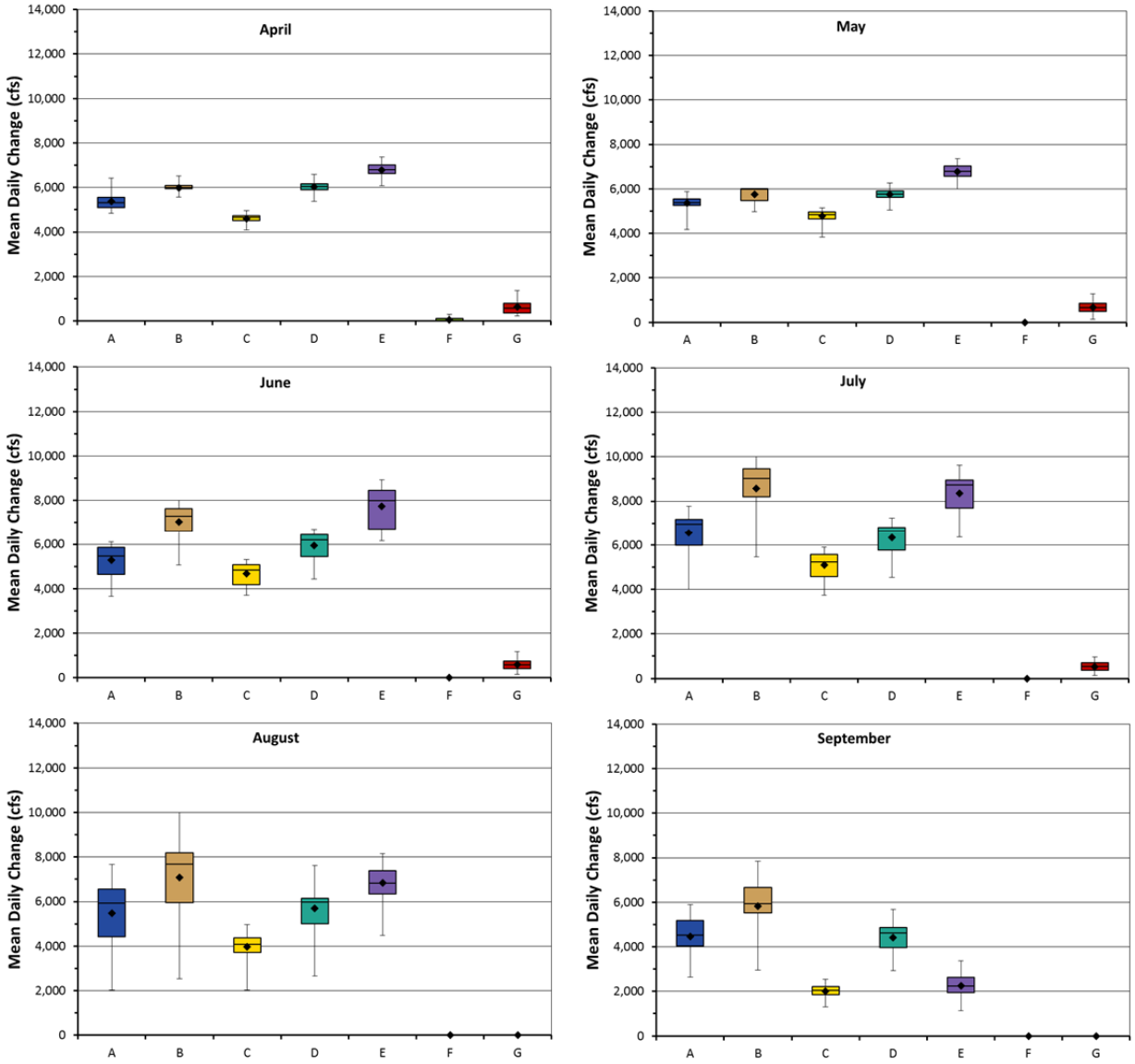

FIGURE 4.2-4 (Cont.)

under Alternative D is most similar; Alternatives C, F, and G are consistently lower; Alternative B is consistently higher; and Alternative E is higher in all months but September and October when load-following curtailment prior to HFEs would occur.

Reservoir Elevations

Lake Powell elevations are affected by potential future hydrology and Glen Canyon Dam operations. Lake Mead elevations are similarly affected by Glen Canyon Dam releases and Hoover Dam operations (including those related to meeting downstream water delivery obligations).

The elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. Figure 4.2-5 presents end-of-calendar-year elevations for Lake Powell and Lake Mead at the 10th, 50th, and 90th percentiles for 21 different hydrology traces and the seven different alternatives. The plots show that uncertainty associated with annual variation in inflow (variation among years) creates a larger range of pool elevations than do the differences within years among alternatives. In addition, differences among alternatives are greater at the 10th and 50th percentiles, corresponding to lower reservoir elevations and drier hydrology. Differences at the 90th percentile, which corresponds to higher reservoir elevations and wetter hydrology, are minimal across all alternatives.

The percentage of traces with Lake Powell falling below 3,490 ft (modeled minimum power pool) and the percentage of traces with Lower Basin shortages are shown in Figure 4.2-6. The probability of these conditions occurring is more affected by annual variation in inflow than by alternative. For Lake Powell elevations, all alternatives show very similar percentages for elevations that are ≤3,490 ft. The percentage of traces ranges between 0 and 5 and remains relatively constant throughout the 20-year period. Typically, alternatives that show differences from Alternative A are due to an alternative releasing more or less water from October through March (the typical low elevation months). Alternatives that release less water in this period will have a lower probability of falling below 3,490 ft (e.g., Alternative F reduces the probability in 2017 and 2032).

For Lower Basin shortages pursuant to the applicable provisions of the LROC as currently implemented through the 2007 Interim Guidelines (i.e., when Lake Mead's elevation is projected to be at or below 1,075 ft on January 1), the percentages are also similar across alternatives, though with slightly more variability than with the Lake Powell minimum power pool. The percentage of traces with Lower Basin shortages generally increases over the 20-year period, ranging from zero in the first years of the period to nearly 62% of traces near the end of the period. The greatest difference across all alternatives is 19% in any given year. The October through December release from Lake Powell is the largest contributing factor in differences between Alternative A and the other alternatives.

Alternatives that release less water in October through December show higher chances of shortages in the Lower Basin (e.g., Alternative F).

Glen Canyon Dam Annual Release

To evaluate potential differences among alternatives related to Glen Canyon Dam annual releases, the following metrics were calculated:

- Frequency of deviation from Alternative A with regard to Lake Powell annual operating tier as specified by the 2007 Interim Guidelines,
- Probability over time of Lake Powell being in each operating tier as specified in the 2007 Interim Guidelines, and
- Frequency and volume of modeled annual release extending beyond the water year.

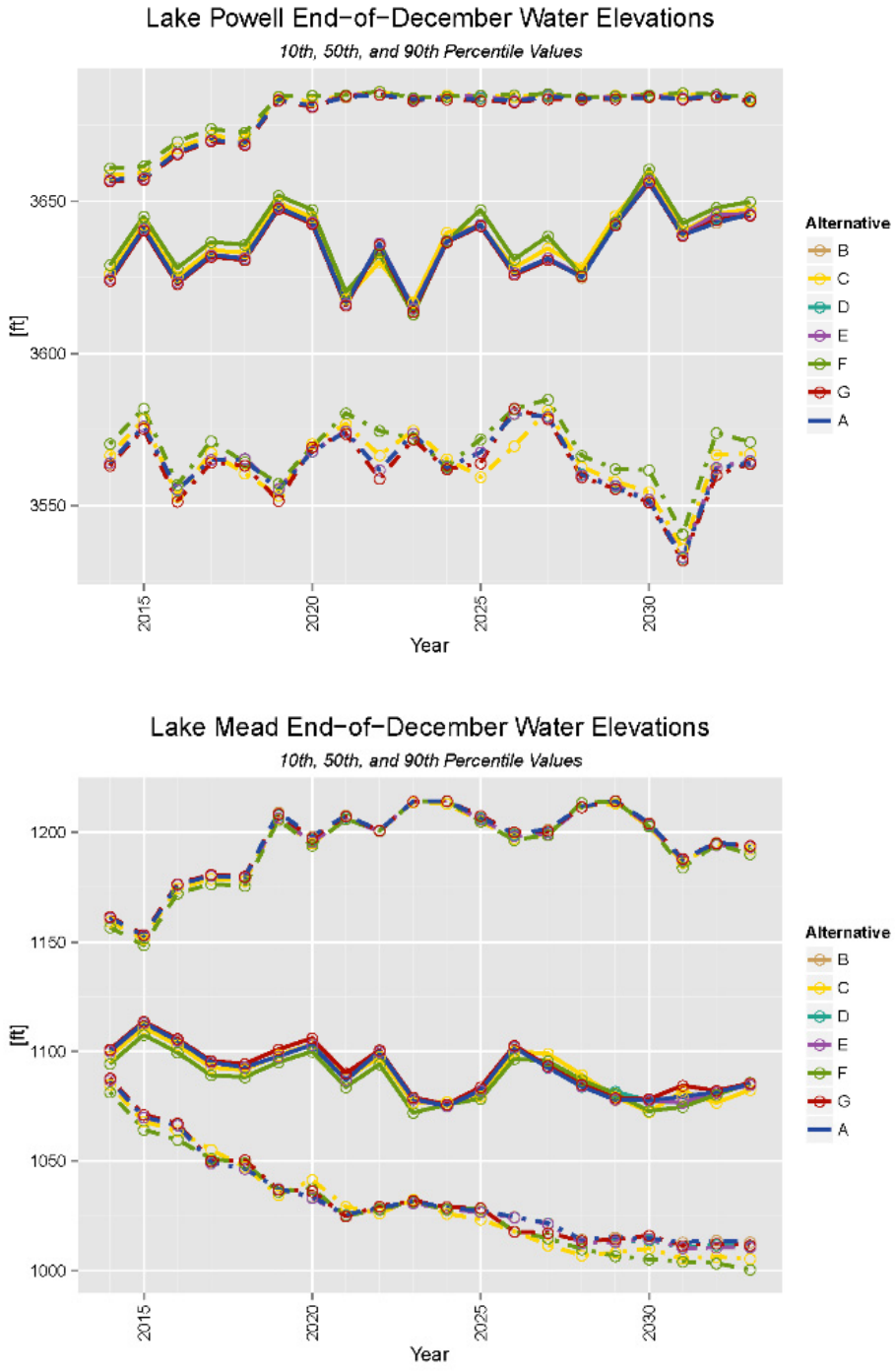

FIGURE 4.2-5 Lake Powell (left) and Lake Mead (right) End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives

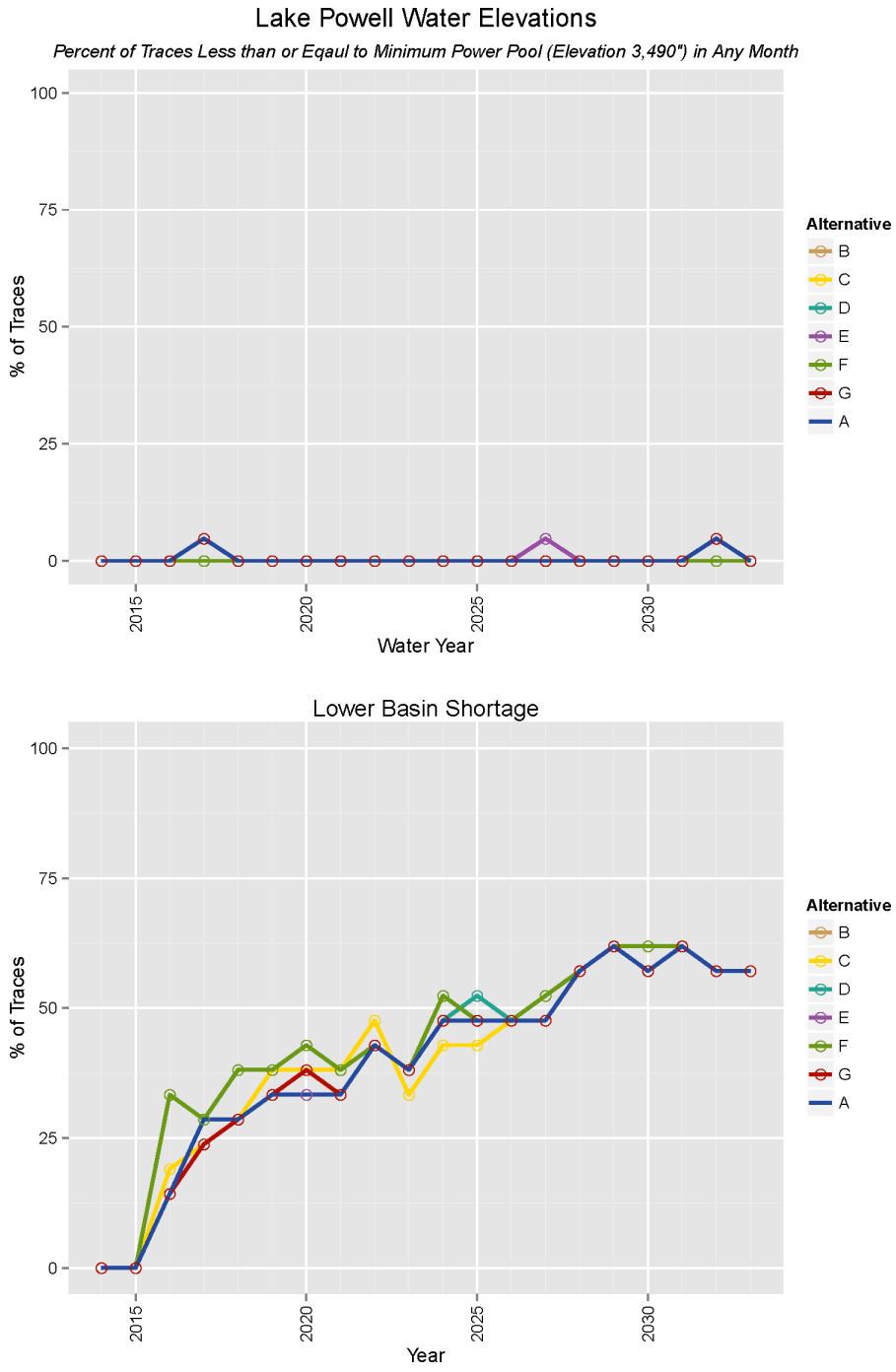

FIGURE 4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces and Seven Alternatives

Frequency of Deviation from Alternative A with Regard to Lake Powell Annual Operating Tier as Specified by the 2007 Interim Guidelines. Figure 4.2-7 shows the frequency of deviation from Alternative A with regard to Lake Powell annual operating tier pursuant to the 2007 Interim Guidelines. This frequency was calculated as the number of years in which an alternative was modeled to be in an operating tier that is different from the modeled operating tier of Alternative A for the same year and trace combination divided by the total number of years (420 years for the 20-year period). For 2014–2026, the operating tiers pursuant to the 2007 Interim Guidelines were used; for 2027–2033, the operating tiers were defined as either an 8.23-maf release or a release greater than 8.23 maf.[4] Operations under most of the alternatives do not result in a different operating tier from that under Alternative A. Of those alternatives that do show differences, the percentage of time in a different tier ranged from 0 to 15.4%. Alternatives with an October through December release volume other than 2,000 kaf occasionally result in a different operating tier from Alternative A. Of the alternatives,

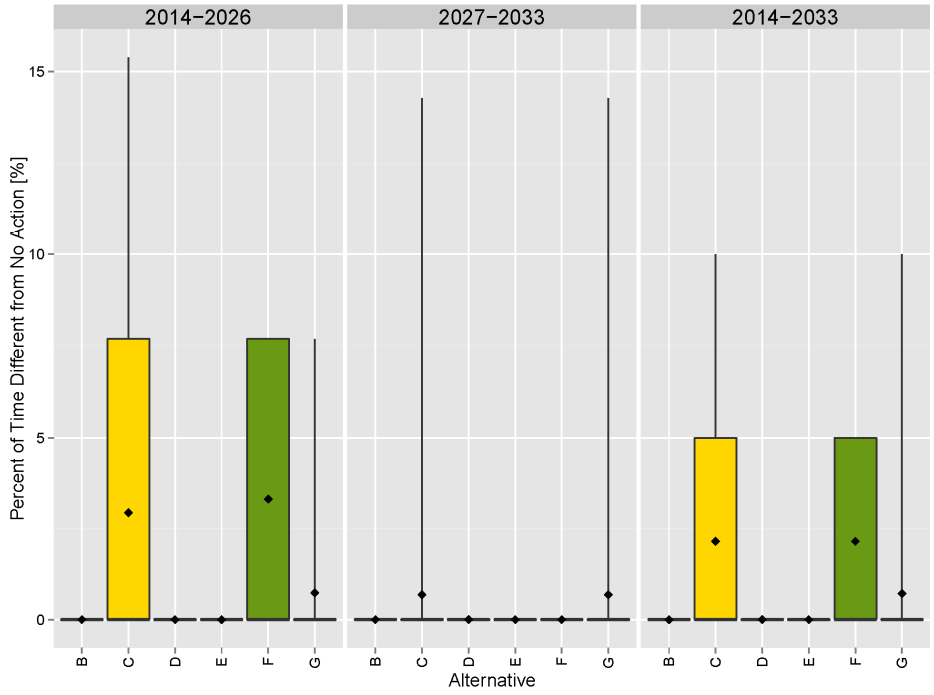

FIGURE 4.2-7 Percentage of Time in Different Operating Tier than Alternative A (The percentage of time in a different operating tier than the No Action Alternative is calculated for each trace and time period. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4 Under the 2007 Interim Guidelines, Lake Powell operates in four possible operating tiers through a full range of reservoir elevations and releases. The Interim Guidelines are in place through 2026 and include a provision that, beginning no later than December 31, 2020, the Secretary of Interior shall initiate a formal review for purposes of evaluating these Guidelines. It is unknown what the outcome of the review will be, including whether or how new guidelines will be implemented. Unless new guidelines are implemented, after 2026, Lake Powell will revert back to the Interim Guidelines' No Action Alternative with tiers defined as either an 8.23-maf release or a release greater than 8.23 maf.

Alternative C is in a different operating tier most frequently, an average of 2.1% of the time during the 20-year LTEMP period. If an alternative is in a different operating tier one year, it is more likely to be in a different operating tier than Alternative A in a following year, and the difference in a year-by-year comparison can cascade through the end of the period.

Probability over Time of Lake Powell Being in Each Operating Tier as Specified in the 2007 Interim Guidelines. Figures 4.2-8 and 4.2-9 show the frequency of occurrence for Lake Powell operating tiers for each alternative during (Figure 4.2-8) and after (Figure 4.2-9) the interim period. The plots indicate that the frequency of each of the tiers is very similar across all alternatives, evidenced by the interquartile, minimum, and maximum values as well as the median and mean values. For all alternatives, the Upper Elevation Balancing Tier is the most common, followed by the Equalization Tier, then the Mid-Elevation Release Tier, and, lastly, the Lower Elevation Balancing Tier. Similar consistency across alternatives is evident in the period 2027–2033.

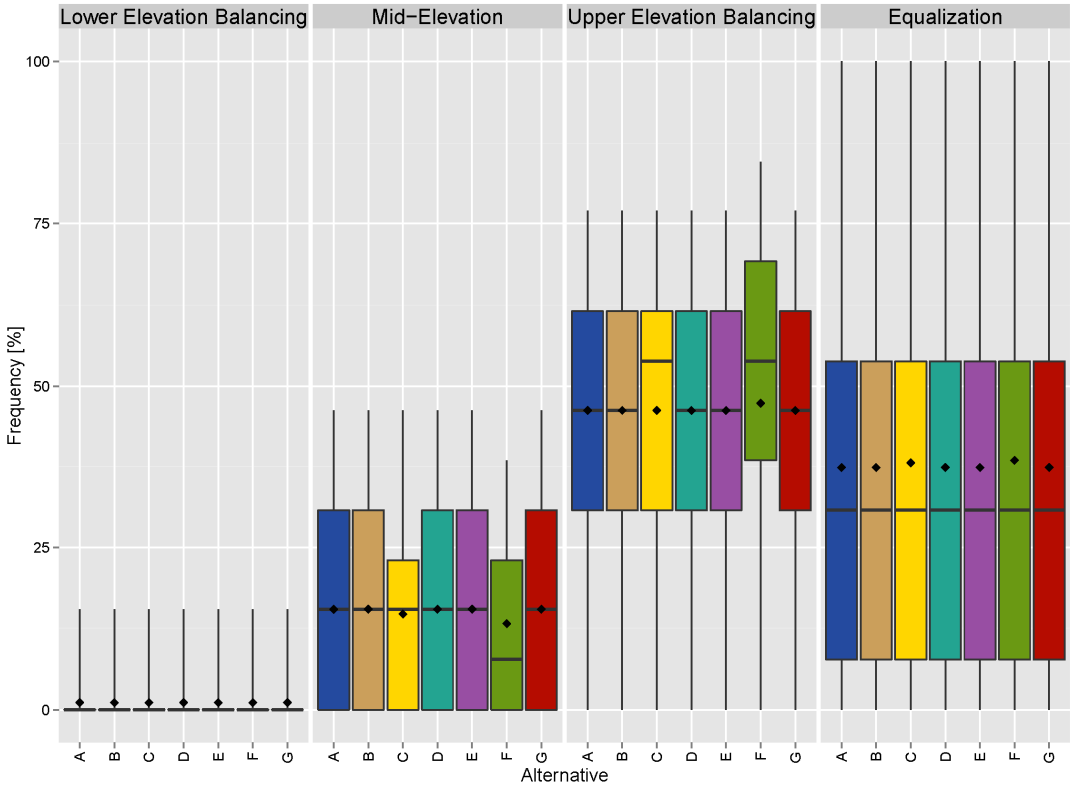

FIGURE 4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

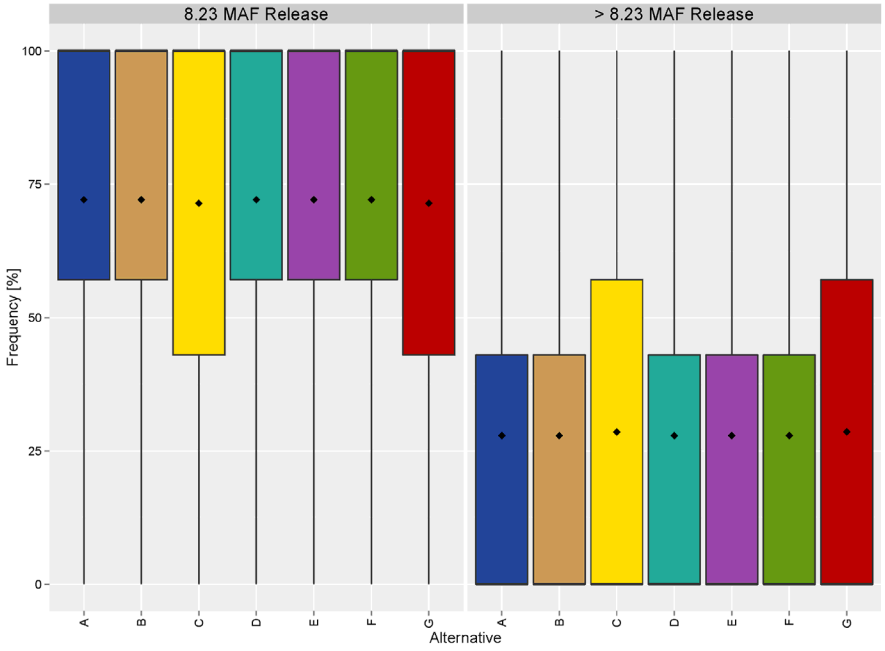

FIGURE 4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Frequency and Volume of Modeled Annual Release Extending Beyond the Water Year. The frequency of modeled annual release extending beyond the water year is shown in Figure 4.2-10. The average number of years with annual releases extending beyond the water year in any 20-year trace is less than 1 for all alternatives, but ranges from 0 to 2. For most action alternatives (except for Alternative B),
the average number of years when annual release extends beyond the water year is less than under Alternative A. In addition, Alternatives C, E, and F reduce the maximum number of annual releases that extend beyond the water year from 2 to 1 per trace. See Section 4.2.2.1 for more details related to the effects due to differences in equalization releases.

The volume of annual releases extending beyond the water year is also similar across alternatives. Across all alternatives, most of the volumes are 0 kaf, with the majority of the remaining volumes less than 500 kaf, and a handful of occurrences ranging up to 2,000 kaf in 1 year. For the action alternatives, the volumes of annual releases extending beyond the water year are generally less than, though sometimes equal to, those under Alternative A.
(See Appendix D for detail.)

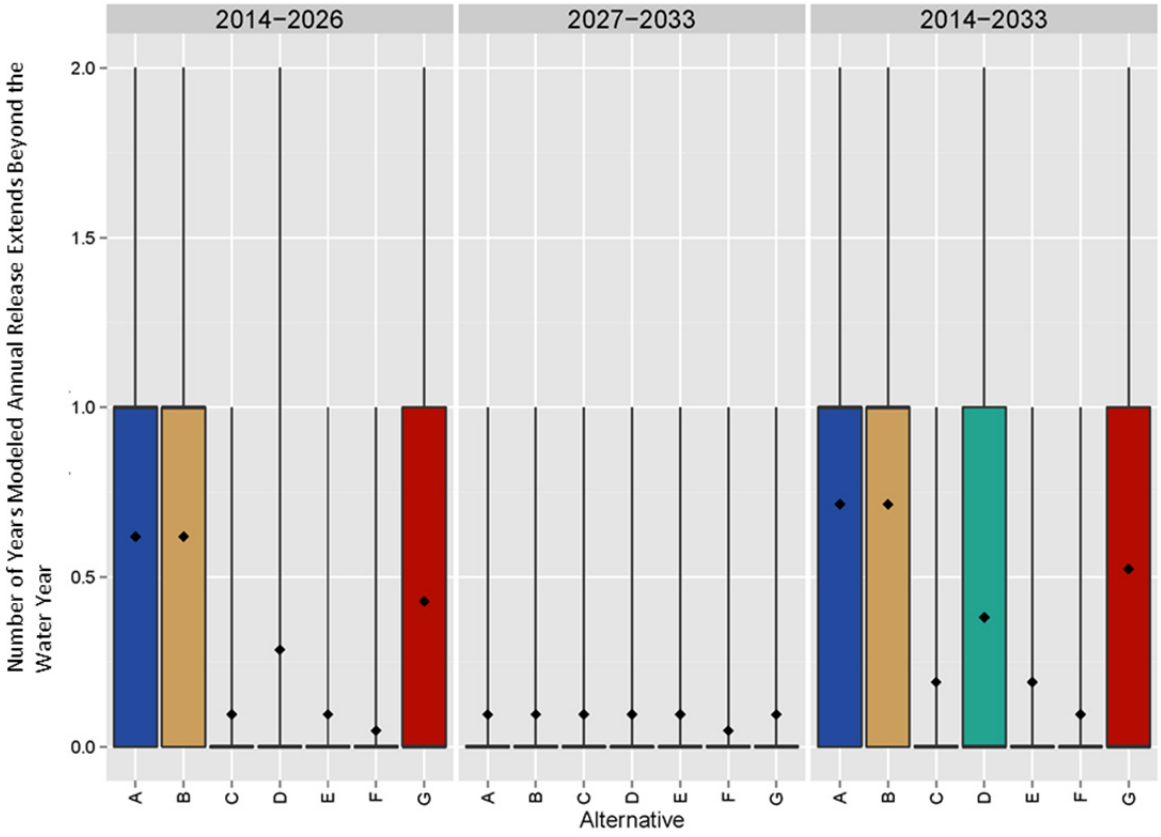

FIGURE 4.2-10 Frequency of Occurrence of Modeled Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.2.2.2 Water Quality

This section discusses the general results of the water quality analyses and focuses on impacts on water temperature and salinity. Overall, there is little difference expected in water quality among the different alternatives. The monthly and daily flow characteristics of alternatives do not vary drastically; any small changes are expected to be comparable across all alternatives.

Water Temperature

This section presents a quantitative description of the modeled temperatures and overall trends (e.g., seasonal changes) within and among the alternatives. More detailed analysis, as it relates to specific resources, is provided within the applicable resource sections.

In general, Glen Canyon Dam operations under the various alternatives are not expected to significantly affect Lake Powell reservoir water quality parameters; however, the dam outlet temperature and thermocline location may be a factor in determining effects on water quality downstream.

Lake Powell

As described in Section 3.3.3.2, Glen Canyon Dam release temperatures are highly dependent on the position of the penstocks (i.e., elevation 3,470 ft) relative to the surface of Lake Powell. In general, when reservoir surface elevations are high, releases tend to be cooler because they originate deeper in the reservoir relative to its surface (e.g., from within the hypolimnion). On the other hand, when reservoir surface elevations are low, withdrawals tend to be warmer because they originate closer to the surface (i.e., from the metalimnion or upper hypolimnion). Regardless of the alternative analyzed, temperature and elevation are highly correlated.

The impact of HFEs on the water quality of Lake Powell will depend on reservoir elevation (Reclamation 2011b). At moderate to high reservoir levels, withdrawal of water for HFEs is not expected to negatively affect water quality in the reservoir. Releases in March–April would occur during the spring recirculation period of the reservoir, and releases in October–November would occur at the end of the thermal stratification period, when surface temperatures are the warmest (Vernieu 2010). At low reservoir levels, such as during 2005, water released for an HFE could draw from the warm top layer of the reservoir, especially in October–November, and result in warm dam releases, but it would not likely affect the overall reservoir temperature or water quality (Reclamation 2011b).

Examination of the modeling results for effects of alternative operations on release temperatures indicated that annual inflow volume to Lake Powell had a greater influence on the release temperature than the operational differences in monthly and daily flows. Under drought conditions, such as those seen recently (e.g., 2005–2010), release temperatures tend to be consistently higher because reservoir elevations are generally low and releases originate closer to the reservoir surface. However, during extreme drought, the elevation of Lake Powell may drop below the minimum power pool elevation of 3,490 ft AMSL. If this occurs, releases cannot be made from the powerplant penstocks and are instead routed through the river outlet tubes located 3,374 ft AMSL. Because water at the level of the river outlet tubes is generally colder due to its depth, release temperatures could drop to less than 10°C. If the reservoir elevations were to drop further, closer to the elevation of the river outlet tubes, the releases would again gradually warm (Reclamation 2007a).

Figure 4.2-11 compares the mean temperatures of water released from Glen Canyon Dam for wet, medium, and dry hydrology traces. These figures illustrate how little temperature variation there is among the seven LTEMP alternatives (within any given trace) compared to the much larger variation across the traces. For example, the minimum, maximum, and mean values for modeled temperature at Glen Canyon Dam vary less than 0.3°C, 0.7°C, and 0.2°C,

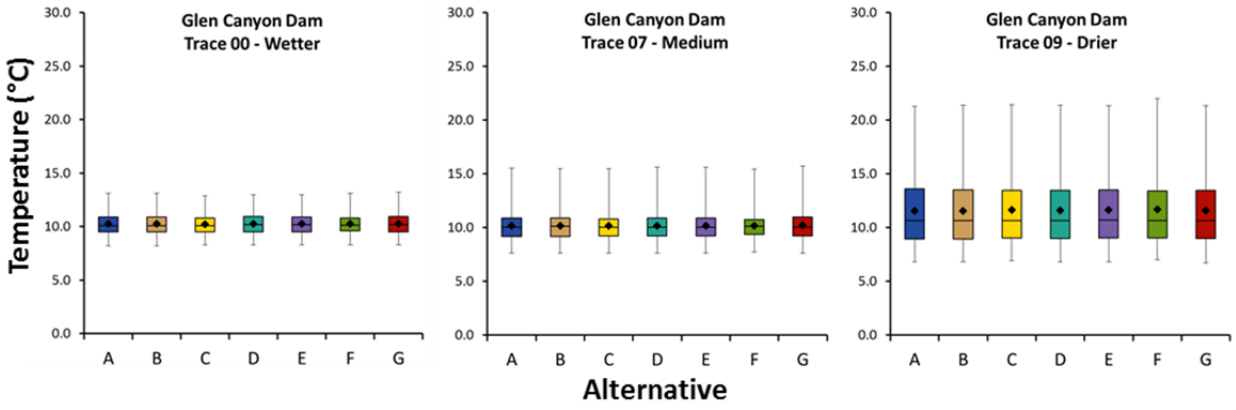

FIGURE 4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

respectively, among the alternatives for any given trace. However, across hydrology traces the minimum, maximum, and mean values vary over a range of approximately 1.5°C, 8.8°C, and 1.5°C, respectively.

Drier hydrology traces exhibit greater variation in temperature values and more pronounced differences among alternatives, although the actual differences in means are still quite small (i.e., less than 0.2°C). This is because drier traces have lower overall inflow volumes and consequently lower reservoir levels in most years. The released water associated with lower reservoir elevations is drawn from closer to the surface, where it is more sensitive to atmospheric conditions (e.g., air temperature and solar radiation). However, the release water associated with higher reservoir elevations (resulting from higher cumulative inflow volumes) tends to be drawn from deeper in the hypolimnion, which exhibits a more stable temperature profile. Therefore, operational differences that have negligible perceived impacts on temperature at larger water volumes (i.e., wetter traces) can become more pronounced during drier traces.

Figure 4.2-12 illustrates mean seasonal[5] release temperatures at Glen Canyon Dam, aggregated across the 21 hydrology traces for the modeled 20-year time period. Overall, the seasonal temperature ranges are similar across alternatives.

The minimum mean release temperatures occur in the spring, with aggregated mean values ranging from 9.0 to 9.3°C, depending on alternative. The lower end of this range is characteristic of Alternatives A and B. The top end of this range is associated with Alternative F, possibly because the reservoir elevation is lower by May after sustained higher releases in March and April. Considering all traces across the entire modeled time period, the full range of mean

5 For the purposes of this discussion, seasonal temperatures are represented by 3-month periods representing the standard meteorological seasons: December–February for winter; March–May for spring; June–August for summer; and September–November for fall.

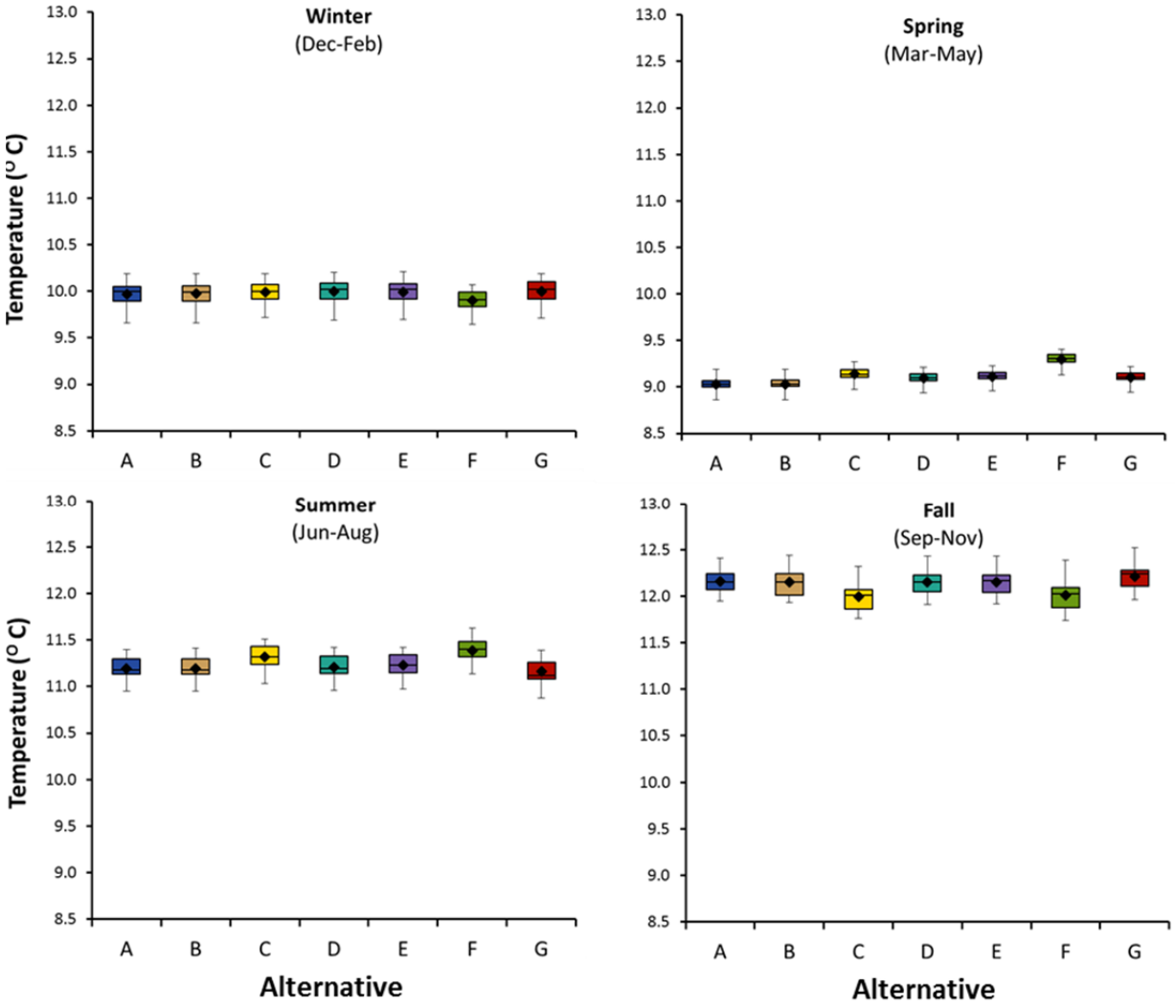

FIGURE 4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

spring release temperatures varied from around 8.8 to 9.5°C, depending on alternative. The bottom of this range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

The peak mean release temperature occurs during the fall, with aggregated means ranging from 12.0 to 12.2°C, depending on alternative; however, there are no significant differences among alternatives in mean release temperature, even in the fall. Considering all traces, the full range of mean fall release temperatures varied from around 10.7 to 14.3°C, depending on the alternative. As with spring temperatures, the bottom of the fall range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

Glen Canyon Dam release temperatures (for all alternatives) are lower in spring than in winter, and lower in summer than in fall. This difference is a result of the lag time associated with warming and cooling of Lake Powell (refer to Section 3.3.3.1 for further information on Lake Powell hydrology).

Colorado River between Glen Canyon Dam and Lake Mead

Once released from the dam, typically warmer air temperatures regulate river temperature. Consequently, the warmer spring and summer months see significant downstream warming while colder winter and fall months have much less downstream warming, and perhaps even downstream cooling (Voichick and Wright 2007). Tributaries, such as the Little Colorado River (river mile [RM] 61), provide warmer inflows in the summer and cooler inflows in the winter (refer to Section 3.3.4.2 for additional details related to Colorado River water temperatures between Glen Canyon Dam and Lake Mead.)

Comparisons of the seasonal trends in river temperatures among the seven LTEMP alternatives are illustrated in Figure 4.2-13 at locations between Glen Canyon Dam (RM 0) and Diamond Creek (RM 225). Temperatures presented in these figures represent modeled values aggregated across the 21 hydrology traces. In general, projected temperatures vary due to three factors: release volume, release temperature, and downstream meteorology and hydrology. The rate at which the water released from a reservoir approaches ambient air temperature as it travels downstream depends on these factors as well (Reclamation 2007a).

Overall, mean seasonal temperatures increase as water moves downstream. Winter river temperatures are the coldest of any season. Mean winter temperatures ranged from 9.7 to 10.2°C at RM 0 (Lees Ferry), 9.9 to 10.4°C at RM 61 (Little Colorado River), 10.2 to 10.6°C at RM 157 (Havasu Creek), and 10.4 to 10.8°C at RM 225 (Diamond Creek). These data also indicate that within any given alternative, there is a very small longitudinal gradient (i.e., at most a 0.5–0.7°C difference for mean; 1.0–1.1°C difference across the full range of values) between the mean temperatures at the Glen Canyon Dam outlet and Diamond Creek during the winter.

For all alternatives, significant downstream warming (i.e., between 6.0 and 7.2°C difference for mean; 6.8–8.1°C difference across full range of values) is expected in the summer. Average summer temperatures are the warmest of any season, ranging from 11.3 to 12.1°C at RM 0, 12.9 to 14.0°C at RM 61, 15.3 to 17.0°C at RM 157, and 16.9 to 19.2°C at RM 225. More details related to temperature values and ranges for each of the seven LTEMP alternatives are presented in Section 4.2.3.

A number of experimental actions (described in detail in Section 2.3) would be incorporated into many of the LTEMP alternatives. Operational actions such as HFEs, TMFs, low summer flows, and sustained low flows for benthic invertebrate production may have noticeable impacts on water temperature at the Glen Canyon Dam outlet and downstream. Past experimental events and water temperature models have provided the following insights into water temperature response to these experimental actions.

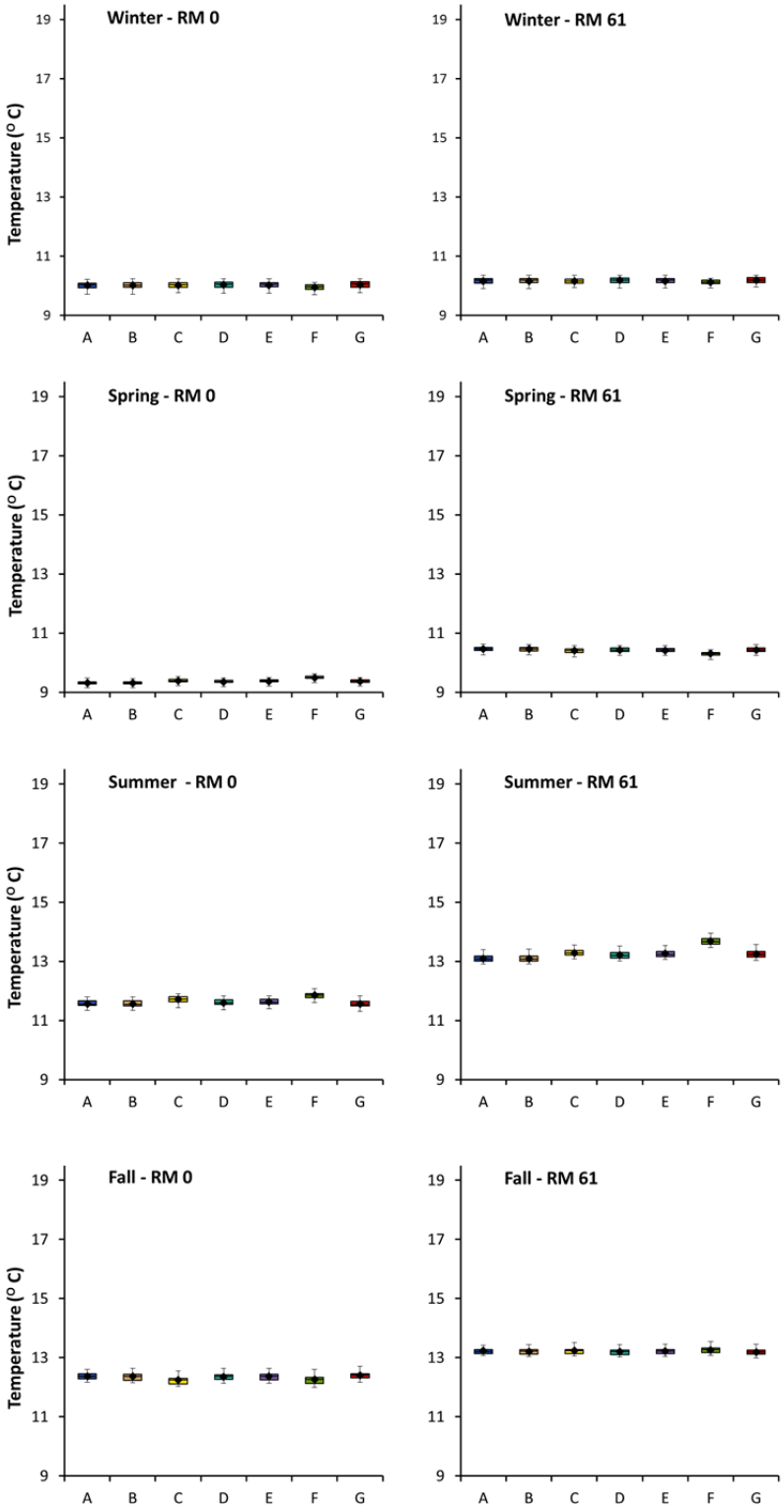

FIGURE 4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

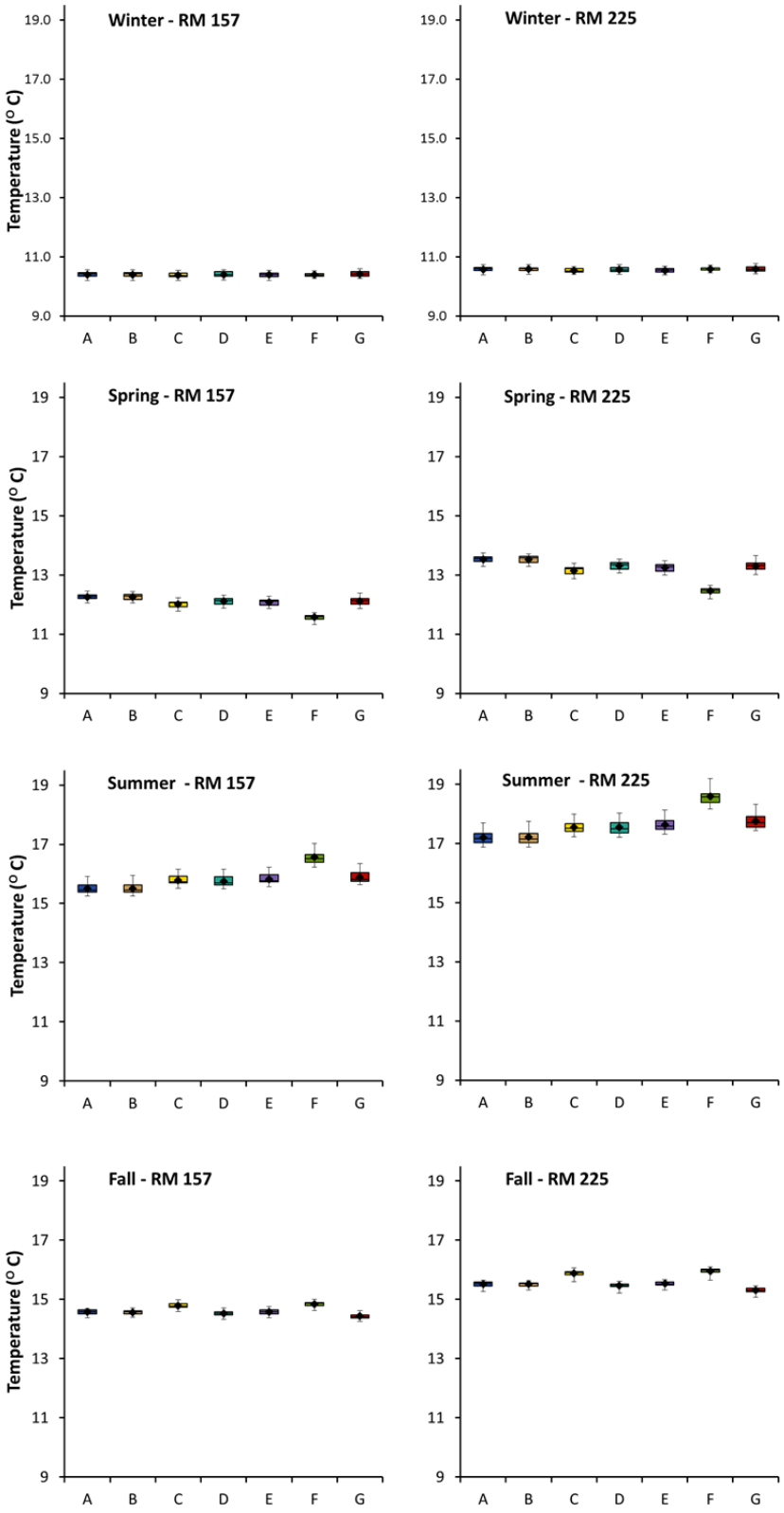

FIGURE 4.2-13 (Cont.)

The magnitude, duration, and seasonal timing of an HFE vary according to sediment input from the Paria River and other resource conditions. In the limited number of HFEs run and analyzed from 1996 to 2011 (i.e., fall of 1996, 2004, and 2008; spring of 2008), effects on water temperature have been observed to be minor and short term, and to result in slight reductions in downstream water temperature (Vernieu et al. 2005; Reclamation 2011b). Modeling conducted for this EIS reflects these observations. In general, fall end-of-month temperatures are approximately 1°C higher at Diamond Creek (RM 225) in years without an HFE event than in comparable fall seasons with HFEs. Downstream temperature cooling is similarly expected for spring HFEs, although temperature decreases are expected to be smaller (end-of-month temperatures 0.1–0.5°C cooler). Considering that the November 2012 HFE (releasing approximately 42,000 cfs for 24 hr) and the November 2013 HFE (releasing nearly 35,000 cfs for 96 hr) took only 55 and 54 hr, respectively, to reach Pearce Ferry (i.e., RM 279) (NPS 2012e, 2013j), any warming would be expected to be small and of short duration.

If very large amounts of sediment are input by the Paria River, HFEs may have durations of up to 336 hr under Alternative G and 250 hr under Alternative D. Modeling indicates that, when considering HFEs of similar magnitude (occurring in the fall), downstream warming increases slightly and gradually as the duration of the HFE increases. For example, the difference between the downstream warming of a 48-hr and 336-hr HFE (both at 45,000 cfs) was less than 1°C.

TMFs have not been tested in the Colorado River; therefore, water temperature effects of these flows are uncertain. Overall, the magnitude of flow changes for TMFs are smaller compared to HFEs. As a result, perceptible temperature changes at the dam or downstream are not expected. For example, a TMF modeled to run for 72 hours at a steady flow of 20,000 cfs does not exhibit noticeable effects on modeled water temperatures.

Experimental low summer flows could occur under Alternatives C, D, and E. Low summer flows are run at approximately 8,000 cfs for the months of July, August, and September. Modeled low summer flows show similar water temperatures just downstream of the dam, with slightly higher downstream warming, when compared to similar conditions without low summer flows. This is because lower velocity flows have a higher surface-area-to-volume ratio (compared to high flows) and greater exposure time with the ambient air, which facilitates water warming through solar radiation and atmospheric heat exchange (Vernieu et al. 2005). When considering individual model traces, variations in downstream temperatures were generally greatest in July (nearly 3°C warmer for low summer flows) and least in September (about 1°C warmer for low summer flows), with August falling in the middle (approximately 2°C warmer for low summer flows).

Macroinvertebrate[6] production flows are one of the experimental modifications to base operations for Alternative D that could be tested during the LTEMP period. For this experiment, flow on Saturdays and Sundays of May through August would be held steady at the minimum monthly flow. These stable weekend flows would be tested to determine whether they improved

6 Animal without a backbone or spinal column, usually replaced by a hard exoskeleton or shell. Examples include insects, worms, crustaceans, snails, or clams.

invertebrate production. This operational action increases the mean daily flows during the weekdays. Water temperature modeling indicates that release temperature would change little (e.g., ±0.01°C), and warming at downstream locations during the summer, as indicated by maximum temperature, would be less than 1°C (0.03°C at the confluence with the Little Colorado River [RM 61] and 0.12°C at Diamond Creek [RM 225]).

Lake Mead

Potential water quality issues in Lake Mead were evaluated based on a concern expressed by Southern Nevada Water Authority that water quality could be affected by significant shifts in the temperature of Colorado River water reaching Lake Mead. The temperature of the water determines its density and its position within the water column of Lake Mead. Warmer Colorado River inflows would enter and flow through Lake Mead in the middle of the water column (Tietjen 2014), and this could then have adverse impacts on bottom water oxygen concentrations, effectively trapping below the inflow area low-DO water that does not mix completely and that could slowly expand down the reservoir.

Modeling was conducted by the Southern Nevada Water Authority on a selected set of LTEMP alternatives (Alternatives A, E, and F) and years (2-year runs) that were considered to represent a reasonable range of potential outcomes at a much finer resolution of temporal and spatial scales compared to other modeling efforts. Because Alternative F was expected to produce the warmest water temperatures of all alternatives in the summer, it was chosen as the potential highest risk case. Modeling indicated there would be negligible differences in the distribution of low-DO areas among modeled alternatives (Tietjen 2015). The input parameters for modeling were limited by the quality of the boundary conditions at the Colorado River inflow. Prediction errors in the models producing this data will propagate through the Lake Mead model.

HFEs were not shown to have measurable impacts on Lake Mead water quality. They are expected to mix a portion of the low-DO water near the sediment-water interface up into the water column near the inflow area to Lake Mead. This should act to reduce (or possibly eliminate) any observed low-oxygen problems (Tietjen 2014).

Salinity

The projected salinity concentrations presented in Figure 4.2-14 are the flow-weighted annual means over the 20-year LTEMP period at Lees Ferry (no criteria established for this location). The results assume continuation of existing and implementation of planned salinity control programs and projects.[7]

[7] Salinity in the river may vary depending on the annual hydrology, but that variability is unrelated to the implementation of any of the LTEMP alternatives.

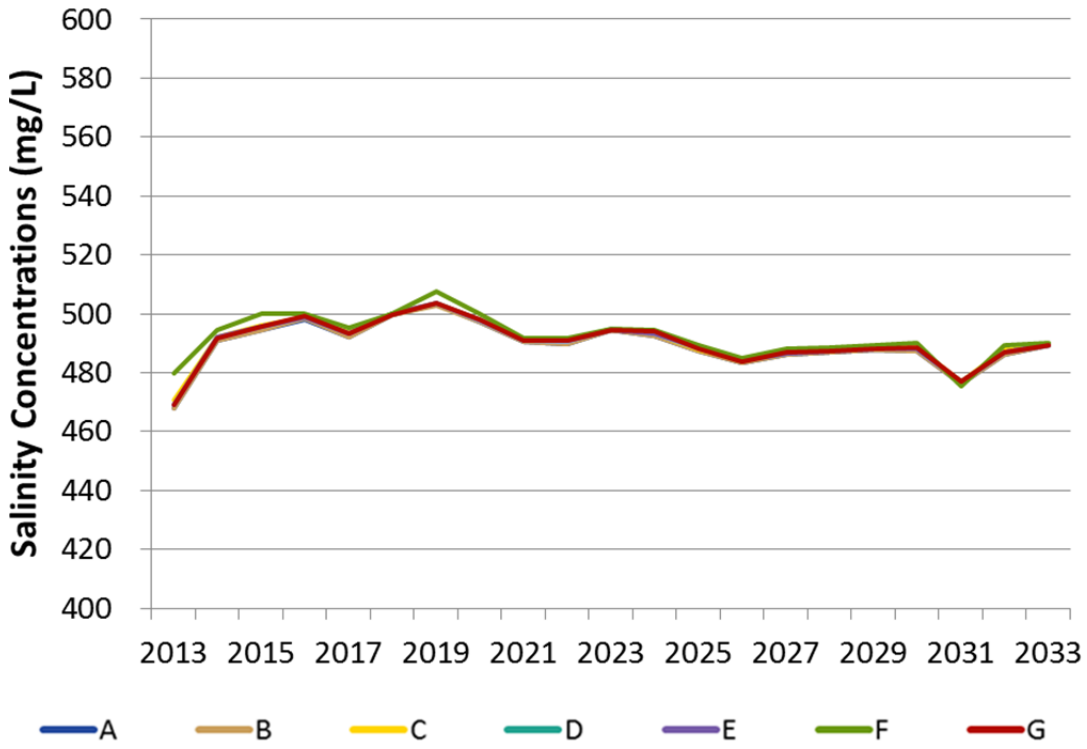

FIGURE 4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry

Under all alternatives, salinity would increase as water moves downstream. Mean concentrations at Lees Ferry are 490 mg/L, with a full range from 468 to 508 mg/L considering the entire modeled period across all seven LTEMP alternatives (Figure 4.2-14). Considering all years individually, the differences in salinity concentrations among the different alternatives is less than 2.5%.

Other Water Quality Parameters

No significant impacts on other water quality parameters (e.g., DO, nutrients, metals, and organics) are expected under any LTEMP alternative. In addition, research (Reclamation 2011b) has indicated that the potential effects of HFEs on other water quality parameters (e.g., turbidity and DO) below the dam would only be temporary, and any observed effects would recover quickly when lower flows returned (refer to Section 3.3.4.2 for more details on the effects of HFEs on water quality of the Colorado River below the Glen Canyon Dam).

With respect to turbidity, a positive correlation with tributary sediment input is also expected (refer to Section 3.3.4.2 for more information on the relationship between turbidity and suspended sediment). However, no impacts are expected because operations will not affect tributary sediment input and, therefore, will not result in differences among the alternatives.

Although an increase in visitor use could result in an increase in the occurrence of pathogens, current National Park Service (NPS) regulations limit the number of river boating trips and passengers. The capacity set by the Colorado River Management Plan of 2006 is reached every year. As a consequence, the numbers of angling and boating trips are not expected to change as a result of any of the alternatives, and no difference in pathogenic or disease-causing organisms is expected because there will be no variation in the number of visitors. However, certain types of flow have been associated with local occurrences of high pathogenic bacterial counts. For example, low steady flows, particularly during periods of high recreational use, can result in local areas of exceedances due to the buildup of bacteria along the shoreline. Higher-volume flows, including HFEs, could mobilize these bacteria harbored in streamside sediments from past recreational use, in effect flushing out areas of concern, but also temporarily increasing downstream bacteria counts. However, any increase would be short lived (i.e., hours or days depending on the duration of the high-flow event) and would be followed by a decrease in the areas flushed by the high flows. As a result, high flows are not likely to result in measurable increases in bacteria or pathogens, given the short time period and the dilution by a large volume of water. However, alternatives with long-duration lower and steadier flows may lead to a higher potential for contamination from bacteria and other pathogens and, thus, could increase the possibility of health hazards associated with contaminated water. Years with low release volumes (<8.23 maf) would have a higher probability of occurrence. The probability of this contamination occurring is expected to be very low, and the effects would be localized for all alternatives. However, there are potential differences among alternatives related to the occurrence of low flows and HFEs. Alternatives C, D, and E include low summer flow experiments during which there could be a slight increase in the potential for bacteria and pathogen contamination compared to Alternatives A and B. Alternatives F and G have the highest (though still low) potential, given the annual occurrence of steady flows.

4.2.3 Alternative-Specific Impacts

The following sections describe the range of alternative-specific impacts on hydrology, (i.e., reservoir releases and elevations, river flows) and water quality. Both water delivery metrics and other system relevant conditions (e.g., reservoir elevations) are discussed for each alternative. Each alternative was modeled using 21 different potential scenarios that accounted for uncertainty in future hydrologic conditions. Figures 4.2-1 through 4.2-14 show the results for all alternatives; plots comparing each action alternative to Alternative A can be found in Appendix D.

The modeling predicted that inflow hydrology has the most effect on operating tier, release volume, and resulting reservoir elevations, whereas the alternatives show smaller effects. Differences among the LTEMP alternatives are expected to be negligible with regard to salinity, turbidity, nutrients, DO, metals/radionuclides, or organic/other contaminants. As a result, temperature, bacteria, and pathogens are the only water quality parameters discussed in this section. When analyzing the temperature differences between the LTEMP alternatives, differences of less than 0.5°C are not regarded as significant because of the inherent temperature variability observed in the natural environment, combined with the reported standard error

(i.e., less than 0.5°C) for the temperature model applied (Wright, Anderson et al. 2008). Thus, only temperature differences greater than 0.5°C are explained in further detail.

4.2.3.1 Alternative A (No Action Alternative)

During the interim period (through 2026), Alternative A would operate at times within each of the four operating tiers, at the following mean annual frequencies: Upper Elevation Balancing Tier—46.2%; Equalization Tier—37.4%; Mid-Elevation Release Tier—15.4%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative A has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

During wet years, the modeling showed that Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. For Alterative A, the mean number of occurrences of annual release extending beyond the water year per 20-year trace is 0.7, with a range of 0 to 2 occurrences per 20-year period. The mean volume of annual release extending beyond the water year is 248 kaf, with a range from 0 to 2,021 kaf.

Under Alternative A, monthly reservoir releases are generally higher in December, January, July, and August and lower in the other months. In the years 2014–2020, when HFEs would be implemented under Alternative A, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell elevations would vary significantly with hydrology but would vary little by alternative. Depending on hydrology, Lake Powell elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Powell at the end of December was about 3,630 ft throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative A, this modeling showed two instances out of 420 (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool.

Lake Mead elevations would also vary significantly with basin hydrology and the resulting Lake Powell release, but would vary little by alternative. Depending on hydrology, Lake Mead elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Mead at the end of December ranged from about 1,100 ft near the beginning of the period to about 1,080 ft near the end of the 20-year LTEMP period. End-of-December elevations at the beginning of the period ranged from about 1,080 ft to about 1,160 ft at the 10th and 90th percentiles, respectively, and from about 1,020 ft to about 1,210 ft near the end of 20-year LTEMP period. Under Alternative A, the percentage of traces with Lower Basin Shortages is 0 for the first 2 years of the period, and then increases to 62% of traces near the end of the 20-year period.

Mean monthly volume under Alternative A would be similar to current conditions and would be highest during months with relatively high hydropower demand (December, January, June, July, and August), when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

Mean daily flows under Alternative A also would represent no change from current conditions, and would be highest in the higher volume months of December, January, June, July, August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative A, the allowable daily range is dependent on monthly volume and ranges from 5,000 to 8,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,000 to 7,800 cfs (Figure 4.2-4). In other months, mean daily change would range from 2,600 to 6,400 cfs.

Seasonal temperature data and trends are provided in Table 4.2-2 for the seven LTEMP alternatives as a function of distance downstream from RM 0 (i.e., Lees Ferry) through RM 225 (i.e., Diamond Creek). The minimum, maximum, and mean temperature data presented in these figures represent values aggregated across the 21 hydrology traces over the 20-year LTEMP period.

For Alternative A, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.6°C (11.6–17.2°F) difference. Spring temperatures warm around 4.2°C (9.3–13.5°C); fall temperatures warm about 3.1°C (12.4–15.5°C).

Under Alternative A, there would be no change from current conditions in the occurrence of bacteria or pathogen contamination along shorelines. The expected probability of this contamination occurring is very low, and would be localized and temporary.

In summary, Alternative A would result in no changes in current conditions related to hydrology or water quality.

4.2.3.2 Alternative B

Alternative B would show little or no difference from Alternative A with regard to operating tier, in almost every one of the 21 hydrology traces modeled. This is the smallest difference among all of the action alternatives. Compared to Alternative A, Alternative B would result in the same frequency of operating tiers, the same average number of occurrences of modeled annual releases extending beyond the water year, and the same volume of annual

TABLE 4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Winter (December–February)												
Alternative A	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative B	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative C	9.8	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.5	10.4	10.5	10.7
Alternative D	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative E	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.5	10.7
Alternative F	9.7	9.9	10.1	9.9	10.1	10.3	10.3	10.4	10.5	10.5	10.6	10.7
Alternative G	9.8	10.0	10.2	10.0	10.2	10.4	10.3	10.4	10.6	10.4	10.6	10.8
Spring (March–May)												
Alternative A	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.5	13.3	13.5	13.7
Alternative B	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.4	13.3	13.5	13.7
Alternative C	9.2	9.4	9.5	10.2	10.4	10.6	11.8	12.0	12.2	12.9	13.2	13.4
Alternative D	9.2	9.4	9.5	10.3	10.4	10.6	11.9	12.1	12.3	13.1	13.3	13.5
Alternative E	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.3	13.0	13.3	13.5
Alternative F	9.3	9.5	9.6	10.1	10.3	10.4	11.3	11.6	11.7	12.2	12.5	12.6
Alternative G	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.4	13.0	13.3	13.7
Summer (June–August)												
Alternative A	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	15.9	16.9	17.2	17.7
Alternative B	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	16.0	16.9	17.2	17.8
Alternative C	11.4	11.7	11.9	13.1	13.3	13.6	15.5	15.8	16.2	17.2	17.6	18.0
Alternative D	11.4	11.6	11.8	13.0	13.2	13.5	15.5	15.8	16.2	17.2	17.5	18.0
Alternative E	11.4	11.6	11.8	13.1	13.3	13.5	15.6	15.8	16.2	17.3	17.6	18.1

TABLE 4.2-2 (Cont.)

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Summer (June–August) (Cont.)												
Alternative F	11.6	11.9	12.1	13.5	13.7	14.0	16.2	16.6	17.0	18.2	18.6	19.2
Alternative G	11.3	11.6	11.8	13.0	13.3	13.6	15.6	15.9	16.4	17.4	17.8	18.3
Fall (September–November)												
Alternative A	12.2	12.4	12.6	13.1	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative B	12.2	12.4	12.6	13.0	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative C	12.0	12.3	12.6	13.1	13.2	13.5	14.6	14.8	15.0	15.6	15.9	16.1
Alternative D	12.1	12.4	12.6	13.0	13.2	13.4	14.3	14.5	14.7	15.2	15.5	15.6
Alternative E	12.1	12.4	12.6	13.0	13.2	13.5	14.4	14.6	14.8	15.3	15.5	15.7
Alternative F	12.0	12.3	12.6	13.1	13.3	13.5	14.6	14.8	15.0	15.7	16.0	16.1
Alternative G	12.2	12.4	12.7	13.0	13.2	13.5	14.3	14.4	14.6	15.1	15.3	15.5

release extending beyond the water year. In addition, the end-of-December elevations under Alternative B for Lake Powell and Lake Mead would be identical to those under Alternative A.

Under Alternative B, monthly reservoir releases would be nearly identical to those of Alternative A. Releases from Lake Powell can vary from Alternative A by up to 4 kaf in 3% of months due to different ramp-down constraints. In years when HFEs would be implemented under Alternative B, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Mean monthly volumes under Alternative B would be identical to those under Alternative A and similar to current conditions. Volume would be highest during months with relatively high hydropower demand (December, January, June, July, and August) when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

Mean daily flows under Alternative B also would be similar to current conditions. They would be highest in the higher volume months of December, January, June, July, and August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative B, the allowable daily change is higher than under Alternative A and ranges from 6,000 to 12,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,500 to 12,000 cfs (Figure 4.2-4). In other months, mean daily change would range from 3,000 to 10,000 cfs.

Modeled water temperature ranges and means under Alternative B are nearly identical to those under Alternative A (Table 4.2-2), because the two alternatives have the same monthly release volumes. Daily fluctuation differences, which are greater for Alternative B relative to Alternative A, are thought to have a negligible impact on water temperature (Anderson and Wright 2007). Other operational differences between the two alternatives related to ramp rates and test flows (e.g., HFEs, hydropower improvement flows, and TMFs) would not affect seasonal temperature trends.

Under Alternative B, there is a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines. This lower probability would result from the slightly higher daily fluctuations under this alternative relative to Alternative A. Experimental hydropower improvement flows would have the lowest probability of occurrence. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative B would result in no change from current condition related to reservoir elevations, annual operating tiers, monthly release volumes, or mean daily flows, but would produce higher mean daily changes in flow. Hydropower improvement flows would cause even greater mean daily flow changes. Compared to

Alternative A, there would be negligible differences in temperature or other water quality indicators, but Alternative B has a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines.

4.2.3.3 Alternative C

Alternative C would show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative C is 210 kaf less than Alternative A in an 8.23-maf release year; this difference could result in a slightly higher end-of-December elevation and sometimes a different operating tier. Alternative C would result in a different operating tier from that under Alternative A in 2.1% of years.

The frequency of operating tiers under Alternative C would be very similar to that under Alternative A. During the interim period (through 2026), Alternative C would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—46.2%; Equalization Tier—38.1%; Mid-Elevation Release Tier—14.7%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative C has 1 year less than Alternative A, with annual releases of 8.23 maf (average of 71.4% of years), and 1 year more than Alternative A, with annual releases greater than 8.23 maf in an average of 28.6% of years. Because of the lower October through December release volume, it is possible that the higher elevation would result in Lake Powell operating in a higher operating tier. This is depicted in Figure 4.2-8, which shows at least one trace that operates in the Upper Elevation Balancing Tier instead of the Mid-Elevation Release Tier as compared to Alternative A (shown as a decrease in the Mid-Elevation Release 75th percentile and a corresponding increase in the Upper Elevation Balancing median relative to Alternative A).

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alternative C, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative C, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual releases extending beyond the water year also would be less than under Alternative A, with an average volume of 107 kaf and a range from 0 to 1,210 kaf.

Under Alternative C, monthly release volumes in July through November would be lower than under Alternative A. Release volumes from December through August are higher than those under Alternative A. In years when HFEs would be implemented under Alternative C, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative C, the monthly volumes in May and June would be increased to accommodate lower July through September

volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.8 times per 20-year trace, with a range from zero to four per trace.

Modeling of experimental low summer flows showed that Alternative C would not affect the operating tier. The modeling of low summer flows also showed a slight potential for increases in annual releases extending beyond the water year; however, they would be operationally modified to help ensure that did not occur.

Lake Powell end-of-December elevations under Alternative C would tend to be slightly higher than those under Alternative A. Under Alternative C, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 1.5 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative C, end-of-December elevations at the 10th percentile were on average 0.7 ft higher than those under Alternative A, and on average 1.0 ft higher than those at the 90th percentile under Alternative A. Under Alternative C, the percentage of traces below minimum power pool would be identical to those under Alternative A.

Lake Mead end-of-December elevations under Alternative C would tend to be slightly lower than those under Alternative A. Under Alternative C, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.6 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C, elevations at the 10th percentile were on average 2.9 ft lower than Alternative A, with a maximum difference of 10 ft. Elevations at the 90th percentile were on average 3.2 ft lower than those under Alternative A. Under Alternative C, the percentage of traces with Lower Basin Shortages are sometimes 5% higher and sometimes 5% lower than under Alternative A; however, the general trend and range of traces with shortages are similar to Alternative A, ranging from 0 for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year simulation.

Compared to Alternative A, mean monthly volume under Alternative C would be higher (by 82,000 to157,000 ac-ft) from February through May, and lower (by 111,000 to 200,000 ac-ft) in August through October; volume would be comparable to that under Alternative A in other months (Figure 4.2-2). The pattern of monthly volumes results from targeted lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 490,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative C would follow the same pattern as monthly volume and would be higher (by 1,300 to 2,500 cfs) than under Alternative A from February through May, and lower (by 1,800 to 3,300 cfs) in August through October; mean daily flow would be comparable to that under Alternative A in other months (Figure 4.2-3).

Under Alternative C, the allowable daily change is lower than under Alternative A, but is proportional to monthly volume (Chapter 2). Mean daily change would be lower than under Alternative A in all months and would range from 1,300 to 6,200 cfs (Figure 4.2-4).

Under Alternative C, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.8°C (11.7–17.6°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.8°C (9.4–13.2°C), and fall temperatures would warm about 3.6°C (12.3–15.9°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative C vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative C, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low and would be localized and temporary.

In summary, compared to Alternative A, Alternative C would result in some change from current conditions related to reservoir elevations, annual operating tiers, monthly release volumes, and mean daily flows, but it would result in lower mean daily changes in flow throughout the year. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.4 Alternative D (Preferred Alternative)

Alternative D would show little or no difference from Alternative A with regard to operating tier. Alternative D does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative D, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative D, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.4 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year

also would be less than under Alternative A, with an average volume of 146 kaf and a range from 0 to 1,495 kaf.

In years without experimental low summer flows, the monthly release volumes under Alternative D would be fairly constant throughout the year, the most constant of all alternatives except Alternative G. In the years when HFEs would be implemented under Alternative D, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative D, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. Under Alternative D, experimental low summer flows would be implemented only during the second 10 years of the LTEMP period, and would use the implementation processes described in Sections 2.2.4.3, 2.2.4.4, and 2.2.4.6. On the basis of release temperatures and the ability to achieve target downstream temperatures, these would take place on average 0.7 times per 20-year trace, with a range of zero to three per trace.

Lake Powell end-of-December elevations under Alternative D would be nearly indistinguishable from those under Alternative A. Under Alternative D, the median elevation for Lake Powell at the end of December would be about 3,630 ft, on average 0.2 ft higher than under Alternative A throughout the 20-year LTEMP period. Near the beginning of the period, end-of-December elevations ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative D, end-of-December elevations were on average 0.2 and 0.1 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative D, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool. This is one more year than under Alternative A and is a result of Alternative D releasing 151 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative D would be very similar to those under Alternative A. Under Alternative D, the median elevation for Lake Mead at the end of December was on average the same as Alternative A: about 1,100 ft near the beginning of the period and about 1,080 ft near the end of the period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative D, elevations were on average 0.7 and 0.4 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative D, implementation of low summer flows would result in one additional trace in shortage in 2025 compared with Alternative A (1 year out of 420 years total). Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Modeling of experimental low summer flows and macroinvertebrate production flows showed that Alternative D would not affect the operating tier. The modeling of low summer flows also showed a slight potential for increases in annual releases extending beyond the water year; however, they would be operationally modified to help ensure that did not occur.

Compared to Alternative A, mean monthly volume under Alternative D would be higher (by 43,000 to 98,000 ac-ft) in October, November, February, March, and April, and lower (by 60,000 to 127,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes approximates that of Western Area Power Administration's (WAPA's) contract rate of delivery. Volume in high-demand months would range from approximately 640,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 620,000 to 1,200,000 ac-ft in other months. Note that adjustments made to Alternative D after modeling was complete resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

Mean daily flows under Alternative D would follow the same pattern as monthly volume and would be higher (by 700 to 3,000 cfs) than Alternative A in October, November, February, March, and April, and lower (by 1,000 to 2,100 cfs) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-3).

Under Alternative D, the allowable daily change would be proportional to monthly volume (Section 2.2.4). Mean daily change would be slightly higher than that under Alternative A in October through June, but the same or less in July through August. Mean daily change would range from about 2,700 to 7,600 cfs (Figure 4.2-4).

Under Alternative D, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.5°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative D vary less than ±0.3°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative D, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative D would result in negligible changes from current conditions related to reservoir elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and lower mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.5 Alternative E

Alternative E would show little or no difference from Alternative A with regard to operating tier. Alternative E does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative E, more water would be released in the earlier months of water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative E, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 109 kaf and a range from 0 to 1,022 kaf.

In years without experimental low summer flows, the monthly releases volumes under Alternative E would be fairly constant throughout the year and comparable to Alternative D. In years when HFEs would be implemented under Alternative E, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative E, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.5 times per 20-year trace, with a range from zero to four per trace.

Lake Powell end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 0.3 ft higherthan under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative E, end-of-December elevations were on average 0.2 and 0.3 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative E, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490 ft minimum power pool. This is one more year than under Alternative A. This is a result of Alternative E releasing 203 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.1 ft lower than under Alternative A throughout the 20-year LTEMP

period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative E, elevations throughout the period averaged 0.9 and 0.7 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative E, implementation of low summer flows would result in one additional trace in shortage in 2020 compared with Alternative A (1 year out of 420 years total) and one fewer trace in 2022. Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, starting at zero for the first 2 years of the model period, then increasing to 62% of traces near the end of the 20-year period.

Implementation of experimental low summer flows under Alternative E would not affect the operating tier, but slight differences could result for volumes of annual release extending beyond the water year and end-of-year elevations at Lake Powell and Lake Mead; however, they would be operationally modified to ensure that did not occur.

Compared to Alternative A, mean monthly volume under Alternative E would be higher (by 45,000 to 128,000) in October, November, February, March, and April, and lower (by 30,000 to 242,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes follows WAPA's contract rate of delivery, but it is lower in August and September to target lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 660,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 580,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative E would follow the same pattern as monthly volume and would be higher (by 700 to 2,100 cfs) than Alternative A in October, November, February, March, and April, and lower in (by 500 to 4,000 cfs) December, January, July, August, and September; volumes would be comparable to those under Alternative A in May and June (Figure 4.2-3).

Under Alternative E, the allowable daily change would be proportional to monthly volume (Chapter 2), and higher than under Alternative A, in all months but September and October (lower in these two months). Mean daily change would range from 1,100 to 9,600 cfs (Figure 4.2-4).

Under Alternative E, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.6°C) difference, notwithstanding the effect of low summer flows. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative E vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative E, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative E would result in negligible change from current conditions related to reservoir elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and higher mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.6 Alternative F

Alternative F would show the greatest differences from Alternative A with regard to operating tier of all the alternatives. The October-through-December release volume for Alternative F is 534 kaf less than Alternative A in an 8.23-maf year; this difference could result in a slightly higher end-of-December Lake Powell elevation, and sometimes a different operating tier. Alternative F would result in a different operating tier from that under Alternative A in 2.1% of years.

Alternative F would result in fewer instances of the Mid-Elevation Release Tier (decrease of 2.2% of years on average) and more instances of the Upper Elevation Balancing and Equalization Tiers (increase of 1.1% of years on average for both tiers). During the interim period (through 2026), Alternative F would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—47.3%; Equalization Tier—38.5%; Mid-Elevation Release Tier—13.2%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative F has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative F, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative F, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, and the lowest of all the alternatives with an average of 0.1 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year is also less than under Alternative A, and the lowest of all alternatives with an average volume of 69 kaf and a range of 0 to 1,135 kaf.

Under Alternative F, monthly release volumes follow a more natural hydrograph pattern than other alternatives, with the highest flows in the spring months April through June and lower flows in the remaining months. Release volumes in December through August are significantly lower than those under Alternative A. When HFEs would be implemented under Alternative F, water would be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative F would be higher than those under Alternative A; this would be the largest difference of all the alternatives. Under Alternative F, the median elevation for Lake Powell at the end of December was about 3,630 ft, on average 3.2 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,565 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,565 ft to about 3,680 ft near the end of the period. Under Alternative F, end-of-December elevations were on average 5.1 and 1.8 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative F, this modeling showed there would be no occurrences of Lake Powell elevations dropping below the minimum power pool.

Lake Mead end-of-December elevations under Alternative F would be lower than those under Alternative A. Under Alternative F, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 2.9 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative F, elevations throughout the period were on average 4.0 and 2.3 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Near the end of the period, however, elevations under Alternative F were up to 12.5 ft lower than those under Alternative A at the 10th percentile. Under Alternative F, the percentage of traces with Lower Basin Shortages would be higher than that under Alternative A in nearly all years, with differences ranging from 0 to 10% higher than under Alternative A. However, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative F would be much higher (by 439,000 to 651,000 ac-ft) in April, May, and June, but much lower (by 214,000 to 433,00 ac-ft) in December, January, July, August, and September (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Volume in high-demand months would range from approximately 430,000 to 1,700,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 440,000 to 1,500,000 ac-ft in other months.

Mean daily flows under Alternative F would follow the same pattern as monthly volume and would be much higher (by 7,400 to 10,600 cfs) in April, May, and June, but much lower (by 3,600 to 7,000 cfs) in December, January, July, August, and September (Figure 4.2-3).

Under Alternative F, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative F, mean winter temperatures (Table 4.2-2) are expected to warm the least, with a difference of about 0.6°C (9.9–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.8°C (11.9–18.6°C) difference. Spring temperatures would warm around 3.0°C (9.5–12.5°C), and fall temperatures would warm about 3.7°C (12.3–16.0°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative F are different than those under Alternative A in the spring and summer seasons. In the spring, the downstream temperature difference at Diamond Creek would be approximately 1.1°C cooler than that for Alternative A. This is likely due to the fact that this alternative has much higher average spring releases, so larger volumes of seasonally cooler Lake Powell water are released downstream (Vernieu et al. 2005; Reclamation 2011b) than in any of the other LTEMP alternatives. In addition, Alternative F features a total of 22 high flows (both sediment-triggered HFEs and other high-flow events) in the spring, which may add to the overall downstream cooling effect.

For the summer period, the downstream mean temperature at Diamond Creek would be approximately 1.4°C warmer than that under Alternative A. This warming is a result of much lower summer flows associated with Alternative F compared to all of the other LTEMP alternatives. These lower flows allow for a larger surface-area-to-volume ratio and greater exposure time with the warmer summer ambient air, which facilitates downstream warming (Vernieu et al. 2005).

Under Alternative F, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from annual low steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E; however, the probability is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative F would result in some change from current conditions related to reservoir elevations and annual operating tiers, large changes in monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A and the other alternatives, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.7 Alternative G

Alternative G is expected to show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative G is 75 kaf more than Alternative A in an 8.23-maf year; this difference could result in a slightly lower

end-of-December Lake Powell elevation and sometimes a different operating tier. Alternative G would result in a different operating tier from that under Alternative A in 0.7% of years.

The frequency of operating tiers under Alternative G would be identical to that under Alternative A during the interim period (through 2026) and nearly the same as Alternative A after the interim period. After the interim period, Alternative G would have at least one trace with fewer annual releases of 8.23 maf (average of 71.4% of years) than Alternative A and at least one trace with more annual releases greater than 8.23 maf (average of 28.6% of years) than Alternative A.

Modeling indicated that, during wet years, Glen Canyon Dam may not always be able to fully release the annual volume within the water year due to forecast uncertainty resulting in modeled annual releases extending beyond the water year. Under Alterative G, more water would be released than under Alternative A in the earlier months of the water year; therefore, Alternative G would not result in as many instances of modeled annual releases extending beyond the water year, nor would it result in volumes that are as high. Under Alternative G, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A with an average of 0.5 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 151 kaf and a range from 0 to 1,440 kaf.

Under Alternative G, monthly release volumes are as constant as possible, given hydrologic uncertainty throughout the water year. Release volumes during December through August are slightly higher than those under Alternative A. In years when HFEs would be implemented under Alternative G, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative G would tend to be slightly lower than those under Alternative A. Under Alternative G, the median elevation for Lake Powell at the end of December would be nearly the same as under Alternative A (about 3,630 ft), and on average 0.4 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative G, end-of-December elevations were on average 1.2 and 0.3 ft lower than those at the 10th and 90th percentiles, respectively, under Alternative A. Under Alternative G, there are two occurrences of Lake Powell below the minimum power pool, the same as under Alternative A.

Lake Mead end-of-December elevations for Alternative G would tend to be slightly higher than those under Alternative A. Under Alternative G, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 1.4 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about

1,010 ft to about 1,210 ft near the end of the period. Under Alternative G, elevations at the 10th percentile were sometimes higher and sometimes lower compared to Alternative A, with differences ranging from 6.8 ft lower to 4.0 ft higher throughout the 20-year period. Elevations at the 90th percentile were nearly identical to those under Alternative A (the maximum difference in any year was 1.0 ft). Under Alternative G, there was one fewer trace in shortage in 2017 compared to Alternative A (1 year out of 420 years total) and one more trace in 2020. Otherwise, the general trend and range of traces with shortage are the same as under Alternative A, starting at zero for the first 2 years of the model run, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative G would be higher (by 71,000 to 286,000 ac-ft) in October, November, March, and April, but lower (by 139,000 to 196,000 ac-ft) in December, January, July, and August (Figure 4.2-2). The monthly pattern for Alternative G is approximately equal to monthly volumes throughout the year, except for adjustments due to changes in forecast. Volume in high-demand months would range from approximately 60,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 600,000 to 1,300,000 ac-ft in other months.

Mean daily flows under Alternative G would follow the same pattern as monthly volume and would be higher (by 1,200 to 4,800 cfs) in October, November, March, and April, but lower (by 2,300 to 3,200 cfs) in December, January, July, and August (Figure 4.2-3).

Under Alternative G, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative G, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.2°C (11.6–17.8°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 2.9°C (12.4–15.3°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative G are slightly warmer than those under Alternative A in the summer season (temperature difference at Diamond Creek is approximately 0.6°C warmer than under Alternative A). As under Alternative F, this summer warming is likely a result of the lower summer flows compared to those of Alternative A, which would facilitate downstream warming (Vernieu et al. 2005). The degree of warming is less than that observed under Alternative F, because summer flows associated with Alternative G are somewhat higher in comparison.

Under Alternative G, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from year-round steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E, but is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative G would result in negligible change from current conditions related to reservoir elevations and annual operating tiers, and even monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.3 SEDIMENT RESOURCES

Issue: How do alternatives affect sediment resources in the project area?

Impact Indicators:

- The amount of sand transported during high flows relative to total sand transport
- Sand mass balance in Marble Canyon
- The size and position of the Colorado River delta in Lake Mead

This section presents an analysis of impacts on sediment resources of the Colorado River corridor between Glen Canyon Dam and Lake Mead, and inflow deltas in Lake Mead. Sediment resources include sandbars, beaches, and lake deltas. Sediment is one of the fundamental components of the ecosystem along the river corridor in Glen and Grand Canyons. The dynamics considered are the building and erosion of sandbars and beaches as well as the sediment remaining in the river channel, in the river corridor below the dam. The sediment objective, as stated in Section 1.4, is to "increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes." This section evaluates alternatives against this objective.

Quantitative analysis using a set of numerical models was conducted for the Colorado River from Lees Ferry (RM 0) to Phantom Ranch (RM 87). Because a quantitative model is only available from Lees Ferry to RM 87, impact assessments for the Colorado River corridor upstream of Lees Ferry, downstream of RM 87, and for lake deltas are more qualitative in nature but were considered sufficient to assess these impacts.

There are two generally opposing processes related to sediment resources downstream of Glen Canyon Dam: (1) sediment deposition in sandbars at elevations above the range of normal flows and (2) retention of sediment within a reach of the river. Because of the limited sand supply, the flows needed to achieve the first objective (e.g., building high-elevation sandbars) reduce the amount of sand retained on the riverbed within a reach. Using dam operations, it is not possible to build high-elevation sandbars without transporting sand out of the reach.

Operations at Glen Canyon Dam directly affect sediment resources via changes in releases and corresponding downstream flows and changes in reservoir elevation in Lakes Powell and Mead. These changes can occur on hourly, daily, monthly, and annual timescales. Changes in river flow result in changes in sandbar sediment storage and riverbed sand storage. Aspects of operations and river flow that affect sediment resources are related to the monthly distribution of annual release volumes, daily fluctuations, and the frequency, magnitude, and

duration of HFEs, TMFs, and proactive spring HFEs. This section analyzes the impacts of LTEMP alternatives on these resources for the 20-year LTEMP period.

4.3.1 Analysis Methods

Sediment resources, such as sandbars and riverbed sand, are linked to flow and to each other, just as most other resources discussed in this EIS are linked to sediment.

Impacts were analyzed on the basis of the following categories of information, which are further explained below:

- Records of river stage, streamflow, and sediment discharge at USGS gaging stations along the river and on principal sediment-producing tributaries;
- Sandbar measurements made by Northern Arizona University;
- Published journal articles; and
- Results from the modified Sand Budget Model.

Sandbar deposits (and sandbar-dependent resources such as camping beaches and some archaeological sites) are affected by the amount of riverbed sand transported under a given alternative. A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars, with corresponding changes in aquatic and riparian habitat (Reclamation 1995). Changes in sandbar and riverbed sand depend primarily on tributary sand supply; the magnitude, frequency, and duration of HFEs; and the magnitude of daily powerplant fluctuations. Because very little of the sediment input to Lake Powell is released from Glen Canyon Dam, and there is little sediment input between the dam and the confluence with the Paria River, high releases contain very little sediment until after they pass through the Glen Canyon reach.

Currently, there is no available model that can predict sandbar response to differing flow release volumes and patterns. It has been established, however, that "large eddy sandbars form when suspended-sediment loads are transported in high concentrations by the main flow. High sandbars are constructed by large magnitude floods that rise to relatively high elevations" (Schmidt and Grams 2011a). Thus, having high flows that are rich in suspended sediment provide the means for potential sandbar growth.

Because a model is not available to simulate reach-wide sandbar response to dam operations, an indicator of sandbar building was developed that represents the conditions necessary for sandbar deposition (high flows rich in suspended sediment). The potential for building sandbars was estimated using the sand load index, which is a comparison of the mass of sand transported at river flows ≥31,500 cfs relative to the total mass of sand transported at all flows (Figure 4.3-1). The index varies from 0 (no sand transported at flows ≥31,500 cfs) to 1 (all sand transported at flows ≥31,500 cfs); the larger the sand load index for an alternative, the more

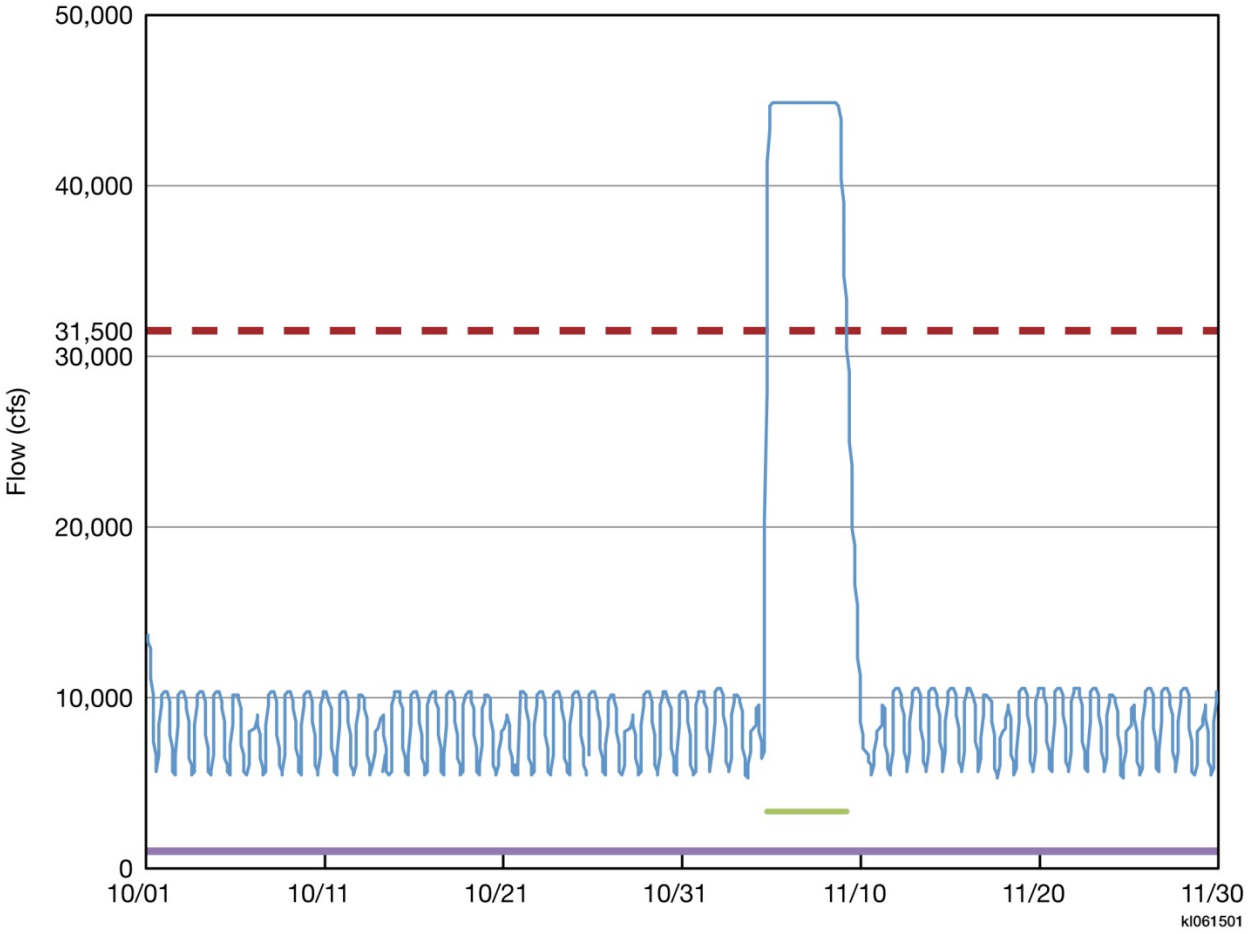

FIGURE 4.3-1 Conceptual Depiction of the Sand Load Index (The blue line is the time series of river flow, and the dashed red line is the threshold condition of 31,500 cfs. The green lines represent the amount of time during which river flow is ≥31,500 cfs. The purple line represents the entire time period of interest. The sand load index is the amount of sand that is transported during the time represented by the green line, relative to the amount of sand transported during the time represented by the purple line.)

potential there is for bar growth (Appendix E). The sand load index only estimates the potential for (and not actual) bar growth, because all sandbars have a maximum potential deposition volume; the closer any given bar is to full, the less deposition will occur (Wiele and Torizzo 2005). The sand load index does not address fully the erosion of sandbars from intervening flows between HFEs.

The increase in potential sandbar growth necessarily increases the mass of sand that moves downstream, decreasing the sand budget. That is, having a high potential for bar growth (resulting from a high sand load index) causes a decrease in the amount of sand on the riverbed, and having a low potential for bar growth (resulting from a low sand load index) allows for more sand to be retained on the riverbed. The measure of sand budget used in this analysis is the sand mass balance index (Figure 4.3-2) calculated for Marble Canyon (RM 0 to RM 61); it is the estimated mass of sand remaining at the end of the 20-year LTEMP period relative to the sand

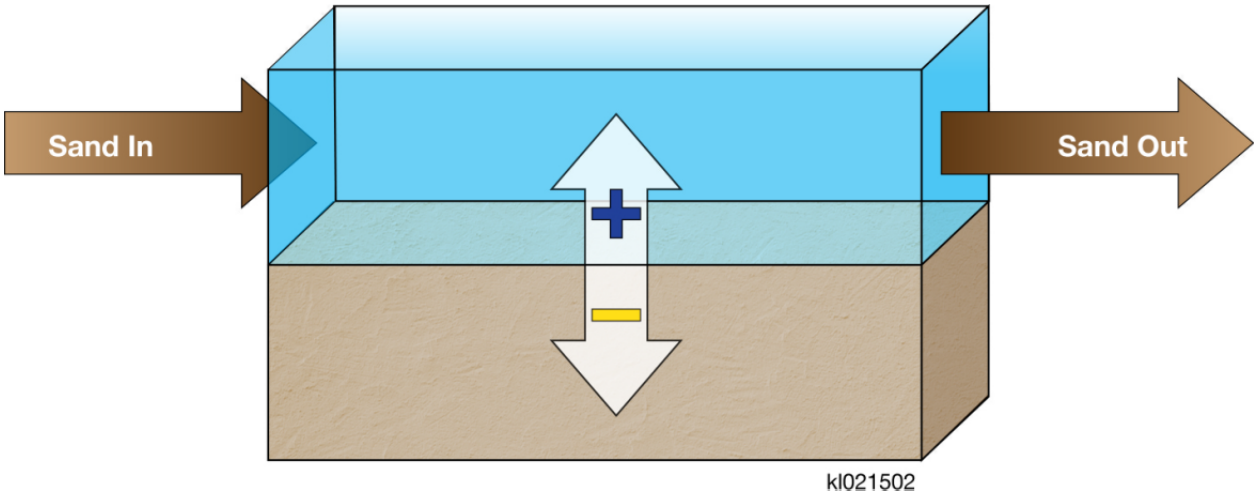

FIGURE 4.3-2 Conceptual Depiction of the Sand Mass Balance Model (The large rectangular solid is a control volume [lower half sand bed and upper half water]. Water and sand are flowing in from the left and out to the right. Purple plus symbol represents the case of a positive sand mass balance where there is an increase in sand thickness due to the "sand in" value being greater than the "sand out" value for a given time period. The yellow minus sign represents the case of a negative sand mass balance, where there is a decrease in sand thickness due to the sand out value being greater than the sand in value for a given time period.)

mass at the start of the period. Data used to calculate the sand mass balance index and the sand load index come from Sand Budget Model outputs.

The Sand Budget Model (Wright et al. 2010; Russell and Huang 2010) is a numerical model that tracks sand storage and transport from Lees Ferry (RM 0) to Phantom Ranch (RM 87). The Sand Budget Model was modified for the purpose of analyzing the impacts of LTEMP alternatives on the sand budget in Marble Canyon (Appendix E). The Sand Budget Model uses empirically based rating curves to compute the sand budget in three reaches; RM 0 to RM 30, RM 30 to RM 61, and RM 61 to RM 87. Modifications to the Sand Budget Model that were implemented for the purposes of the analysis in this EIS include (1) determining when HFEs would be triggered, (2) reallocation of monthly water volumes (less water released in months without HFEs to accommodate HFE water release volume in months with HFEs), and (3) implementation of a trout recruitment model provided by fish subject matter experts to identify years when TMFs would be triggered (Section 4.5).

Potential future sediment delivery from the Paria River can affect results from the modified Sand Budget Model. The mean and median annual sand load from the Paria River for the approximately 50-year time period from October 1, 1963, to January 1, 2014, is approximately 761,000 metric tons and 756,000 metric tons, respectively (Topping 2014; GCMRC 2015b). Three different time series of sediment load for the Paria River were considered to account for uncertainty (Appendix E), with the mean annual input ranging from 648,000 metric tons to 918,000 metric tons. The three 20-year time series selected approximate

the 10, 50, and 90% exceedance probabilities, as well as represent the entire historical sediment record explicitly.

Each alternative was modeled in the modified Sand Budget Model with 21 different potential hydrology scenarios (Section 4.1) and three different potential Paria River sediment loads (Section 4.3.1 and Appendix E) to account for uncertainty in future conditions. Comparisons between alternatives are made using the average of these 63 combinations of simulations per alternative, and confidence in the comparisons can be found by considering the inter-quartile range of the 63 simulations. The inter-quartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

The output of the Sand Budget Model includes the hourly time series of both the mass of sand transported at the downstream boundary of each reach and the sand budget (sand in minus sand out) for each of the three reaches (Figure 4.3-2). Both of these time series are used in the assessment of impacts on sediment resources.

Impacts on sediment resources in the Grand Canyon upstream of RM 87, as analyzed here, are considered in general to be indicative of impacts further downstream, although the timing and magnitude of effects may be different. A quantitative assessment of the alternatives on the sediment resource downstream of RM 87 has not been made, but the literature suggests that the relative rankings of the alternatives would be maintained for downstream reaches (Hazel et al. 2010; Grams et al. 2015).

Lake deltas can be described by their size, which is directly affected by the amount of sand delivered to the delta, and by longitudinal position in a canyon, which is directly affected by reservoir elevation.

The position of the Lake Powell deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, is dictated by the water surface elevation of Lake Powell.

The size of any given delta on Lake Powell, whether it is the mainstem Colorado River or the tributaries, will not be affected by Glen Canyon Dam operations because operations cannot affect the amount of sediment being delivered to the upstream deltas.

The positions of the Lake Mead deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, are dictated by the elevation of Lake Mead. Lake Mead elevations are analyzed on a monthly timescale, and the change in elevation from one month to the next depends primarily on the amount of water released from Glen Canyon Dam during that month and the release schedule from Hoover Dam. A lower release volume from Hoover Dam and a higher release volume from Glen Canyon Dam would result in a higher water surface elevation in Lake Mead, causing deltas to form farther up the canyon. The size of Lake Mead's tributary deltas would not be affected by Glen Canyon Dam operations because these operations cannot affect the amount of sediment being delivered to the reservoir's tributary deltas. Glen

Canyon Dam operations can only affect the amount of sediment being delivered to the Colorado River delta in Lake Mead. The sand mass balance results from the modified Sand Budget Model are used to estimate the relative effects of the alternatives on the amounts of sediment that eventually would reach the Colorado River delta in Lake Mead under the alternatives.

4.3.2 Summary of Impacts

General impacts on sandbars, riverbed sand, and lake deltas are discussed below. Specific impacts on these resources are discussed under each alternative in Section 4.3.3. These impacts vary among the alternatives as a result of differences in dam operations, including monthly distribution of annual release volume, within-day fluctuations in releases, and the frequency, magnitude, and duration of high flows, such as sediment-triggered HFEs, TMFs, and proactive spring HFEs. Of these three types of high flows, sediment-triggered HFEs result in the largest impact on sediment resources.

Sandbars are built by high flows. According to Schmidt and Grams (2011a), "the HFE research program demonstrated that eddy sandbars are quickly constructed by high flows if those flows have high suspended-sand concentrations." They also state that "high flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, and 2008 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons" (Schmidt and Grams 2011a). This physical understanding of the process was verified in subsequent high-flow experiments.

Preliminary results indicate that sandbar building occurred in Marble Canyon and the Grand Canyon during each of the fall HFEs conducted in 2012, 2013, and 2014. Sandbars were larger following each HFE at more than half of the 45 long-term monitoring sites (Grams et al. 2015). Immediately following the 2012, 2013, and 2014 HFEs, sandbars were larger at 52%, 52%, and 57% of the monitoring sites, respectively (Grams 2016). Sandbar size did not change substantially at 35% of the monitoring sites following each of the same HFEs. The most recent topographic surveys completed in the fall of 2015 indicated that the total sand volume of the long-term monitoring sandbars increased during the first implementations of the HFE protocol (Grams 2016).

Sandbars erode between HFEs. Erosion rates tend to be highest immediately after a flood (when bars have the most sediment available for erosion), then decrease with time (Grams et al. 2010). Furthermore, "monitoring data show that sandbars erode more quickly as release volumes and daily fluctuations increase, whereas the rate of erosion is reduced when tributary sand inputs continue to occur following sandbar building" (Melis et al. 2011). Steadier flows erode bars at a lower rate than fluctuating flows (Wright, Schmidt et al. 2008).

High flows necessarily export relatively large volumes of sand in order to transfer sand from the riverbed to high-elevation portions of sandbars (Wright, Schmidt et al. 2008). Within-day fluctuations resulting from powerplant operations also increase the amount of sediment that is transported downstream. As noted by Wright and Grams (2010), a steady flow will transport less sand than an equivalent-volume fluctuating flow and retain more sandbars and beaches.

These dynamics are well understood, but the sand load index does not fully address the potential erosion of sandbars from intervening flows.

In order to understand effects on sediment resources, it is necessary to evaluate both the indicators for sandbar growth potential (sand load index) and the indicator for sand budget (sand mass balance index). Both are affected by the number, frequency, and duration of HFEs. During a 20-year period, there are a maximum of 40 possible HFEs (one in the fall and one in the spring each year) if there were sufficient water and sediment volume (see Figure 4.3-5 in Section 4.3.3). Some alternatives limit the maximum number of HFEs that can occur during the 20-year LTEMP period. Alternatives A and B would have the fewest HFEs, because HFEs would not be conducted after 2020 under Alternative A, and HFEs are limited to one every other year under Alternative B; consequently, these alternatives would have the lowest potential for building sandbars as indicated by their relatively low sand load index values. Alternatives F and G would have the most HFEs, highest sand load index values, and greatest potential to build bars. Alternatives C and D would have slightly fewer HFEs than Alternatives F and G, while Alternative E would be a bit lower because spring HFEs would not be implemented in the first 10 years of the LTEMP period. These four alternatives show relatively large improvements in the potential to build sandbars over Alternatives A and B. These differences among alternatives are discussed in greater detail for each alternative in Section 4.3.3.

Alternatives C and E include steady flows associated with HFEs (these steady flows are also referred to as load-following curtailment). Alternative C would implement steady flows before and after a spring HFE and fall HFE. Alternative E would only implement steady flows prior to a fall HFE. Although load-following curtailment does help conserve sediment prior to and after an HFE, the effect is relatively small because of the short duration of the curtailment, and the fact that two other factors reduce sand transport during this time period regardless of curtailment—HFEs reduce the average flow for the remainder of the month, and HFEs are applied in the lowest volume months out of the year.

In contrast to the 277 mi of Marble Canyon and Grand Canyon, the 15-mi Glen Canyon reach of the Colorado River receives very little sediment input. The Glen Canyon reach will continue to be affected by the river during equalization flows, HFEs, or other high-flow events that continue to remove sediment within the reach. Sediment in the Glen Canyon reach is largely a non-renewable resource because the first major sediment-bearing tributary is the Paria River, 16 mi below the dam. As a result, HFEs and other high flows do not generally contribute to the replenishment or retention of beaches within the Glen Canyon reach, and pre-dam beach sediments may continue to be lost.

Annual releases from Glen Canyon Dam affect the transport of sand on the bed of the river as much as, if not more than, alternative-specific dam operations. For all alternatives, years or periods of years that have a relatively low average annual release volume tend to transport less sand, whereas those with higher average annual release volumes tend to transport more sand downstream.

The only delta in Lake Mead that can be affected by LTEMP alternatives in terms of both location and size is the Colorado River delta in Lake Mead; the tributary deltas in Lake Mead will be affected in terms of position by dam operations, but not in terms of size. Using historical data on the GCMRC data portal (GCMRC 2015b), nearly half (approximately 46%) of the suspended sand load reaching the gage at Diamond Creek (RM 225) since October 2002 can be accounted for by suspended sand leaving Marble Canyon (RM 0 to 60). The other half of the suspended sand reaching Diamond Creek comes from tributaries downstream of Marble Canyon, most notably the Little Colorado River. The mass balance across alternatives varies by almost a factor of 3 (Table 4.3-1), but this magnitude of variability is insignificant when compared to both the average amount of sediment leaving Marble Canyon (10,000 kilotons per year) and the average amount of sediment reaching Diamond Creek (22,000 kilotons per year). Therefore the alternatives considered will have minimal impact on the size of the Colorado River delta in Lake Mead.

The position of deltas in Lake Mead is directly affected by reservoir elevation. The elevations of Lake Powell and Lake Mead are more sensitive to future hydrology and corresponding annual releases from Glen Canyon Dam (Section 4.1) than to any alternative. Figures 4.3-3 and 4.3-4 present the minimum, mean, and maximum monthly elevations relative to full pool for 21 different hydrology traces across the seven alternatives. Pool elevations and the effects on deltas are ultimately controlled by regional hydrologic conditions and will be minimally affected by the alternatives. Alternative-specific impacts on reservoir deltas were not further analyzed and are not discussed in Section 4.3.3.

4.3.3 Alternative-Specific Impacts

The impacts of LTEMP alternatives on sediment resources are summarized in Table 4.3-1. Indicators of riverbed sand are mainly derived from modeling, and sandbar indicators are the result of field surveys, modeling, and empirical data. Numerical values, based on sources of information listed in Section 4.3.1, were used as indicators of impacts for all sediment resources. Alternative-specific results for the number of HFEs, sand load index values, and sand mass balance index values are presented in Figures 4.3-5, 4.3-6, and 4.3-7, respectively. Some uncertainty exists in the numerical values shown in these figures, in Table 4.3-1, and in the subsequent discussion of alternatives. In general, however, uncertainty would not affect relative differences among alternatives and would allow a comparison among the alternatives because the uncertainties apply across all alternatives. This uncertainty does mean that very small differences between alternatives may not be meaningful.

TABLE 4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Least HFEs of any alternative; would result in the lowest potential for building sandbars (highest impact of alternatives), and the highest sand mass balance (lowest impact of alternatives)	Compared to Alternative A, sandbar building potential would increase 10%, but higher fluctuations would result in lower sand mass balance (80% decrease)	Compared to Alternative A, sandbar building potential would increase 157%, but sand mass balance would decrease 112%	Compared to Alternative A, sandbar building potential would increase 152%, but sand mass balance would decrease 47%	Compared to Alternative A, sandbar building potential would increase 119%, but sand mass balance would decrease 96%	Compared to Alternative A, sandbar building potential would increase 167%, but sand mass balance would decrease 230% (highest impact of alternatives)	Compared to Alternative A, sandbar building potential would increase 176% (lowest impact of alternatives), but sand mass balance would decrease 182%
High Flow Events							
Average number of HFEs triggered in 20 years	5.5	7.2 (31% increase)	21.3 (287% increase)	21.1 (284% increase)	17.1 (211% increase)	19.3 (38.1)[b] (251% and 593% increase, respectively)	24.5 (345% increase)
Maximum number of HFEs that could be implemented	14	10	40	38	30	40	40
Sandbars							
Sand load index value (20-year value)	0.21	0.23	0.54	0.53	0.46	0.56	0.58
Sand load index, relative to Alternative A (% change)	0%	10% increase	157% increase	152% increase	119% increase	167% increase	176% increase

TABLE 4.3-1 (Cont.)

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Sediment Balance							
Sand mass balance index (kilotons)[c]	–1,010	–1,810	–2,140	–1,480	–1,980	–3,320	–2,840
Sand mass balance index, relative to No Action (% change)	0%	80% decrease	112% decrease	47% decrease	96% decrease	230% decrease	182% decrease
Mean relative to average annual Paria sand load	–1.3	–2.4	–2.8	–2.0	–2.6	–4.4	–3.7
Interquartile range relative to annual Paria sand load	–4.9 to 1.5	–5.2 to 0	–5.3 to –0.6	–3.9 to 0	–5.3 to –0.2	–5.5 to –3.4	–5.9 to –1.8
Lake Mead Delta	The size and the position of the Colorado River Delta in Lake Mead is influenced more by regional hydrology and less by the dam operation alternatives considered in this analysis						

[a] The results presented here are from modeling conducted prior to making several adjustments to Alternative D, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and an adjustment in the monthly release volumes, as described in Section 2.2.4. The actual number of HFEs would be about 19.8 (1.3 fewer) and would result in a slightly lower sand load index and higher sand mass balance index. Change in monthly release volumes would result in a slight increase in sediment transport (1.2%), resulting in a lower (not quantified) sand load index and a lower sand mass balance index. Elimination of load-following curtailment would result in a 0.6% decrease in sand mass balance index. See Section 4.1 for more detail.

[b] If alternative-defined annual spring flood (24 hr, 45,000 cfs flow if no sediment-triggered HFE) is counted, there would be a total of 38.1 HFEs.

[c] Sand mass at end of 20-year LTEMP period from RM 0 to 61 relative to start of LTEMP period; negative indicates net loss of sediment.

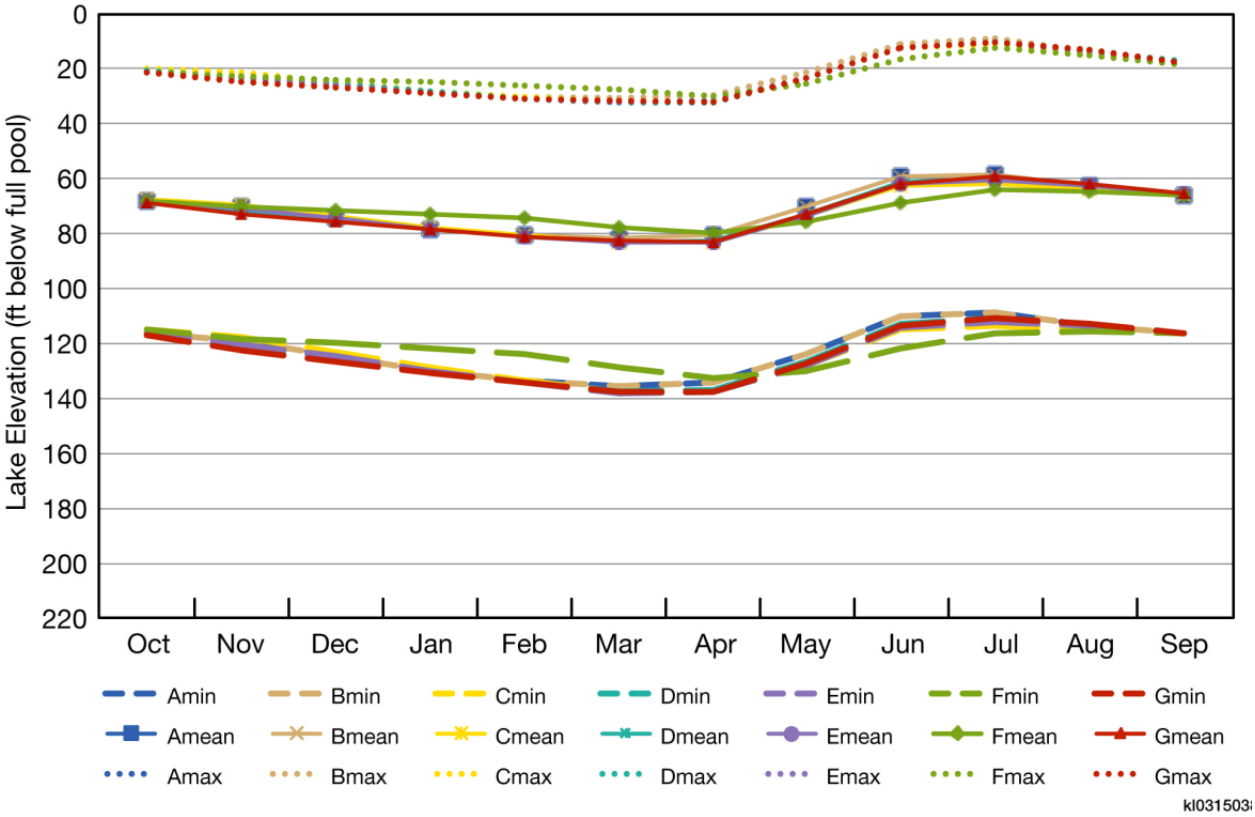

FIGURE 4.3-3 Variation in Lake Powell Pool Elevation Relative to Full (3,700 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

4.3.3.1 Alternative A (No Action Alternative)

Under Alternative A, HFEs would continue only for the period of the current HFE protocol, which will expire in 2020. In addition, spring HFEs would not occur until 2016 at the earliest. Therefore, Alternative A provides for a maximum of 14 HFEs during the 20-year period. On average, across 21 hydrology and 3 sediment time series (63 simulations total), there would be 5.5 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 39% of the maximum possible under Alternative A, and 14% of the overall maximum of 40 (one spring and one fall HFE every year).

The estimated 20-year average sand load index for Alternative A is 0.21, with an inter-quartile range of 0.17–0.24 (Figure 4.3-6). This indicates that about 20% of the sediment transported over the 20-year LTEMP period is transported when discharge is >31,500 cfs, resulting in potential sandbar building. The sand load index cannot currently be directly compared to sandbar response or size, but this value provides a baseline to which the other alternatives can be compared, and this alternative can be compared to dam operations that have been in place since 2012.

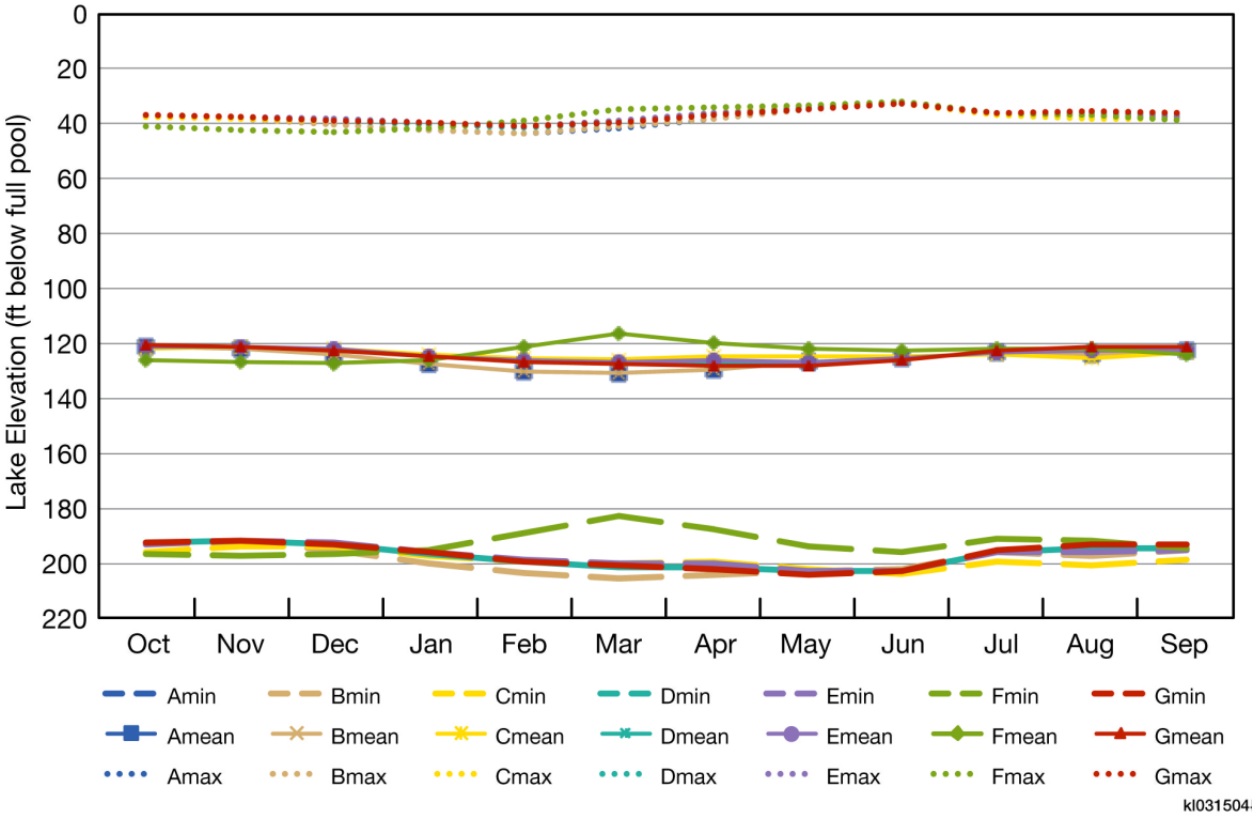

FIGURE 4.3-4 Variation in Lake Mead Pool Elevation Relative to Full (1,229 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

Alternative A is a continuation of the current HFE protocol as defined in the 2011 EA (Reclamation 2011b). Three HFEs have been conducted under the HFE protocol; for these, sandbars increased in both volume and area as they did in response to the three preceding HFEs of 1996, 2004, and 2008 (Grams 2014). The sand load index for Alternative A of 0.21 is the lowest of all alternatives (Table 4.3-1), indicating the lowest potential for building sandbars. This is due to the expiration of the HFE protocol in 2020, which in turn leads to the lowest number of HFEs for the simulation period of all alternatives. It is expected that bar building would continue through the HFE protocol window, and then bars would erode and decrease in size after 2020.

Under Alternative A, there would be an estimated average net loss of 1,010 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 1.3 times the annual average sand input from the Paria River. About 46% of the 63 conditions modeled resulted in a positive sand mass balance. This alternative retains, on average, the most sand in Marble Canyon of any alternative, but, as discussed above, the lowest potential for sandbar building after 2020.

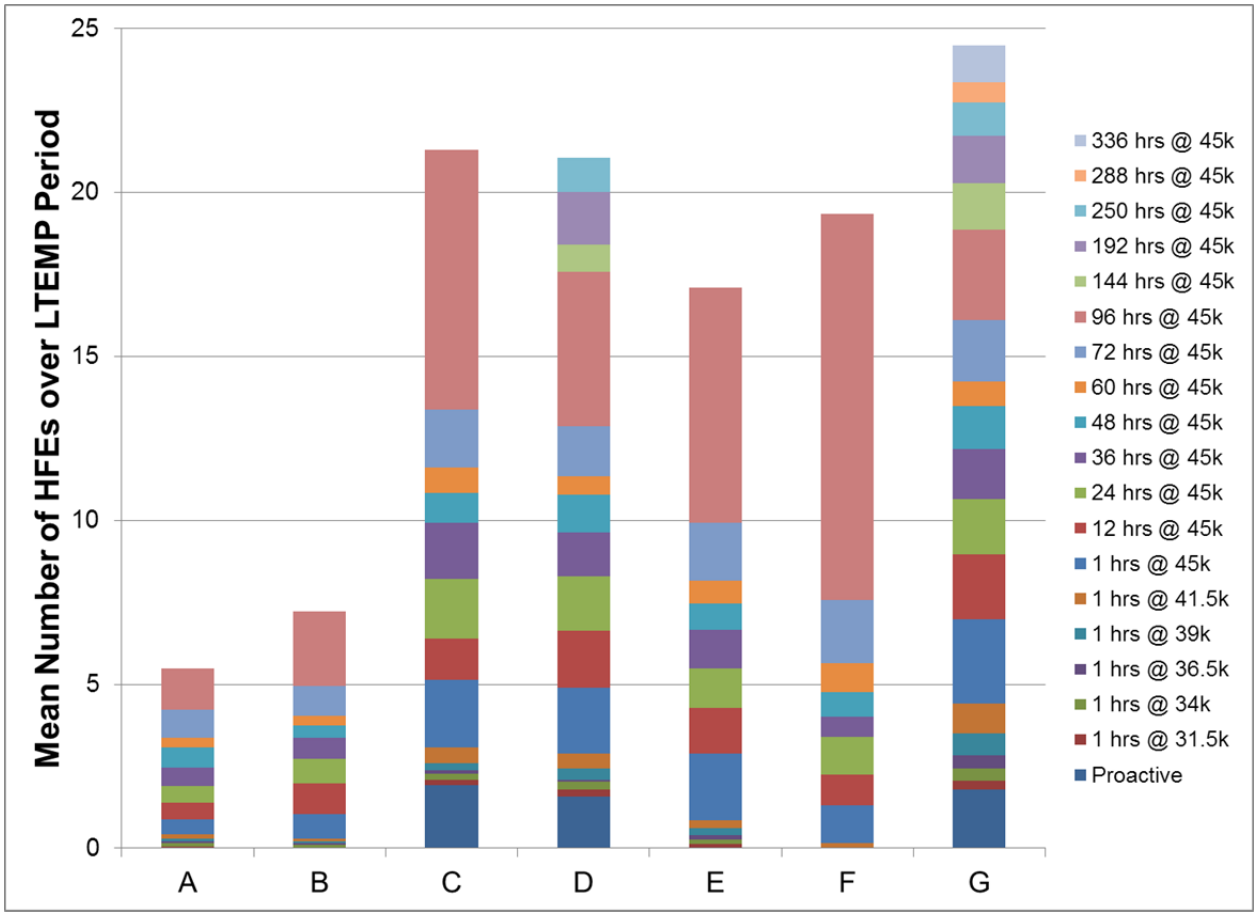

FIGURE 4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives

In summary, Alternative A has the least HFEs of any alternative and would result in the highest sand mass balance, but the lowest potential for building sandbars.

4.3.3.2 Alternative B

Under Alternative B, spring and fall HFEs could be implemented during the 20-year LTEMP period, but HFEs would not be implemented more often than once every 2 years. Therefore, Alternative B would allow a maximum of 10 sediment-triggered HFEs during the 20-year LTEMP period. On average, there would be 7.2 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 72% of the maximum possible under the alternative, and 18% of the maximum of 40 possible under other alternatives.

The estimated 20-year average sand load index for Alternative B is 0.23, with an inter-quartile range of 0.20–0.27 (Figure 4.3-6). The estimated average sand load index for Alternative B is 10% greater than the sand load index for Alternative A, suggesting slightly higher bar-building potential under Alternative B. The number of HFEs and the sand load index

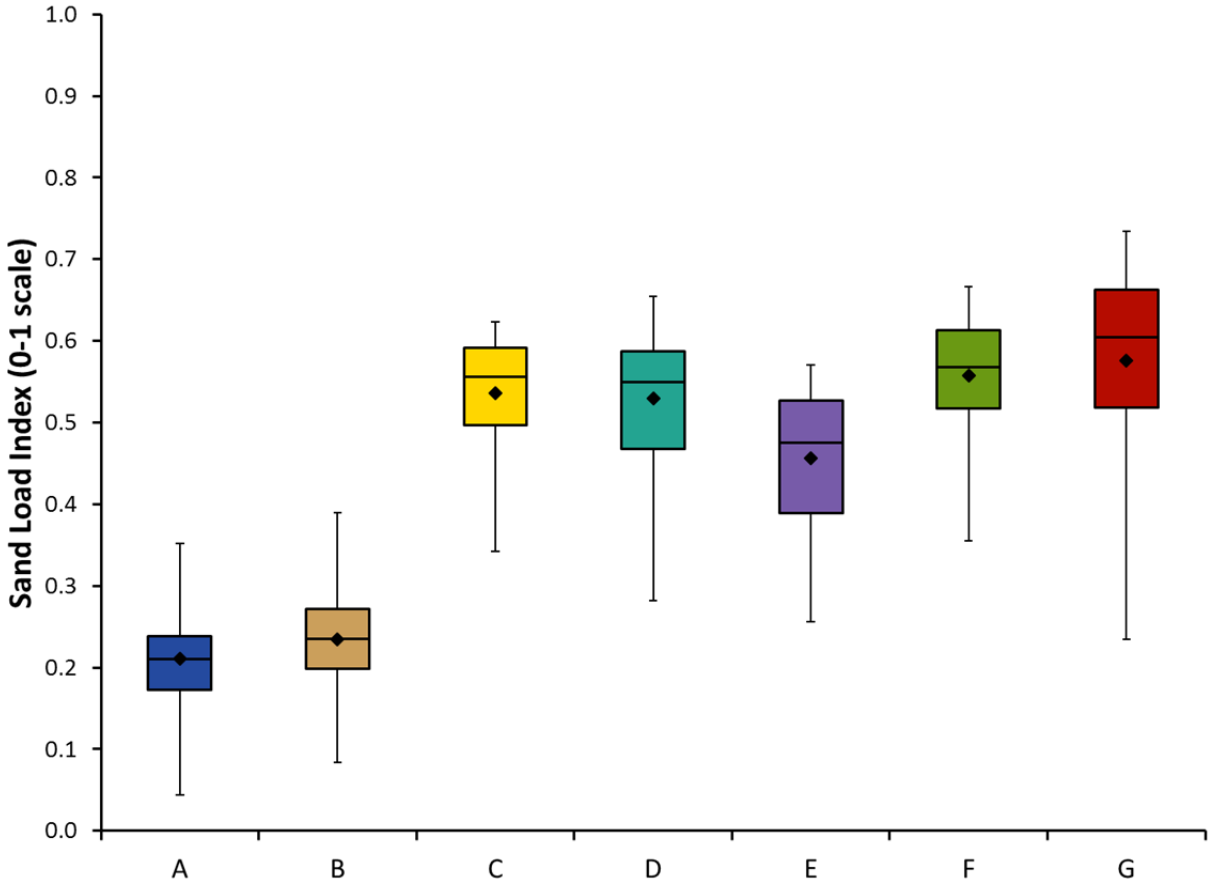

FIGURE 4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values indicate a greater potential for building sandbars. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

for this alternative are comparable to those under Alternative A. The largest difference is with the timing of the HFEs. The limitation to one HFE every 2 years in Alternative B implies that sandbars should persist throughout the simulation period, although the bars may become smaller during the periods between HFEs.

Under Alternative B, there would be an estimated average net loss of 1,810 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.4 times the annual average Paria River sand input. About 27% of the 63 conditions modeled resulted in a positive sand mass balance. The estimated average net loss of sand under Alternative B is a larger depletion (about 80% higher) compared to Alternative A. This difference can be attributed to the higher within-day fluctuations under Alternative B. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

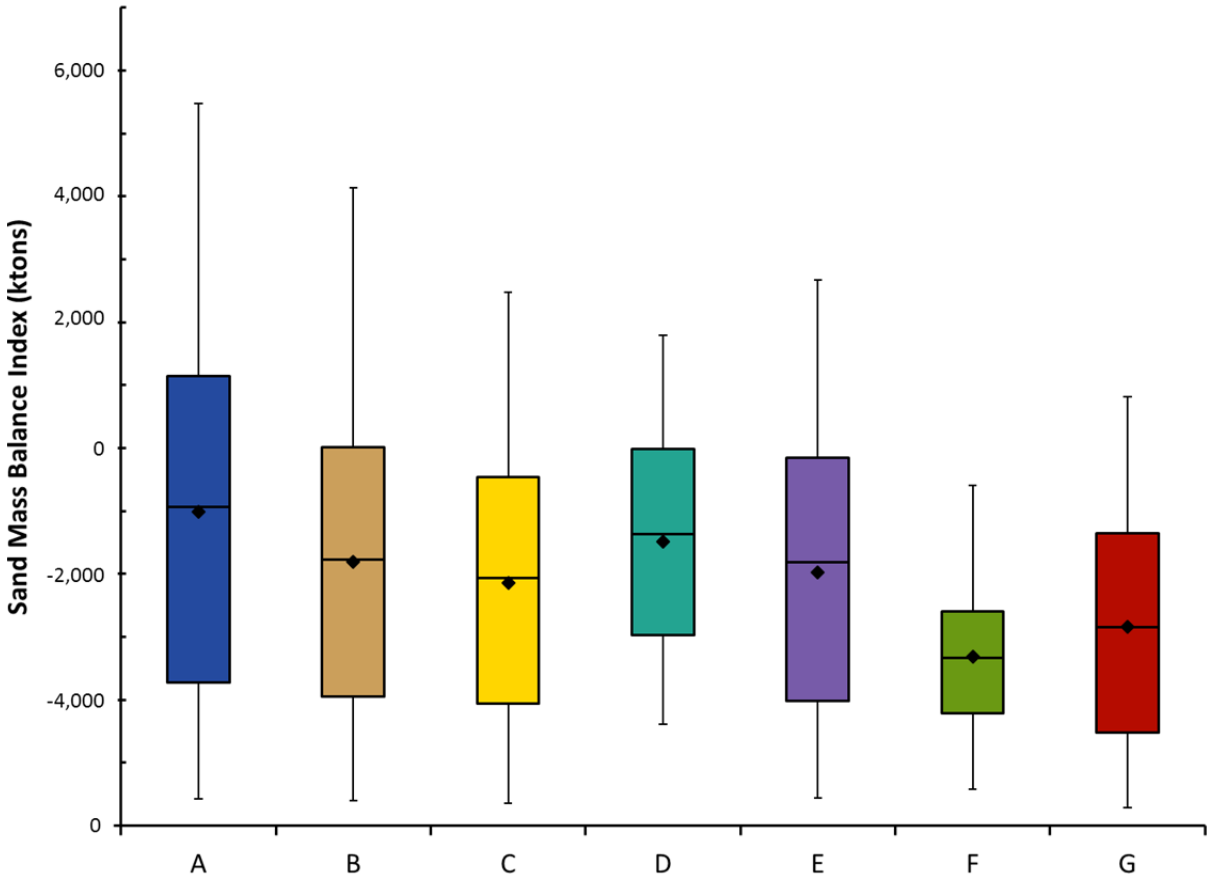

FIGURE 4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values are considered better than lower values. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative B, including hydropower improvement flows, TMFs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. Hydropower improvement flows and TMFs were modeled for Alternative B, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

Hydropower improvement flows would feature increased daily fluctuation ranges and ramp rates that would resemble those of operations at Glen Canyon Dam prior to the early 1990s (Section 2.2.2). Under Alternative B, this experimental operation would be implemented a maximum of four times over the 20-year LTEMP period in years with annual volumes of 8.23 maf or less. This additional fluctuation range would reduce the mean sand load index to 0.22, which is still slightly higher than Alternative A, and would result in a sediment depletion of 2,400 kilotons. This larger depletion of sediment is a direct result of the larger daily fluctuation range. This depletion would affect the channel bed sediments and the sandbars, reducing their size.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall there would be minimal adverse impacts on sediment resources because TMFs would not change monthly volumes. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of HFEs on sediment would be much greater than the effects of TMFs on sediment.

In summary, Alternative B has a sandbar-building potential that would be similar to that under Alternative A, but higher fluctuations would result in lower sand mass balance.

4.3.3.3 Alternative C

Under Alternative C, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative C provides for a maximum of 40 sediment-triggered HFEs. On average, there would be 21.3 HFEs triggered and implemented (Figure 4.3-5), which is 53% of the maximum possible under the alternative, and 53% of the overall maximum of 40.

The estimated 20-year weighted average sand load index for Alternative C is 0.54, with an inter-quartile range of 0.50–0.59 (Figure 4.3-6). The estimated average sand load index under Alternative C is 2.6 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.6 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative C. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs as well as proactive spring HFEs. The reduced fluctuations of Alternative C also serve to conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative C, there would be an estimated average net loss of 2,140 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.8 times the annual average Paria River sand input. About 22% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative C is a larger depletion (about 112% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on mass balance than operational characteristics of the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative C, including TMFs, proactive spring HFEs, extended-duration HFEs (volume constrained), low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, long-duration HFEs, and low summer flows were modeled for Alternative C, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources (Appendix E). TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Proactive spring HFEs are intended to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. Proactive spring HFEs occur in high-volume release years (≥10 maf), unless a sediment-triggered HFE had occurred earlier in the spring. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these proactive HFEs would be effective at building and retaining sandbars, and field tests of this type of HFE are necessary to evaluate their potential effectiveness. Under Alternative C, proactive spring HFEs would only be continued if tests indicate a positive bar response.

Under Alternative C, extended-duration fall HFEs would be of equal release water volume to those triggered under the existing HFE protocol but would be of lower magnitude (e.g., 5-day 36,000 cfs HFE instead of a 4-day 45,000 cfs HFE). The difference in peak and duration for a given release volume will have a relatively minor effect on sediment transport but was not simulated for this analysis. Because of the nonlinear relationship between flow magnitude and sediment transport, a longer duration, same-volume HFE would transport less sand than a shorter duration, higher magnitude HFE. Such an HFE would also have a lower sand load index, and thus would have a lower potential to build sandbars.

Implementation of low summer flows would require higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

In summary, Alternative C would result in higher bar-building potential, but lower sand mass balance than Alternative A.

4.3.3.4 Alternative D (Preferred Alternative)

Under Alternative D, fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input, but spring HFEs would not be allowed in the first 2 years of the LTEMP period. Therefore, Alternative D provides for a maximum of

38 sediment-triggered HFEs. Modeling indicated that on average, there would be 21.1 HFEs triggered and implemented (Figure 4.3-5), which is 55% of the maximum possible under the alternative, and 53% of the overall maximum of 40. Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer).

The estimated 20-year average sand load index for Alternative D is 0.53, with an inter-quartile range of 0.47–0.59 (Figure 4.3-6). The estimated average sand load index under Alternative D is 2.5 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.5 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative D. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during much of the LTEMP period. In addition, the more equal monthly volumes relative to those of Alternative A conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs. Adjustments made to Alternative D after modeling was completed would result in a reduction in the sand load index estimate presented here (see Section 4.1). The prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE, elimination of experimental load-following curtailment after fall HFEs, and adjustments in the monthly release volumes would all contribute to a reduction in sand load index. Alternative D would continue to be ranked fourth among alternatives (between Alternatives C and E) in terms of the sand load index.

Under Alternative D, there would be an estimated average net loss of 1,490 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.0 times the annual average Paria River sand input. About 25% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative D is a larger depletion (about 46% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives. Adjustments made to Alternative D after modeling was completed would result in a reduction in the sand mass balance index estimate presented here (see Section 4.1). The prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE would result in an increase in sand mass balance index, but elimination of experimental load-following curtailment after fall HFEs, and adjustments in the monthly release volumes would contribute to a reduction in sand mass balance index (0.6% and 1.2%, respectively). Alternative D would continue to be ranked second among alternatives (between Alternatives A and B) in terms of sand mass balance index.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative D, including TMFs, proactive spring HFEs, extended-duration HFEs, low summer flows, macroinvertebrate production flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, macroinvertebrate

production flows, and low summer flows were modeled as an integral part of Alternative D, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. By definition, proactive spring HFEs are HFEs that occur in 10-maf or greater annual release years when there is limited spring sediment input. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative D, proactive spring HFEs would only be continued if tests indicate a positive bar response. As stated above, adjustments made to Alternative D after modeling was complete included prohibition of proactive spring HFEs in the same water year as an extended-duration fall HFE. This prohibition would result in an average of 0.2 fewer proactive spring HFEs over a 20-year period (1.4 compared to 1.6).

Under Alternative D, extended-duration fall HFEs (up to 250 hr) would be implemented during the 20-year LTEMP period, depending on sediment conditions. Modeling demonstrated that extended-duration HFEs would have substantial effects on both the sand load index (increases index value) and the sand mass balance index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building. Extended-duration HFEs would result in higher sand load index values, and consequently higher bar-building potential, than more typical 96-hour or shorter HFEs, but would also transport more sand out of the Marble Canyon reach. Extended-duration HFEs would be tested in up to 4 years during the LTEMP period and only when sufficient sand input from the Paria River would support the extended flow.

Implementation of low summer flows requires higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

Macroinvertebrate production flows would consist of steady flows during the weekends of May through August. These experimental flows are expected to have a relatively minor effect on sand load index and sand mass balance index values.

In summary, Alternative D would result in higher sandbar-building potential than Alternative A, while preserving more sand than all alternatives except Alternative A.

4.3.3.5 Alternative E

Under Alternative E, fall HFEs could be implemented during the 20-year LTEMP period, but spring HFEs would not be implemented in the first 10 years of the program. Therefore, Alternative E provides for a maximum of 30 HFEs during the 20-year period. On average, 17.1 HFEs would be triggered and implemented (Figure 4.3-5), which is 57% of the maximum possible under the alternative, and 43% of the overall maximum of 40.

The estimated 20-year average sand load index for Alternative E is 0.46, with an inter-quartile range of 0.39–0.53 (Figure 4.3-6). The estimated average sand load index is 2.2 times greater than for Alternative A. This does not imply that bars would be 2.2 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative E. Higher bar-building potential is a consequence of the potential for sediment-triggered HFEs throughout the LTEMP period under this alternative. The more equal monthly volumes relative to those of Alternative A also conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative E, there would be an estimated average net loss of 1,980 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.6 times the annual average Paria River sand input. The estimated average net loss of sand under Alternative E is a larger depletion (about 96% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative E, including TMFs, low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs and low summer flows were modeled for Alternative E, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5.1.2). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Implementation of low summer flows would require higher releases of water in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Because sediment transport has a nonlinear relationship with flow, the increase in sand that is transported during the spring is of larger magnitude than the decrease in sediment transport during the summer. The net effect over the year is an increase in overall downstream sand transport, resulting in less sediment being available for transport during an HFE.

In summary, Alternative E would result in higher bar-building potential than Alternatives A and B, but not the other alternatives, and would have lower sand mass balance than Alternative A.

4.3.3.6 Alternative F

Under Alternative F, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative F provides for a maximum of 40 sediment-triggered HFEs. Under the alternative, in years when a spring HFE was not triggered, there would be a 24-hour 45,000 cfs release in the beginning of May, regardless of the availability of sediment. On average, 19.3 sediment-triggered HFEs would be called for in the 20-year LTEMP period (Figure 4.3-5), which is 48% of the maximum possible under the alternative, and 48% of the overall maximum of 40 (one spring and one fall HFE every year). If the alternative-prescribed annual May events in years without sediment-triggered HFEs are counted, there are on average 38.1 HFEs during the 20-year LTEMP period.

The estimated 20-year average sand load index for Alternative F is 0.56, with an inter-quartile range of 0.52–0.61 (Figure 4.3-6). The estimated average sand load index under Alternative F is 2.7 times greater than the sand load index under Alternative A. This does not imply that bars would be 2.7 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative F. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, as well as a 24-hour 45,000 cfs release in May in years when a spring HFE is not triggered by sediment input.

Under Alternative F, there would be an estimated average net loss of 3,320 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 4.4 times the annual average Paria River sand input, about 230% higher than under Alternative A. This is the largest depletion associated with any of the alternatives, resulting from the high frequency of HFEs, including an alternative-prescribed flood every spring regardless of tributary sediment inflows, as well as extended elevated flow releases (approximately 20,000 cfs) for the duration of May and June. None of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that that future hydrology and sediment input results in a lesser impact on the mass balance than the alternative.

Other than sediment-triggered spring and fall HFEs, no experimental elements are identified under this alternative.

In summary, Alternative F has the highest number of HFEs and would result in the highest bar-building potential, but the lowest sand mass balance of all alternatives.

4.3.3.7 Alternative G

Under Alternative G, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative G provides for a maximum of 40 sediment-triggered HFEs. On average, 24.5 HFEs would be triggered and implemented (Figure 4.3-5), which is 61% of the maximum possible under the alternative, and 61% of the overall maximum of 40. This is the only alternative that would allow for HFE durations of up to 336 hr at the 45,000-cfs peak flow rate, and there would be no limit to the number of extended-duration HFEs as long as they could be supported by sediment inputs.

The estimated 20-year average sand load index for Alternative G is 0.58, with an inter-quartile range of 0.52–0.66. This is the alternative with the highest average sand load index. The estimated average sand load index for Alternative G is 2.8 times greater than the sand load index for Alternative A. This does not imply that bars will be 2.8 times larger under this alternative as compared to Alternative A, but it does suggest that there would be significantly more bar-building potential under Alternative G. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during the entire LTEMP period. The lack of daily fluctuations under Alternative G and equal monthly volumes also would conserve more sediment during normal operations, thus making more sediment available for transport during HFEs.

Under Alternative G, there would be an estimated average net loss of 2,840 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 3.7 times the annual average Paria River sand input. About 6% of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. The estimated average net loss of sand under Alternative G represents a depletion that is about 182% greater than that under Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in as much impact on the mass balance as the alternative definition.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative G, including TMFs, proactive spring HFEs, extended-duration HFEs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, and extended-duration HFEs were modeled for Alternative G, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would have a minimal effect on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative G, proactive spring HFEs would only be continued if tests indicate a positive bar response.

In this alternative, extended-duration HFEs may be up to 336 hr long and would be triggered by the appropriate sediment conditions. Modeling demonstrated that extended-duration HFEs would have important effects on both the sand load index (increases index value) and the sand mass balance index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building.

In summary, Alternative G has the second-highest number of HFEs and would result in the second-highest bar-building potential and the second-lowest sand mass balance of all alternatives.

4.4 NATURAL PROCESSES

Issue: How do alternatives affect physical conditions which drive the natural processes that support native plants and animals, and their habitats, in Glen and Grand Canyons?

Impact Indicators:

- Flow characteristics, including monthly release patterns and within-day variability
- Seasonal water temperature patterns
- Sediment mass balance and sandbar building potential
- Water quality (nutrients and turbidity)

The Colorado River Ecosystem is defined as the Colorado River mainstem corridor and interacting resources in associated riparian and terrace zones located primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (GCNP). It includes the area where dam operations impact physical, biological, recreational, cultural, and other resources. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals. As described in Chapter 3, management policies identified by the NPS (NPS 2006d) state that "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species."

Major physical drivers of natural processes in the Colorado River Ecosystem are flow, water temperature, sediment transport, and water quality (including nutrients and turbidity). The

nature of these parameters directly and/or indirectly determines the abundance, condition, and status of habitats for native and nonnative plants and animals in the ecosystem below the dam.

The natural processes within the Colorado River Ecosystem reflect historic changes to the system (Chapter 3). The existing facilities and laws and regulations further constrain the options for fully restoring the original natural processes within the canyon. It is not possible to operate the dam in a manner that could restore to pre-dam conditions the physical parameters that drive natural processes. Nonetheless, physical and chemical parameters that influence natural processes and native and nonnative species communities may be affected differently by each of the LTEMP alternatives.

4.4.1 Analysis Methods

The range of variability of physical parameters in the Colorado River Ecosystem is constrained by the operational limits of the dam, but varies by alternative. It is assumed that the natural abundance, diversity, and genetic and ecological integrity of plant and animal species native to the river will be influenced by the physical riverine conditions that are produced under each alternative.

A conceptual model showing expected linkages among dam releases, physical conditions, habitats, and affected ecological resources is shown in Figure 4.4-1. As shown, the primary effects of any alternative on plant and animal species below the dam will be a direct function of the changes in the physical conditions (e.g., sediment transport, water temperature) that would occur under each alternative; how those alternative-specific changes affect habitat quality, quantity, and stability; and how aquatic and terrestrial biota will respond to those changes. Thus, the evaluation of how each alternative may affect natural processes below Glen Canyon Dam was based on the examination of how selected physical parameters would differ under each alternative. These differences in physical parameters were assessed as described in Sections 4.2.1 (for temperature-, flow-, and water-quality-related indicators) and 4.3.1 (for sediment-related indicators). These evaluations were then considered together to provide a qualitative determination of how natural processes in the river below Glen Canyon Dam would be affected under each alternative. Table 4.4-1 identifies the role of each of the physical parameters in influencing natural processes in the Colorado River Ecosystem.

4.4.2 Summary of Impacts

One of the most important factors affecting ecological resources (i.e., native plants and animals and their habitats) in the Colorado River Ecosystem is the interannual variability in the hydrology of the system, as driven by weather patterns and climatic conditions. Under a natural hydrograph, physical conditions in the river would include a hydrograph with peak flows and volumes in later spring/early summer, daily flows ranging on average from 1,000 cfs in winter to >92,000 cfs in spring and summer, and daily fluctuations only in response to precipitation events and tributary inflows (Section 3.2.2.2). Water temperatures would range from near freezing in winter to 30°C (86°F) in the late summer, and turbidity would be high throughout the year

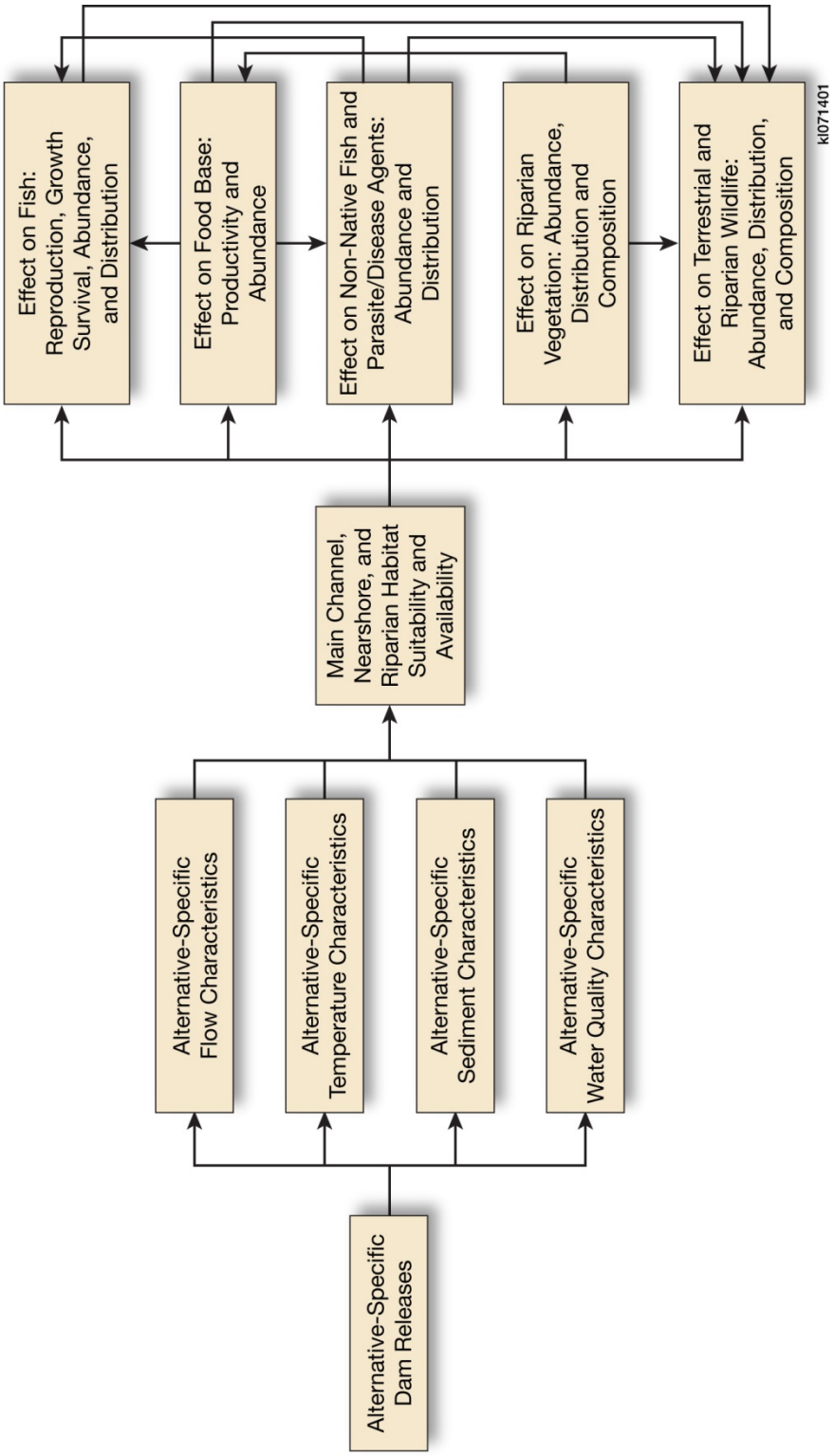

FIGURE 4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem

TABLE 4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative

Indicator	Role in Affecting Natural Processes
Flow-Related Indicators	
Peak and base flows	The frequency, magnitude, duration, and timing of peak and base flows directly affect aquatic and riparian habitats and their biota, as well as other physical factors such as water temperature and sediment transport, deposition, and loss, which in turn affect aquatic and riparian habitats, native fish and aquatic invertebrates, the aquatic food base, and riparian vegetation and wildlife. There are also direct effects from peak and base flows on vegetation.
Monthly release volumes	The magnitude and pattern of monthly release volumes affect sediment transport and physical conditions that influence important life history parameters of aquatic biota, such as egg laying and hatching in fish, as well as the quality and quantity of mainstem and nearshore aquatic habitats and riparian habitats along the main channel.
Mean daily flows	The magnitude and pattern of daily flows (including ramp rates) affect main channel and nearshore aquatic habitats, riparian habitats, and the biota that rely on these habitats.
Mean daily flow fluctuations	Daily flow fluctuations (including ramp rates) affect sediment transport and directly affect daily changes in stage, which in turn affect mainstem riparian vegetation, main channel and nearshore aquatic habitat stability, and productivity and distribution of the aquatic food base.
Temperature-Related Indicators	
Mean main channel water temperatures	Water temperatures affect reproduction, growth, and survival of fish and aquatic invertebrates in main channel and nearshore habitats, as well as productivity of the aquatic food base.
Sediment-Related Indicators	
Sediment transport and deposition	These sediment parameters affect main channel and nearshore aquatic habitats as well as riparian habitats, the biota that rely on these habitats, and the aquatic food base.
Elevation of annual sediment deposition	Elevation of annual sediment deposits affects distribution, abundance, and composition of riparian vegetation and terrestrial wildlife habitat.
Water-Quality-Related Indicators	
Turbidity	Turbidity affects predator-prey relationships among aquatic biota, as well as primary productivity.
Nutrients	Nutrients affect aquatic habitat quality for fish, invertebrates, and the aquatic food base.

(Section 3.2.3.2). It is under such conditions that natural processes would act to develop, support, and maintain the original native ecosystems of the river.

The nature, magnitude, pattern, and duration of flows, as well as water temperatures and water quality, in the Colorado River Ecosystem are so strongly constrained by the presence of the dam and by the existing laws and regulations that govern conveyance of water between the Upper and Lower Basins that it is not possible for any of the alternatives to restore natural processes in the system to pre-dam conditions. In addition to their effects on flow, Glen Canyon Dam and Lake Powell trap most of the sediment from the Upper Basin that would normally be transported into and through the Colorado River in Glen and Grand Canyons. The dam also serves as a physical barrier to the movement of riverine organisms between the Upper and Lower Basins. In this context, the LTEMP alternatives have relatively similar effects and have the potential to produce only relatively small changes in current conditions that could improve natural processes.

Regardless of which alternative is implemented, there would be little change from current conditions with regard to maximum daily flow limit (25,000 cfs), minimum daily flow limit (5,000 to 8,000 cfs), mean Glen Canyon Dam release water temperature, overall turbidity or nutrient concentrations, or the maximum height of annual sediment deposition (elevation of 45,000 cfs flows). Thus, natural processes dependent on these physical factors would not differ from current operations, and these are not discussed further in the analysis below.

Some changes in natural processes may be expected under all alternatives, as reflected by expected changes in one or more of the physical indicators, but these changes from current conditions are expected to be relatively modest, especially for the fluctuating flow alternatives (Alternatives B–E) (Table 4.4-2). By altering the monthly release patterns and eliminating within-day fluctuations, the two steady-flow Alternatives F and G would result in the greatest changes to natural processes relative to those under current conditions.

Alternatives with greater daily flow fluctuations (Alternatives B and E) could result in reductions in nearshore habitat stability compared to the other alternatives, and thus have greater impacts on aquatic and riparian biota in nearshore habitats (Sections 4.5, 4.6, and 4.7).

Compared to Alternative A, natural processes influenced by sediment dynamics would be improved under other alternatives because the potential for sandbar building (as inferred from sand load index estimates) would increase. In contrast, sediment depletion from Marble Canyon (as inferred from sand mass balance index estimates) would increase for these alternatives compared to Alternative A. This sediment depletion, however, would be balanced by greater deposition of sediment in areas above the normal range of flows where that sediment could benefit terrestrial ecosystems. This redistribution of sediment would restore, albeit to a limited extent, the natural pattern of sediment distribution.

Alternative F may have the greatest effect of all alternatives on natural processes. Alternative F is the only alternative with a monthly release pattern that has been seasonally adjusted to more closely follow the seasonal pattern of inflow and (along with Alternative G) has the least daily flow fluctuations, which would result in more stable and presumably higher

TABLE 4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources[a]

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Existing natural processes related to flow, water temperature, water quality, and sediment resources would continue, but replenishment of sandbars would diminish after 2020, when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be comparable nearshore habitat stability as a result of similar within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, there would be lower nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within season variability; more frequent sandbar building resulting from more frequent HFEs..	Compared to Alternative A, year-round steady flows would result in the greatest nearshore habitat stability, slightly higher summer water temperatures, and the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Flow-Related Indicators							
Peak and base flows	No change from the current frequency, magnitude, and timing of HFE releases and base flows; spring and fall HFEs would occur when triggered until existing protocol expires in 2020.	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; number of HFEs would be limited to no more than one every other year..	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff..	Fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but would not be implemented in first 2 years.	Fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but would not be implemented in first 10 years.	An annual hydrograph that features a 2-month long peak flow period and relatively low summer, fall, and winter base flows would support natural processes dependent on natural patterns of snowmelt runoff; spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period.	Spring and fall HFEs would occur when triggered throughout the 20-year LTEMP period; sediment-triggered spring HFEs and proactive spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff..
Mean monthly release volume and mean daily flow	No change from current conditions, with highest mean monthly release volumes and mean daily flows in winter and summer.	Same as Alternative A.	Higher mean monthly volumes and mean daily flows in winter, spring, and summer with lowest volumes in late summer and autumn favoring conservation of sediment inputs during the monsoon period.	Relatively even monthly volumes and mean daily flows favoring conservation of sediment year-round.	Relatively even monthly volumes and mean daily flows, but lower volumes in late summer favoring conservation of sediment inputs during the monsoon period.	Monthly volumes and daily flows seasonally adjusted to more closely match monthly pattern of inflows with high spring flows and low summer through winter flows.	Monthly volumes and daily flows are approximately equal, favoring conservation of sediment year-round.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Flow-Related Indicators (Cont.)							
Mean daily changes in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs; no change from the current daily maximum limit of of 25,000 cfs, and daily minimum limit of 5,000 to 8,000 cfs.	Mean daily change higher in all months (range about 2,500 to 12,000 cfs, and even higher with hydropower improvement flows), which could reduce stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Mean daily change lower in all months (about 1,300 to 6,200 cfs), which could increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Mean daily change slightly higher in Oct. through Jun., which could slightly reduce nearshore habitat stability. Mean daily change in other months comparable to Alternative A (range about 2,700 to 7,600 cfs); no change from the current daily maximum and minimum limits.	Mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs), which could reduce stability of nearshore habitats; no change from the current daily maximum and minimum lmits.	Steady flows will increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.	Steady flows will increase stability of nearshore habitats; no change from the current daily maximum and minimum limits.
Temperature-Related Indicators							
Mean Glen Canyon Dam release water temperature	Mean seasonal release temperatures are expected to be about 9.9°C in winter (about 9.7–10.2°C), 9.0°C in spring (8.8–9.2°C), 11.3°C (10.9–11.4°C) in summer, and 12.2°C (11.9–12.4°C) in fall.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Temperature-Related Indicators (Cont.)							
Mean seasonal main channel water temperature and downstream warming	No change from current conditions. Mean seasonal water temperatures between Lees Ferry and Diamond Creek range 10.0–10.6°C in winter, 9.3–13.5°C in spring, 11.6–17.2°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.6°C.	Same as Alternative A.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.2°C in spring, 11.7–17.6°C in summer, and 12.3–15.9°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.5°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.3°C in spring, 11.6–17.6°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 6.0°C.	Mean seasonal water temperatures range 9.9–10.6°C in winter, 9.5–12.5°C in spring, 11.9–18.6°C in summer, and 12.3–16.0°C in fall. Greatest amount of winter (0.9°C), summer (6.7°C), and fall (3.7°C) warming, and least amount of spring (3.0°C) warming of all alternatives.	Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.8°C in summer, and 12.4–15.3°C in fall. Second highest summer warming (6.2°C) of all alternatives.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Sediment-Related Indicators							
Sediment transport and deposition	No change from current conditions with reduction of sandbar area and volume after HFE protocol expires in 2020; 20-yr average SLI of 0.21 and SMBI of −1,010.	Slight increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates; an 11% increase in the SLI, which could slightly increase sandbar building potential, and an 80% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; lower fluctuations would result in lower erosion and transport rates; a 154% increase in the SLI and a 112% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; fluctuations comparable to Alternative A; a 151% increase in the SLI and a 47% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates; a 116% increase in the SLI and a 96% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates; a 164% increase in the SLI and a 230% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates; a 173% increase in the SLI and a 182% decrease in the SMBI compared to Alternative A.
Water Quality-Related Indicators							
Turbidity	No change from current conditions expected.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
Nutrients	No change from current conditions expected.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.

[a] SLI = sand load index; SMBI = sand mass balance index.

quality nearshore and riparian habitats (Sections 4.5, 4.6, and 4.7). Under Alternative F, the timing of achieving suitable downstream main channel water temperatures could reduce overall temperature suitability for spawning and incubating humpback chub and other native fishes, but improve temperatures for growth of young-of-year (YOY) humpback chub (Section 4.5.2.1).

4.4.3 Alternative-Specific Impacts

Although alternatives did not differ with regard to minimum and maximum daily flow limits, mean Glen Canyon Dam release water temperature, turbidity, or nutrient concentrations, alternatives do differ with regard to the frequency, magnitude, and timing of HFEs, monthly flow volumes, mean daily flows, within-day flow fluctuations, and sediment dynamics (Table 4.4-2). These factors have the potential to produce only small changes in current conditions and thus are expected to have relatively small effects on natural processes, as discussed below. In 2026, the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a) that are currently in place will expire. Without knowing how dam operations may change at that time, it is not possible to postulate with any acceptable level of certainty how natural processes may be affected. Thus, the following assessments of alternative-specific impacts do not consider any changes in operations after 2026.

4.4.3.1 Alternative A (No Action Alternative)

Under Alternative A, there would be little change in physical parameters from current conditions; mean monthly release volumes, mean daily flows, and mean daily changes in flow would be the same as current conditions (Section 4.2). Because the current HFE protocol as defined in the 2011 EA (Reclamation 2011b) would continue under Alternative A, sediment deposition rates would not be expected to differ from current levels. Sandbar building would be expected to continue through the HFE protocol window, but bars would likely then erode and decrease in size after 2020 (Section 4.3). Vegetation and wildlife dependent on replenished sandbars would decline in abundance after the protocol expires in 2020 (Sections 4.6 and 4.7).

In summary, under Alternative A, no changes from current conditions are expected in physical factors associated with monthly volumes, daily flows, and flow changes, water temperature, and water quality. As a consequence, natural processes in the Colorado River Ecosystem are not expected to differ from current conditions (Table 4.4-2).

4.4.3.2 Alternative B

Under Alternative B, mean monthly volumes and mean daily flows would be the same as those under Alternative A (Sections 4.2 and 4.3), and thus natural processes influenced by these parameters are not expected to change from current conditions. However, Alternative B would have a greater mean daily change in flow in all months (Section 4.2), and thus may affect natural processes that support aquatic ecology and vegetation, decreasing nearshore habitat stability and affecting native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that

inhabit these areas (Section 4.5). Under Alternative B, no changes from current conditions are expected in physical factors associated with monthly volumes, daily flows, and water temperature.

Sediment-triggered spring HFEs under Alternative B would support natural processes that are dependent on natural patterns of snowmelt runoff, but would be limited in frequency compared to all alternatives except for Alternative A. While the average and maximum number of sediment-triggered HFEs would be similar to that under Alternative A, the sand load index (an indicator of sandbar building potential) could be higher under Alternative B (Section 4.3). Thus, sediment-influenced natural processes that affect riparian vegetation, terrestrial wildlife, and nearshore aquatic habitats could be somewhat improved under Alternative B, but would be lower relative to other alternatives, which have more frequent HFEs. Within-day flow fluctuations would result in higher rates of sandbar erosion than under any other alternative.

In summary, in comparison to Alternative A, the higher mean daily changes in flow under Alternative B in all months may act to decrease sediment conservation and favor wetland processes (unless hydropower improvements are implemented), but reduce nearshore habitat stability, which would affect fish, aquatic invertebrates, benthic productivity, and riparian species in those habitats (Table 4.4-2).

4.4.3.3 Alternative C

Mean monthly volumes as well as mean daily flows under Alternative C would be higher in February through May, but lower in August through October when compared to Alternative A. In addition, within-day changes in flow would be lower in all months under Alternative C than under Alternatives A, B, D, and E. The lower magnitude of daily fluctuations under Alternative C would improve the quality and stability of some nearshore habitats and benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species (Sections 4.5, 4.6, and 4.7).

Sediment-triggered and proactive spring HFEs under Alternative C would support natural processes dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. Reduced volume in August through November would favor sediment retention during the monsoon period and increase the frequency, magnitude, and duration of fall HFEs, the size and persistence of sandbars, and the aquatic and riparian species that depend on these habitats (Sections 4.3, 4.6, and 4.7). These lower monthly volumes would also favor some increased warming in the summer and fall compared to Alternative A. The lower magnitude of daily changes in flows under Alternative C would reduce the erosion rates of sandbars.

In summary, compared to Alternative A, the higher monthly release volumes and daily flows in winter, spring, and summer, as well as the lower mean daily changes in all months under Alternative C, may increase sediment conservation and increase the stability of nearshore habitats and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). The relatively high frequency of spring

HFEs would support natural processes dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.4 Alternative D (Preferred Alternative)[8]

Compared to Alternative A, Alternative D would have slightly higher mean monthly volumes and daily flows in November and February through April, and lower volumes and flows in December, January, and July, August, and September (Section 4.2), providing less seasonal variation in flow across the year than most alternatives. Mean daily changes in flow for Alternative D would be comparable to Alternative A. Thus natural processes influenced by daily changes in flow would differ little from current conditions, and the quality and stability of some nearshore aquatic habitats (including backwaters) would be comparable to those under current conditions. Under Alternative D, there would be some increased warming, especially in summer, compared to Alternative A.

Sediment-triggered and proactive spring HFEs under Alternative D would support natural processes dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. The relatively even pattern of monthly volumes would serve to conserve sand, and, as a consequence, spring and fall HFEs would be triggered frequently under Alternative D. Thus, this alternative has a relatively high potential for sandbar building compared to other alternatives (Section 4.3). The higher number of HFEs could increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats (Sections 4.6 and 4.7).

In summary, natural processes influenced by monthly volumes, daily flows, and within-day changes in flow would differ little between Alternatives A and D (Table 4.4-2). However, the more even monthly release volumes and daily flows would favor sediment conservation and also provide some increase in downstream water temperatures especially in the summer. The relatively high frequency of spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.5 Alternative E

Compared to Alternative A, mean monthly volumes as well as mean daily flows under Alternative E would be higher in October, November, February, and March, but lower in December, January, July, August, and September. This increase in within-day fluctuations may affect natural processes that support aquatic ecology and vegetation, decreasing nearshore habitat stability and affecting native fish, trout, benthic productivity, aquatic invertebrates, and riparian

8 Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on natural processes.

species that inhabit these areas (Sections 4.5, 4.6, and 4.7). Lower August release volumes would favor some increased warming in the summer compared to Alternative A.

Sediment-triggered spring HFEs under Alternative E would support natural processes dependent on natural patterns of snowmelt runoff, but their lower frequency would not provide the same level of benefit as Alternatives C, D, F, and G. August and September volumes would be lower to conserve sediment during the monsoon period. The mean daily change in flow under Alternative E would be higher than under Alternative A in all months but September and October, when the daily change would be lower. The greater daily change in flow under this alternative could increase the erosion rates of sandbars. This alternative has a relatively high potential for sandbar building, compared to other alternatives (Section 4.3). The higher number of HFEs could increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats.

In summary, in comparison to Alternative A, the relatively even monthly release volumes and daily flows of Alternative E, together with lower summer volumes and flows, would favor sediment conservation during monsoon periods, and would provide some increase in downstream water temperatures, especially in the summer. Higher mean daily changes in flow in all months but October and November may reduce nearshore habitat stability, which would affect fish, aquatic invertebrates, benthic productivity, and riparian species in those habitats (Table 4.4-2). Sediment-triggered spring HFEs would support natural processes dependent on natural patterns of snowmelt runoff, but their frequency would be low relative to Alternatives C, D, F, and G. The high frequency of sediment-triggered HFEs would increase sandbar building relative to Alternative A.

4.4.3.6 Alternative F

In contrast to all other alternatives, Alternative F has a pattern of monthly volumes and daily flows that are seasonally adjusted to more closely match the pattern of Lake Powell inflow and the natural snowmelt runoff pattern, with high spring flows and low summer through winter flows. Under Alternative F, the highest mean monthly release volumes and mean daily flows occur in March through June, and lower volumes and daily flows occur in December, January, and July through August (Section 4.2). Under Alternative F, there would be no within-day flow changes except those needed for HFEs or other high-flow releases, or as a result of changes in the runoff forecast, equalization flows, or natural precipitation events and tributary inflows. This alternative has the highest number of HFEs of all the alternatives. Thus among all the alternatives, Alternative F is expected to result in flow-related natural processes that are most different from current conditions, but most similar to an unregulated condition. Steady flows are expected to reduce the erosion of sandbars, provide for more stable main channel and nearshore aquatic habitats, and increase productivity in these habitats (Sections 4.5, 4.6, and 4.7).

Relative to other alternatives, Alternative F would have the lowest water temperatures in spring and the warmest temperatures in summer (Section 4.2). This pattern and magnitude of downstream warming are due, in part, to the monthly patterns in release volumes and daily flows, as well as the relative absence of daily flow fluctuations, under Alternative F. As a result,

temperature-linked natural processes could be affected more under Alternative F than under any of the other alternatives..

Alternative F has a greater potential for sediment conservation and deposition, and significantly more potential for sandbar building, than any other alternative but Alternative G. These HFEs would increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats.

In summary, the monthly release volumes and daily flows under Alternative F would more closely match the pattern of inflows, with high spring and low summer through winter flows. In comparison with Alternative A, this pattern of monthly volumes and daily flows, together with steady within-day flows, would increase sediment conservation and increase the stability of nearshore habitat stability, and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). Alternative F would have the least amount of spring warming, and the greatest amount of summer warming of all alternatives. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.4.3.7 Alternative G

Under Alternative G, mean monthly volumes as well as mean daily flows would be higher in October, November, and February through April, but lower in December, January, July, and August (Section 4.2). These steady flows would serve to conserve sediment relative to other alternatives, but would provide no seasonal variability, and therefore could affect natural processes reliant on such variability. There would be no mean daily changes in flow except for ramping during HFEs or in response to changes in the runoff forecast, equalization flows, or precipitation events and tributary inflows. Steady flows are expected to reduce the erosion of sandbars, improve the quality and stability of nearshore and main channel aquatic habitats, and increase benthic productivity (Section 4.5).

Alternative G would have less downstream warming, and thus cooler downstream main channel water temperatures in spring and warmer downstream temperatures in summer, compared to Alternative A and all other alternatives but Alternative F (Section 4.2). As with Alternative F, this pattern of downstream warming is due, in part, to the pattern of monthly release volumes under Alternative G.

Sediment-triggered and proactive spring HFEs under Alternative G would support natural processes that are dependent on natural patterns of snowmelt runoff. The relatively high frequency of spring HFEs relative to Alternatives A, B, and E would also contribute to those processes. Alternative G has the highest average number of sediment-triggered HFEs of all the alternatives (Section 4.3). These HFEs would result in the most bar-building of any of the alternatives, increase the size and persistence of sandbars, and support the aquatic and riparian species that depend on these habitats (Sections 4.6 and 4.7).

In summary, the more even monthly release volumes and daily flows under Alternative G, together with steady within-day flows, may increase sediment conservation and increase nearshore habitat stability, and thus benefit native fish, trout, benthic productivity, aquatic invertebrates, and riparian species that use those habitats (Table 4.4-2). This alternative also has the second-highest summer warming of all alternatives. The relatively high frequency of spring HFEs would support natural processes that are dependent on natural patterns of snowmelt runoff. The high frequency of spring and fall HFEs would increase sandbar building relative to Alternative A.

4.5 AQUATIC ECOLOGY

The assessment of impacts on aquatic ecology focused on four groups of aquatic resources: the food base (consisting of invertebrates, algae, and aquatic plants), native fish (including the endangered humpback chub [*Gila cypha*]), nonnative fish (including rainbow trout [*Oncorhynchus mykiss*]), and aquatic fish parasites. The specific attributes and conditions evaluated, the analysis methods, and the assessment results are presented in the following sections. Additional details are provided in Appendix F.

Issue: How do alternatives affect aquatic resources (food base, native and nonnative fishes, and fish parasites) between Glen Canyon Dam and Lake Mead?

Impact Indicators:

- Abundance, distribution, and availability of the aquatic food base
- Native and nonnative fish reproduction, survival, growth, and distribution
- Availability and quality of aquatic habitats
- Distribution and potential for spread of fish parasites

4.5.1 Analysis Methods

The evaluation of the potential impacts of LTEMP alternatives on aquatic resources below Glen Canyon Dam is based on alternative-specific differences in operations (including monthly and annual flow patterns and within-day flow fluctuations), and flow and non-flow actions. These characteristics of alternatives can affect aquatic organisms directly or through their effects on habitat availability and quality. The analysis methods for impacts on aquatic food base, native fish, nonnative fish, and aquatic parasites are presented next.

4.5.1.1 Aquatic Food Base

The aquatic food base assessment considers the effects of flow and temperature on the amount of food that is available to fish and other animals in Glen and Grand Canyon. The assessment focuses on changes at key locations in the Colorado River: RM 0 (Lees Ferry within the Glen Canyon reach), RM 61 (Little Colorado River within the Marble Canyon reach), and RM 225 (Diamond Creek within the Grand Canyon reach). As discussed in Section 3.2.1.2, within-day flow variation in releases continues downstream and decreases little as flows pass through Marble and Grand Canyons. Water, on the other hand, can warm considerably by the time it travels from the dam to western Grand Canyon (Section 3.2.2.2).

The effects of flow and temperature on the aquatic food base were evaluated by examining a number of important factors. The potential influence of flow on the aquatic food base includes changes in invertebrate drift (food organisms dislodged and moved by river current, e.g., algae, plankton, invertebrates, and larval fish); stranding of aquatic organisms in the varial zone (the portion of the river's edge affected by the daily range of flows); and effects to species abundance, composition, and diversity. Stranding of organisms in the varial zone may lead to their death, while growth of primary producers such as *Cladophora* is reduced in the varial zone. The potential influence of temperature includes changes in diatom composition; invertebrate egg development, fecundity, growth, maturation, number of yearly generations, and/or emergence of adults for aquatic insects with terrestrial adult stages; invertebrate composition, diversity, and production (e.g., biomass of benthic macroinvertebrates per unit of area per unit of time); and occurrence and distribution of invasive and parasitic species (Clarke et al. 2008; Poff et al. 1997; Power et al. 1988; Renöfält et al. 2010).

To assess potential flow effects on the aquatic food base, a qualitative comparison among alternatives was conducted because an appropriate quantitative model was not available. This qualitative analysis was based on potential impacts of elements of base operations (e.g., release volumes, maximum and minimum flows, daily flow range, and ramp rates) and other experimental flow actions (e.g., HFEs, low summer flows, TMFs, and hydropower improvement flows). To assess potential temperature effects on the aquatic food base, expected mean monthly temperatures at Lees Ferry, Little Colorado River, and Diamond Creek were compared to temperature requirements for select primary producers, zooplankton, and benthic macroinvertebrate species (Valdez and Speas 2007).

4.5.1.2 Nonnative Fish

The assessment of impacts on nonnative fish evaluated effects on reproduction, survival, growth, and abundance downstream of Glen Canyon Dam. The assessment considered results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of nonnative fish (e.g., see Makinster et al. 2010), as well as studies of the effects of experimental flows (such as HFEs and trout removal flows) on nonnative fish (e.g., Makinster et al. 2011; Korman et al. 2012; VanderKooi 2015; Gimbel 2015). In addition, species-specific models that incorporated factors such as annual release volumes, water temperatures, and monthly and within-day changes in flows were used to examine effects at selected locations downstream of Glen Canyon Dam.

A coupled rainbow trout–humpback chub model was used to evaluate potential effects of alternatives on (1) the number and size of rainbow trout in the Glen Canyon reach, and (2) the number of age-0 rainbow trout expected to move (emigrate) into the Marble Canyon and Little Colorado River reaches over the 20-year LTEMP period. The model estimates the number of rainbow trout that move downstream as a function of trout spawning and recruitment in the Glen Canyon reach. Historic observations and previous modeling suggest that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman, Persons et al. 2011; Korman et al. 2012;

Section 3.5.4). Recruitment for a given year was predicted to be higher if a spring HFE occurred in that year or in the previous year, based upon empirical relationships reported by Korman et al. (2011c). At the time modeling was conducted, there was insufficient information to draw a conclusion about whether fall HFEs would have a similar effect on the recruitment of trout. The model considered this uncertainty about the effect of fall HFEs on trout recruitment by examining two hypotheses: (1) fall HFEs would have no effect on recruitment and (2) recruitment would increase at the same rate as seen with spring HFEs, but for only 1 year instead of 2 years. Preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015).

The number of trout recruits in the Glen Canyon reach, and the numbers of trout and humpback chub in the Little Colorado River reach were used to determine when TMFs and mechanical removal in the Little Colorado River reach, respectively, would be triggered under certain alternatives. As described in Appendix F, TMFs are triggered in the rainbow trout–humpback chub model when the estimated number of YOY trout in the Glen Canyon equal or exceed 200,000. The actual trigger implemented could be higher or lower depending on the results of experiments, and these triggers would be developed in consultation with the Arizona Game and Fish Department (AZGFD) and other entities as appropriate (Section 2.2.4.6).

Two factors must coincide to trigger mechanical removal trips in the rainbow trout–humpback chub model: (1) there must be more than 760 adult rainbow trout projected for the test reach in the vicinity of the Little Colorado River confluence (RM 63–RM 64.5) and (2) the projected adult humpback chub population must be less than 7,000 individuals. Once triggered, the model assumes that six mechanical trip passes would occur during the year. The triggering factors for mechanical removal in the model reflect criteria in the decision protocol outlined in Reclamation's Nonnative Fish Control EA (Reclamation 2011b). Under Alternative D, mechanical removal of nonnative fish would be implemented in the Little Colorado River reach if Tier 1 conservation actions actions failed to reverse declining trends in humpback chub populations and adult abundance dropped below 7,000. If triggered, mechanical removal efforts would cease if a calculated relative predator index (see Appendix O) declined to 60 rainbow trout per kilometer for 2 years, or if the number of humpback chub exceeded 7,000.

Technical details about the coupled rainbow trout-humpback chub model are presented in Appendix F. The combined model uses an age-structured population dynamics model to predict the abundance and growth of rainbow trout in Glen Canyon, and the number of those fish that migrate into Marble Canyon. The model makes predictions on an annual time step for fish that are 1 to 6 years of age. Annual recruitment (i.e., the number of age-0 fish that enter the population in a given year) is predicted based on flow statistics, and annual growth is predicted as a decreasing function of overall rainbow trout abundance. Abundance, in combination with estimates of age-specific angling vulnerabilities, is used to make predictions of angling catch rates and predicted abundance and size distributions are used to compute the number of quality-sized fish (i.e., trout ≥16 in. total length) potentially available for capture in the fishery. The number of fish migrating into Marble Canyon each year (out-migrants) is predicted as a proportion of the previous year's recruitment, and is used as an input in a submodel that estimates the potential number of fish that eventually migrate down to the confluence of the

Little Colorado River, where their effects on humpback chub are simulated in the humpback chub submodel. Basic parameters and those for key functional relationships in the trout submodel were derived or fitted to values from a stock synthesis model developed by Korman et al. (2012). That model used 21 years of electrofishing-based catch-per-effort data for Glen and Marble Canyons, in conjunction with length frequencies and considerable auxiliary information, to estimate annual recruitment, survival rate, growth parameters, and outmigration patterns for rainbow trout.

As with most models of biological systems, a number of simplifications and assumptions were made in the rainbow trout-humpback chub model. The model was tested by comparing predictions of key state variables such as recruitment, outmigration, and size at the terminal age generated using flow statistics from the historical record between 1990 and 2010 with observations and best estimates of those values for the same period. Predictions of angling catch rates were compared to annual estimates derived from creel surveys (Makinster et al. 2011). Predictions of rainbow trout abundance were compared to interannual trends from electrofishing surveys conducted by the AZGFD. Predictions of recruitment, asymptotic length, and outmigration were compared to best-fit estimates from a stock synthesis model developed by Korman et al. (2012). Overall, the predictions generated by the model resulted in a relatively good fit to historic observations and estimates.

Water temperature is a major factor affecting the distribution and abundance of fish through effects on reproduction, growth, and survival (Valdez and Speas 2007). A temperature model (Wright, Anderson et al. 2008) was used to estimate alternative-specific downstream temperatures and determine their suitability to support reproduction, growth, and survival of nonnative fish (specifically, rainbow and brown trout, smallmouth bass, green sunfish, channel catfish, and striped bass) at locations downstream of Glen Canyon Dam. The temperature suitability model assumed that the potential for self-sustaining populations of nonnative fish at specific locations is related to the combined suitability of temperatures for spawning, egg incubation, and growth of each species. Possible values for temperature suitability can theoretically range from 0 (completely unsuitable for one or more life history aspects) to 1 (magnitude and timing of temperatures would be optimal for all life history aspects). The temperature suitability modeling evaluates the potential for all life history needs to be met in the mainstem river, but some species are known to use tributaries for spawning, incubation, and growth. Thus, the model predicts relatively low temperature suitability even in some areas where species populations appear to be self-sustaining. In addition, modeled temperatures do not consider the potential for warming near tributary mouths or in shallow nearshore areas. Thus, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem Colorado River, rather than as an exact predictor of the potential for the presence or absence of nonnative fish species at particular locations.

The distribution and abundance of nonnative fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.3 Native Fish

The assessment of impacts on native fish considered the effects of alternative-specific differences in mainstem flow, water temperature, and sediment regimes on the following:

- The potential for the establishment of self-sustaining populations of native fish at selected mainstem locations;
- Changes in potential levels of competition and predation from nonnative fish;
- Potential increases in parasite infestations; and
- Main channel and nearshore habitat quality, quantity, and stability.

The evaluation of potential impacts of the alternatives on native fish included consideration of the results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of native fish (e.g., Coggins and Walters 2009; Albrecht et al. 2014; Gerig et al. 2014), as well as studies of the effects of experimental flows (such as HFEs and other flows) and water temperature on native fish (e.g., Makinster et al. 2011; Korman et al. 2010; Ward 2011; Ward and Morton-Starner 2015).

The coupled rainbow trout–humpback chub model described in Section 4.5.1.2 was also used to evaluate potential effects of alternatives on the humpback chub population in the Little Colorado River aggregation over the 20-year LTEMP period. The model estimated survival, growth, and abundance of adult humpback chub based on water temperatures and the estimated abundance of rainbow trout in the Little Colorado River reach, as well as previously reported rates (Yackulic et al. 2014). The effects of triggered mechanical removal and TMFs on trout abundance also were modeled (see Section 4.5.1.2). In order to evaluate the potential for operational scenarios to lead to extinction or improvement of the humpback chub population in the Grand Canyon, the modeled estimate of the minimum number of adult humpback chub that would occur during each 20-year simulation period was compared among alternatives.

Technical details about the humpback chub submodel are provided in Appendix F. The humpback chub submodel was based on the best available scientific information. As presented in Appendix F, the model provided a good fit between simulated adult humpback abundance and abundance estimates developed by Coggins and Walters (2009) for a period of time (1990–2008) that is separate from the period of time (2009–2013) over which most parameters were estimated. However, like all models, it is a simplified representation of the actual system it seeks to describe.

Water temperature is an important factor that affects the distribution and abundance of native fish through its effects on reproduction, growth, and survival (Valdez and Speas 2007). Species-specific models were used to estimate temperature suitability for native fish (including humpback chub) using the same methods and assumptions described in Section 4.5.1.2. As mentioned in that section, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem

Colorado River, rather than an exact predictor of the potential for the presence or absence of native fish species at particular locations.

The distribution and abundance of native fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, turbidity (which may affect predation rates), and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.4 Aquatic Parasites

The potential for fish parasites to expand their distribution within the river and result in infestations of native and nonnative species was examined for each alternative. Species-specific temperature suitability models, together with information on current distribution, life history, and ecological requirements (e.g., McKinney, Robinson et al. 2001; Choudhury et al. 2004; Hoffnagle et al. 2006) were used to predict the potential for each alternative to provide conditions in the mainstem river that could increase the occurrence and abundance of fish parasites at selected locations between Glen Canyon Dam and Lake Mead. The evaluations focused on four parasite species: Asian tapeworm (*Bothriocephalus acheilognathi*), anchor worm (*Lernaea cyprinacea*), trout nematode (*Truttaedacnitis truttae*), and whirling disease (*Myxobolus cerebralis*).

4.5.2 Summary of Impacts

The potential impacts of each alternative on the aquatic food base, trout, warmwater nonnative fish, native fish, and aquatic parasites are summarized in Table 4.5-1 and described in the following sections.

4.5.2.1 Aquatic Food Base

The impacts of LTEMP alternatives on the aquatic food base are expected to be negligible, beneficial, or adverse depending on the alternative. Some operational characteristics may cause both beneficial and adverse impacts (e.g., benthic productivity may increase while drift rates decrease with a reduction in daily fluctuations). The impacts are described in the following sections.

Flow Effects on the Aquatic Food Base

In general, flow effects on the aquatic food base depend on the magnitude of daily flows and the within-day and seasonal variability of those flows. The low-flow channel (permanently wetted area) supports most of the primary and secondary production in regulated rivers (Jones 2013b). Steady flows or reduced fluctuations may create conditions that allow a large standing crop of benthic algae and invertebrates to develop, particularly during spring and

summer months (Leibfried and Blinn 1987; Pinney 1991; Shannon et al. 2001). Steady flows may also prevent the daily loss or reduction in size of backwaters. More stable backwaters potentially support increased planktonic and benthic communities (Reclamation 1995; Behn et al. 2010). Steady flows or reduced fluctuations may increase benthic productivity over the long term, which will increase invertebrate drift (the preferred food of fish such as trout and humpback chub that feed in the water column) over the long term (Kennedy, Yackulic et al. 2014).

Alternatives with wider daily fluctuations (e.g., Alternatives B and E) would have greater impacts on the aquatic food base than would those with lower fluctuations. Because of repeated cycles of inundation and exposure, the varial zone does not provide consistent conditions for benthic production. The varial zone also provides poor habitat for species with multiple life history stages (Jones 2013) by dewatering of emergence and oviposition sites (Vinson 2001; Kennedy et al. 2016). In the Glen Canyon Dam tailwaters, *Gammarus* standing stock and fecundity are lower, seasonal recruitment of young is briefer, and fewer young are recruited into the population in the varial zone compared to the permanently wetted zone. In addition, *Gammarus* mortality increases in the varial zone (Angradi and Kubly 1993; Ayers and McKinney 1996; Ayers et al. 1998).

Flow fluctuations may increase the amount of organisms available to drift-feeding fish, although this may only occur for a short period (e.g., a few days or less), depending on the density and replacement capacity of benthic invertebrates. For example, a twofold daily variation in discharge resulted in a more than tenfold increase in drift concentrations of *Gammarus* and New Zealand mudsnails, while blackfly drift concentrations decreased by over 80% as discharge doubled. Midge drift concentrations increased proportionally to discharge (Kennedy et al. 2014).

Flows up to 31,500 cfs do not have a large scouring effect on the aquatic food base downstream of Glen Canyon Dam, whereas flows of 41,000 to 45,000 cfs may scour a large portion of the aquatic food base (Reclamation 2011b). The highest mean daily flows for most alternatives would be <14,700 cfs (in an 8.23-maf year), except under Alternative F, which would have mean daily flows of 20,000 cfs in May and June. Thus, aquatic food base scouring would not be expected from base operations regardless of alternative. All alternatives would have HFEs of 45,000 cfs that would last up to 96 hr, while the lengthiest 45,000 cfs HFEs would be 250 hr for Alternative D and 336 hr for Alternative G. Scouring of the aquatic food base by HFEs would be expected for all alternatives. The potential extent of benthic scouring, and the subsequent length of time needed for recovery of the aquatic food base, would be higher with longer duration 45,000-cfs HFEs. In addition, the number and frequency of HFEs may affect scouring and subsequent recovery of the aquatic food base. Table 4.5-2 summarizes the impact on the aquatic food base from HFEs from Glen Canyon Dam that occurred between 1996 and 2008. The March 2008 HFE reduced the biomass and coverage of aquatic macrophytes. This restructured the invertebrate community in favor of fast-growing insect taxa (e.g., chironomids and blackflies) that prefer bare substrates, while disadvantaging non-insect taxa such as New Zealand mudsnails that prefer macrophyte beds (Cross et al. 2011). In subsequent years (2009–2012), aquatic macrophytes restablished, New Zealand mudsnails became dominant, and chironomids and blackflies declined (Gimbel 2015). Preliminary results indicate that recent fall HFEs have not elicited the kind of food base response observed in March 2008. It is possible that

TABLE 4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology

Aquatic Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Compared to Alternative A, slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows; habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced; lower trout abundance; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; habitat quality and stability for nonnative and native fish may be higher; higher trout abundance even with implementation of TMFs and mechanical removal; no difference in humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base and drift; experimental macroinvertebrate production flows may further increase productivity and diversity; habitat quality and stability for nonnative and native fish are expected to be slightly higher; negligible change in trout abundance with implementation of TMFs, and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, slightly higher productivity of benthic aquatic food base, and similar or increased drift; habitat quality and stability for nonnative and native fish would be slightly lower; lower trout abundance with implementation of TMFs and mechanical removal; slightly higher humpback chub abundance.	Compared to Alternative A, increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year; positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives; higher trout abundance; slightly lower humpback chub abundance.	Compared to Alternative A, relatively high productivity of aquatic food base and long-term drift; greater habitat stability for nonnative and native fish; higher trout abundance even with implementation of TMFs and mechanical removal; slightly lower humpback chub abundance.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base							
Mainstem benthic productivity	No change from current conditions until 2020; no HFEs after 2020 may lower blackfly and midge production.	Compared to Alternative A, slightly lower benthic production due to higher daily flow fluctuations; infrequent HFEs may decrease blackfly and midge production.	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows from December through August, lower daily range in flows, and more frequent HFEs (which may increase blackfly and midge production).	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows and more frequent HFEs (which may increase blackfly and midge production); experimental macroinvertebrate production flows may also increase productivity and diversity.	Compared to Alternative A, potential increase in benthic production due to more uniform monthly flows and more frequent HFEs (which may increase blackfly and midge production), but increase would be offset by higher within-day flow fluctuations.	Compared to Alternative A, potential increase in benthic production in spring and early summer from increased monthly flows with no daily flow fluctuations, but lower rest of year due to low steady flows; frequent HFEs may increase blackfly and midge production.	Compared to Alternative A, benthic production relatively high and consistent throughout the year due to relatively stable monthly flows with no daily flow fluctuations, but this may favor species that lack a terrestrial adult stage; frequent HFEs may increase blackfly and midge production.
Drift	No change from current conditions.	Compared to Alternative A, increased drift due to higher within-day fluctuations.	Compared to Alternative A, increased drift due to increased benthic production.	Compared to Alternative A, increased drift due to increased benthic productivity. Higher weekday flows following experimental macroinvertebrate production flows may temporarily increase drift.	Compared to Alternative A, increased drift due to higher within-day fluctuations.	Compared to Alternative A, increased drift due to increased benthic production.	Compared to Alternative A, increased drift due to increased benthic production.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base (Cont.)							
Nearshore benthic productivity	No change from current conditions and levels, although no HFEs after 2020 may adversely affect backwater establishment.	Compared to Alternative A, potentially lower nearshore productivity due to higher daily range in flow; infrequent HFEs throughout the LTEMP period may slightly improve backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from lower daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity based on more uniform monthly release volumes; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, nearshore productivity slightly lower based on somewhat higher daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Compared to Alternative A, potential increase in nearshore productivity from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.
Trout							
Spawning habitat	No change from current conditions.	Compared to Alternative A, potential decrease in spawning habitat availability and stability due to higher within-day flow fluctuations during the spawning period.	Compared to Alternative A, potential increase in spawning habitat availability and stability due to lower within-day flow fluctuations during the spawning period.	Compared to Alternative A, slight potential decrease in spawning habitat availability and stability due to slightly greater within-day flow fluctuations during the spawning period.	Compared to Alternative A, lowest spawning habitat availability and stability due to highest average within-day flow fluctuations during the spawning period.	Compared to Alternative A, spawning habitat relatively available and stable within spring months due to absence of within-day flow fluctuations, but high flows in May and June affect availability and stability.	Compared to Alternative A, greatest spawning habitat availability and stability due to absence of within-day flow fluctuations and even monthly distribution of flows.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Stranding	No change from current conditions and levels.	Compared to Alternative A, greatest potential for increased stranding resulting from highest down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, potential increase due to higher down-ramp rate.	Compared to Alternative A, relatively low potential for stranding due to absence of within-day flow fluctuations, but large drops in flow would occur after high flows in May and June.	Compared to Alternative A, lowest potential for stranding due to absence of within-day flow fluctuations and even monthly distribution of flows.
Population size in Glen Canyon reach	No change from current conditions and levels. Estimated mean abundance 95,000 age-1 and older fish.	Compared to Alternative A, small potential decrease compared to Alternative A. Estimated abundance 74,000 age-1 and older fish.	Compared to Alternative A, small potential increase because of frequent HFEs and lower daily flow fluctuations. Estimated mean abundance 102,000 age-1 and older fish.	Compared to Alternative A, negligible change. Estimated mean abundance 93,000 age-1 and older fish.[a]	Compared to Alternative A, small potential decrease because of higher flow fluctuations. Estimated mean abundance 88,000 age-1 and older fish.	Compared to Alternative A, greatest potential increase among all alternatives because of frequent HFEs and steady flows. Estimated mean abundance 160,000 age-1 and older fish.	Compared to Alternative A, potential increase because of frequent HFEs and steady flows. Estimated mean abundance 132,000 age-1 and older fish.
Number of fish >16 in. total length (TL) in Glen Canyon reach	No change from current condition. Estimated abundance 770 fish.	Compared to Alternative A, potential increase because higher fluctuations and relatively few HFEs lower recruitment and reduces competition. Estimated mean abundance 870 fish.	Compared to Alternative A, negligible change. Frequent HFEs and lower fluctuations increase recruitment but TMFs control trout numbers. Estimated mean abundance 750 fish.	Compared to Alternative A, negligible change. Frequent HFEs increase recruitment but TMFs control trout numbers. Estimated mean abundance 810 fish.	Compared to Alternative A, potential increase because of higher fluctuations, few spring HFEs, and implementation of TMFs lower recruitment and reduces competition. Estimated mean abundance 830 fish.	Compared to Alternative A, greatest potential decrease because steady flows, annual spring HFEs, and no TMFs result in high recruitment and increased competition. Estimated mean abundance about 600 fish.	Compared to Alternative A, potential decrease.. Steady flows and frequent HFEs result in high recruitment and increased competition, but TMFs offset increases. Estimated mean abundance about 700 fish.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Emigration from Glen Canyon to Marble Canyon	No change from current conditions. Estimated mean emigration about 37,000 fish/yr.	Compared to Alternative A, lowest potential emigration because higher fluctuations and relatively few HFEs lower recruitment. Estimated mean emigration about 30,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Frequent HFEs and lower fluctuations increase recruitment. Estimated mean emigration about 44,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Frequent HFEs increase recruitment, but offset by fluctuations and TMFs. Estimated mean emigration about 41,000 fish/yr.[a]	Compared to Alternative A, negligible change; fewer spring HFEs, higher fluctuations, and TMFs result in low recruitment. Estimated mean emigration about 38,000 fish/yr.	Compared to Alternative A, highest potential emigration. Annual spring HFEs, steady flows, and lack of TMFs result in high recruitment. Estimated mean emigration about 72,000 fish/yr.	Compared to Alternative A, potential increase in emigration. Steady flows and frequent HFEs result in high recruitment, but TMFs offset increases. Estimated mean emigration about 59,000 fish/yr.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, some improvement in suitability at RM 61 but reduced suitability at RM 157 and RM 225.	Similar to Alternative A.
Warmwater Nonnative Fish							
Nearshore habitat quality, availability, and stability	No change from current levels and conditions.	Compared to Alternative A, possible decrease due to highest ramp rates and within-day flow fluctuations of all alternatives.	Compared to Alternative A, potential increase associated with lower within-day fluctuations.	Compared to Alternative A, potential increase in habitat availability and stability based on more uniform monthly release volumes.	Compared to Alternative A, possible decrease due to higher within-day fluctuations in most months.	Compared to Alternative A, possible increase resulting from elimination of within-day flow fluctuations.	Compared to Alternative A, possible increase resulting from elimination of within-day flow fluctuations.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Parasites							
Potential for increased establishment and infestation	No change from current conditions and levels.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
Native Fish							
Humpback chub population size	No change from current levels. Estimated average minimum number of adults about 5,000; estimated lowest minimum number of adults about 1,500.	Compared to Alternative A, greatest potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,400; estimated lowest minimum number of adults about 1,900; higher fluctuations could reduce food base productivity and limit chub numbers.	Compared to Alternative A, negligible change. Estimated average minimum number of adults 5,000; estimated lowest minimum number of adults about 1,500.	Compared to Alternative A, potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,200; estimated lowest minimum number of adults about 1,800; potential increase in food base productivity could favor chub.	Compared to Alternative A, potential increase resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,300; estimated lowest minimum number of adults about 1,600; higher fluctuations could reduce food base productivity and limit chub numbers..	Compared to Alternative A, greatest potential decrease resulting from highest increases in trout recruitment. Estimated average minimum number of adults about 4,400; estimated lowest minimum number of adults about 1,400; potential increase in food base productivity could offset some adverse impacts on chub.	Compared to Alternative A, potential decrease resulting from increased trout recruitment. Estimated average minimum number of adults about 4,700; estimated lowest minimum number of adults about 1,700; potential increase in food base productivity could offset some adverse impacts on chub.
Temperature suitability for humpback chub at aggregation locations	No change from current levels at all locations.	Similar to Alternative A.	Compared to Alternative A, small potential reduction.	Similar to Alternative A.	Compared to Alternative A, small potential reduction.	Compared to Alternative A, greatest potential reduction.	Similar to Alternative A.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Native Fish (Cont.)							
Humpback chub growth in main channel	Negligible change from current conditions. Estimated growth of YOY humpback chub in mainstem about 24 mm at RM 61 and about 50 mm at RM 213.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, but greatest potential increase. Estimated growth of YOY humpback in mainstem about 26 mm at RM 61 and about 54 mm at RM 213.	Similar to Alternative A.
Temperature suitability for other native fish	Negligible change from current levels at all locations.	Similar to Alternative A.	Similar to Alternative A.	Compared to Alternative A, small potential increase at downstream locations.	Similar to Alternative A.	Compared to Alternative A, small decrease at RM 225.	Compared to Alternative A, slight potential increase at downstream locations.
Interactions between native and nonnative fish	Negligible change from current levels for most species	Compared to Alternative A, negligible change for most species. Possible decrease in humpback chub–rainbow trout interactions with reduced trout emigration to Marble Canyon reach.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative B.	Compared to Alternative A, possible increase in interactions with warmwater nonnative fish at downstream locations, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.	Compared to Alternative A, possible increase in interactions with warmwater nonnative fish at downstream locations, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.

[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the number of trout produced under Alternative D.

TABLE 4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base

High Flow Experiment	Impact on Aquatic Food Base
45,000 cfs for 7 days, March 26–April 2, 1996	Scouring; 3- to 4-month reduction in abundance and biomass
31,000 cfs for 3 days, November 5–7, 1997	No effects detected
31,000 cfs for 3 days, May 2–4, 2000	No effects detected
31,000 cfs for 3 days, September 4–6, 2000	Some taxa and reaches affected; recovery period not determined
41,000 cfs for 2.5 days, November 21–23, 2004	Possible delayed recovery because HFE occurred in the fall after the growing season
41,500 cfs for 2.5 days, March 5–7, 2008	Reduced biomass of some taxa (e.g., New Zealand mudsnails and *Gammarus*) persisted for >1 year; enhanced drift biomass of some taxa such as midges and blackflies associated with their increased benthic production that lasted >1 year

Source: Reclamation (2011b); Cross et al. (2011).

in the fall, macrophytes and non-insect invertebrates are more resistant to disturbance than they are in spring; however, repeated fall HFEs may shift the food base to a new equilibrium (Kennedy et al. 2015). It is also possible that fall HFEs temporarily reduce macrophyte cover, but that it recovers the following spring. Thus, timing rather than magnitude appears to be the main factor affecting the response of the aquatic food base to HFEs (Gimbel 2015).

The seasonal timing of HFEs (i.e., spring vs. fall) may influence the magnitude of ecological response and recovery rates of ecosystem processes. Recovery times are generally shorter for spring HFEs than for fall HFEs as a result of longer day lengths and warmer river temperatures in spring and summer. Fall HFEs precede winter months of minimal insolation, low temperatures, and reduced gross primary productivity (Cross et al. 2011). HFEs are expected to favor production of midges and blackflies within the Glen Canyon Dam tailwaters, apparently because the short-term adverse effects of scouring lead to an increase in future habitat quality for these organisms (Cross et al. 2011). In addition, although an HFE could reduce total invertebrate production, it may increase the amount of invertebrate prey available to rainbow trout by shifting the invertebrate assemblage toward species that are prone to drift (Cross et al. 2011). Fewer HFEs would occur under Alternatives A and B (Table 4.3-1). Therefore, these alternatives are not expected to cause long-term changes in invertebrate production due to HFEs, but neither would they favor the production of midges and blackflies in the short term after the HFE. The other five alternatives would have HFEs frequent enough to alter mainstem benthic productivity, which favors blackfly and midge production (Table 4.5-1).

Understanding the cumulative effects of multiple HFEs will be an important consideration of the experimental plan for all alternatives. More frequent HFEs in the Grand Canyon could cause a shift to more scour-resistant taxa, resulting in an overall decrease in

macroinvertebrate diversity, and possibly abundance, resulting in a reduction in the aquatic food base (Reclamation 2011a). Fishing guides working in Lees Ferry report that *Gammarus* is less abundant now than it was in the 1980s. While scientific studies do not support these observations, it is possible that declines have not been detected by benthic invertebrate studies that first started in the 1990s (Kennedy 2016). Although HFEs could be a causative agent in a decline of *Gammarus*, other causes are more plausible, especially predatory losses associated with dramatic trout density increases since the 1980s (Kennedy 2016). Humpback chub dietary studies suggest that *Gammarus* abundance may have declined in the area of the Little Colorado River. *Gammarus* comprised about 40% of the humpback chub diet in the early 1990s (Valdez and Ryel 1995), but only 2% of their diet in 2008 (Cross et al. 2013). However, the decline of *Gammarus*, at least as a component of humpback chub diet, does not seem to have been detrimental to the fish (i.e., the humpback chub population declined in the early 1990s but increased by 2008) (Kennedy 2016). See Section F.2.2.1 (Appendix F) for a discussion of potential effects of frequent HFEs on the aquatic food base.

TMFs would be tested under Alternatives B, C, D, E, and G. During the high-flow portions of TMF cycles, drift rates should increase, making more food available to trout and other fish. The very brief (less than 1 day) low-flow portion of TMF cycles are expected to have minor effects on the production of aquatic invertebrates because substrates would be exposed for such a short period of time. No TMFs would occur under Alternative F, and TMFs would only be tested under Alternative A (No Action Alternative). TMFs would be tested and implemented, if tests are successful, for the other alternatives.

A more thorough discussion of potential flow effects on the aquatic food base is provided in Appendix F.

Temperature Effects on the Aquatic Food Base

The species composition, diversity, and production of the aquatic food base in the Colorado River could change in response to water temperature variations (Stevens, Shannon et al. 1996; Valdez et al. 2000). Blinn et al. (1989) observed that epiphytic diatom communities, which serve as an important food source for macroinvertebrates and some fish, change from upright (stalked) diatoms to closely adnate diatoms (those that grow flat on the substrate) with an increase in water temperature from 12 to 18°C (54 to 64°F). This is an important consideration because adnate forms of diatoms are generally more difficult for macroinvertebrates and fish to consume compared to stalked diatoms.

Temperature modeling results (Section 4.1.2.3) indicate that mean monthly temperatures over the 20-year LTEMP period for all alternatives will be ≤14.1°C (57.4°F) at Lees Ferry (RM 0) and the confluence with the Little Colorado River (RM 61). Thus, temperature differences among the alternatives are not expected to alter the diatom composition in the Glen Canyon or Marble Canyon reaches of the Colorado River. However, at Diamond Creek RM 225 (Grand Canyon reach), mean summer temperatures (July through September) for all alternatives would be high enough (e.g., ≥17°C [63°F]) to potentially favor adnate diatom species (see Table F-5, Appendix F). Mean monthly temperatures at Diamond Creek would be highest

for Alternative F ranging from 18.5 to 20.5°C (65.3 to 68.9°F) and least for Alternatives A and B ranging from 17.2 to 17.5°C (63.0 to 63.5°F). However, increased algae production in the Grand Canyon reach, may not be realized because this reach is strongly light-limited due to higher turbidity levels.

Section 3.5.2 describes the improved aquatic food base conditions provided by *Cladophora* compared to *Oscillatoria* (types of algae). Light and flow conditions are the primary factors that affect the presence of these organisms in the Colorado River even though modeled monthly temperatures near Lees Ferry and the Little Colorado River otherwise favor the presence of *Cladophora*, which has a favorable temperature range of 13 to 17°C (55 to 63°F), compared to *Oscillatoria*, which has a favorable temperature range of 18 to 21°C (64 to 70°F) (Valdez and Speas 2007). This also applies to the Diamond Creek area, although modeled water temperature conditions in late spring and summer would favor *Oscillatoria* over *Cladophora* for all alternatives, particularly Alternative F where monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) (see Table F-5, Appendix F). Because conditions at Diamond Creek are already more suitable for *Oscillatoria* (which is more tolerant of turbidity) than *Cladophora*, it would remain more prevalent in the Grand Canyon reach.

The modeled mean monthly temperatures in the Colorado River downstream of Glen Canyon Dam are within the favorable temperature range for most macroinvertebrates (see Table F-7, Appendix F). However, the modeled mean monthly temperatures for all alternatives for January through April range from 8.7 to 9.9°C (47.7 to 49.8°F) at Lees Ferry, which is below the lowered favorable temperature of 10°C (50°F) for blackflies (Valdez and Speas 2007). The modeled mean monthly temperatures would also be below favorable temperatures for blackflies near the Little Colorado River for February and March. Conversely, modeled monthly temperatures of 17.2 to 20.5°C (63.0 to 68.9°F) for July through August near Diamond Creek under all alternatives would be higher than the upper favorable temperature for planarians 16°C (61°F) (Valdez and Speas 2007).

Production rates of macroinvertebrates could increase by 3 to 30% for every 1°C (1.8°F) increase in annual temperatures (Valdez and Speas 2007). Temperature modeling results indicate that annual average temperatures would vary among alternatives by ≤0.2°C (0.4°F) at Lees Ferry, Little Colorado River, and Diamond Creek. This implies that temperature differences among alternatives are not likely to affect production of aquatic food base organisms. However, comparison of monthly average temperatures indicates a potential small difference among some of the alternatives during the summer at Diamond Creek. Most temperature differences among alternatives would be <0.5°C (0.9°F) and therefore not considered significant. However, Alternative F would be as much as1.5 to 3.0°C (2.7 to 5.4°F) higher than the other alternatives in the summer. Thus, summer macroinvertebrate productivity could be higher under Alternative F compared to the other alternatives.

A more thorough discussion of potential temperature effects on the aquatic food base is provided in Appendix F.

4.5.2.2 Nonnative Fish

The potential impacts of the alternatives on nonnative fish are described in this section and summarized in Table 4.5.2-1. Because of distinct differences in habitat needs and distributions, impacts on coldwater nonnative fish (trout) and warmwater nonnative fish are considered separately.

Impacts on Trout

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999; McKinney, Speas et al. 2001; McKinney, Robinson et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Korman et al. 2012). Increases in abundance have been attributed to the changes in flows beginning with interim flows in 1991 and later the implementation of MLFF in 1996. These changes both increased minimum flows and reduced fluctuations in daily flows, which created more stable and productive nursery habitats for rainbow trout in Glen Canyon (McKinney et al. 1999). Declines in abundance (such as observed from 2001 to 2007) have been attributed to the combined influence of warmer water releases from Glen Canyon Dam, high abundance and increased competition, and periodic DO deficiencies, along with possible limitations in the food base (Makinster et al. 2007). Increases in recruitment levels and trout abundance in the Glen Canyon reach during 2008 and 2009 are believed to be due to improved habitat conditions and survival rates for YOY rainbow trout resulting from the March 2008 HFE (Makinster et al. 2011).Recruitment of rainbow trout in Glen Canyon has been positively and strongly correlated with annual flow volume and reduced hourly flow variation; recruitment has also increased after two of three high-flow releases related to the implementation of equalization flows (Korman et al. 2012). The abundance of rainbow trout within the Glen Canyon reach affects the condition (a measure of the weight-length relationship, or "plumpness") of rainbow trout in the population. When abundance of rainbow trout is high, their condition typically deteriorates, so large numbers of fish generally also lead to fish of poorer quality to anglers in terms of size and condition (Makinster et al. 2011) and can also lead to declines in abundance.

Because rainbow trout spawning occurs mostly in the main channel of the Glen Canyon reach, the quality and availability of rainbow trout spawning habitat are expected to be affected by within-day flow fluctuations (McKinney, Speas et al. 2001; Korman, Kaplinski et al. 2011; Korman and Melis 2011), which vary among the alternatives. Within-day flow fluctuations in this reach may act to periodically dewater some spawning areas (redds) while down-ramping may strand larval or YOY rainbow trout (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011). Recent captures of young-of-the-year trout in the vicinity of the Little Colorado River confluence suggest that there may be some rainbow trout spawning in lower Marble Canyon; the degree to which spawning and recruitment of trout in this portion of the river might be affected by flow manipulations, including TMFs, is not clear. Mainstem spawning and recruitment of brown trout (*Salmo trutta*) in the Grand Canyon are thought to be limited because of unsuitable temperatures, competition from rainbow trout, and limited availability of suitable habitat for spawning and rearing of YOY trout (Makinster et al.

2010; Reclamation 2011a,b). Because brown trout reproduction primarily occurs in tributaries, especially in Bright Angel Creek (Reclamation 2011a, b), their spawning habitats generally would not be affected by the flows associated with any of the alternatives. The following discussion focuses on potential effects of the alternatives on rainbow trout.

Evaluation of the stability of rainbow trout spawning habitat for each of the alternatives considered the average allowable daily fluctuation and the evenness of the monthly volumes during the peak spawning months (March through May). Under Alternative A, no changes from current conditions are expected in spawning habitat availability or stability. Rainbow trout spawning habitat would be less stable under Alternatives B and E than under Alternative A because both would allow greater levels of within-day fluctuations during the peak spawning months. Alternative E is expected to have the lowest stability since daily fluctuations and variation in monthly volumes are slightly greater than under Alternative B during the peak spawning months. Compared to Alternative A, Alternatives D and C would have lower allowable within-day fluctuations, similar or greater monthly volumes, and less variable monthly volumes during the spawning period; as a consequence, rainbow trout spawning habitat availability and stability under Alternatives D and C would be higher than under Alternative A. The two steady flow alternatives (Alternatives F and G) would provide the greatest level of spawning habitat stability.

Because of differences in down-ramp rates for base operations (i.e., not considering effects of HFEs and TMFs), the potential for stranding of YOY trout is expected to vary among the alternatives (Table 4.5-1). Potential for stranding under Alternative A is expected to be similar to that under current conditions. Stranding potential under Alternative G would be the lowest since there would be no within-day fluctuations for hydropower generation and relatively small down-ramping events between months. Although Alternative F would also exclude within-day fluctuations for hydropower operations, there would be large drops in flows after the annual 45,000 cfs spike releases that would occur in May and after the week-long 25,000 cfs high flow that precedes the drop to base flows at the end of June; as a consequence, stranding of YOY trout could be significant under this alternative. Compared to Alternative A, the greatest increase in stranding potential would occur under Alternative B, which has down-ramp rates of 3,000 to 4,000 cfs/hr (100% to 166% higher than any of the other alternatives). Alternatives C, D, and E may have a similar increased stranding potential, with down-ramp rates 66% higher than under Alternative A. As noted above, the degree to which spawning and recruitment of trout in lower Marble Canyon (i.e., in the vicinity of the Little Colorado River) might be affected by flow manipulations, including TMFs, is not clear.

As described in Section 4.5.1.2, a coupled rainbow trout–humpback chub model, which considers effects of flow variability, annual volumes, HFEs, and TMFs, and effects of annual trout numbers was used to evaluate potential effects of alternatives on the number and average size (length) of rainbow trout in the Glen Canyon reach, on the number of rainbow trout in the Glen Canyon reach exceeding 16 in. in total length, and on the number of age-0 rainbow trout expected to move into the Marble Canyon and Little Colorado River reaches over the 20-year LTEMP period. Among the alternatives, the model estimated average abundances of age-1 (i.e., individuals that are 1 year old) and older rainbow trout over the 20-year LTEMP period that ranged from about 65,000 to 196,000 individuals in the Glen Canyon reach (Figure 4.5-1).

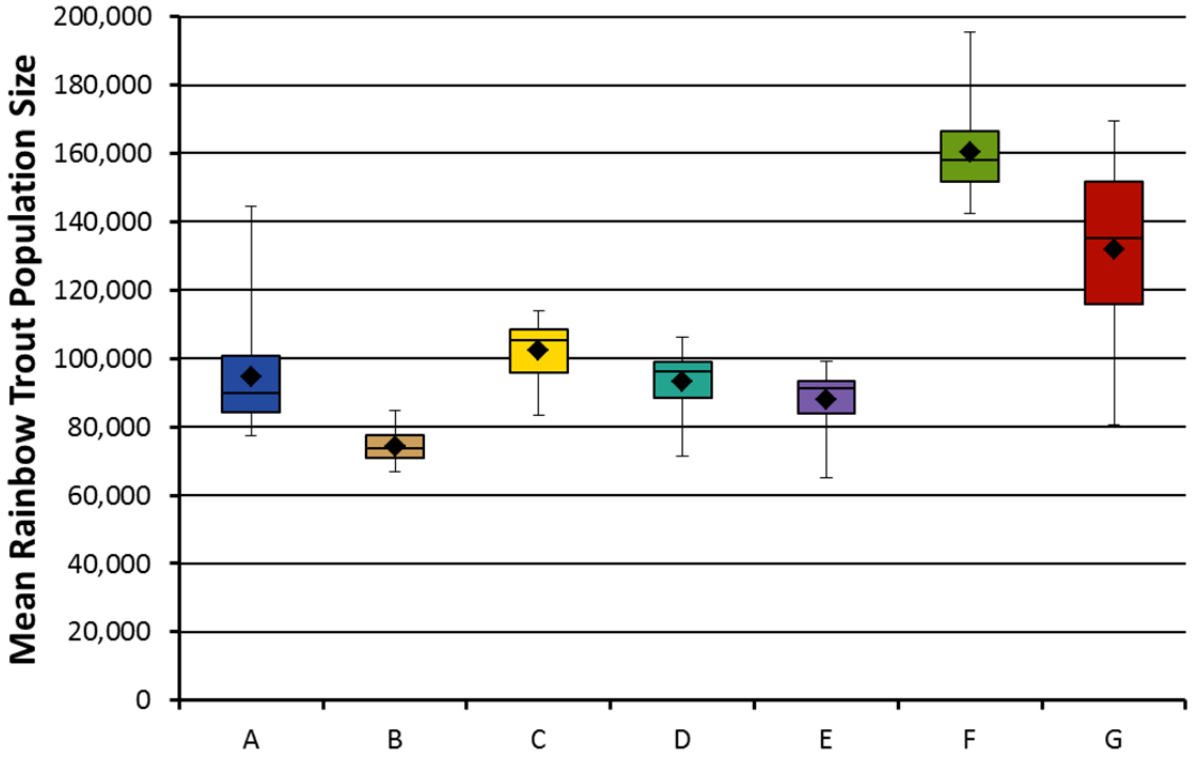

FIGURE 4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum. Means were calculated as the average for all years within each of the 21 hydrology runs.)

Although there is a considerable amount of overlap in the ranges of the estimates for some alternatives, the overall estimated average rainbow trout abundance in the Glen Canyon reach was greatest under Alternatives F and G and lowest under Alternative B, with intermediate abundance levels under Alternatives A, C, D, and E.

The model predicts that annual recruitment of rainbow trout will increase as a function of greater annual volumes, reduced daily variation in flow between May and August, and the occurrence of spring HFEs (see Appendix F). Modeling indicated that alternatives with more frequent HFEs (especially spring HFEs) would have higher recruitment rates. These factors could lead to increased mean abundance of rainbow trout in the Glen Canyon reach and ultimately in the Little Colorado River reach. TMFs and mechanical removal would be used under some alternatives to offset increases in abundance.[9] Because of the effects of trout density

[9] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

on growth rates due to competition for food and other resources, it is expected that the average size of rainbow trout would decrease as average population size increases (Korman, Kaplinski et al. 2011). Modeling results indicated that the average size of age-1 and older rainbow trout over the LTEMP period would be greatest under Alternative B, smallest under Alternatives F and G, and intermediate under Alternatives A, C, D, and E (see Appendix F).

The results of the trout modeling for LTEMP alternatives are consistent with historic observations and previous research, which suggests that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012; Section 3.5.4). Equalization flows, which would occur under all alternatives, are also expected to result in increased rainbow trout recruitment during years in which they occur. The high spring flows of Alternative F and spring HFEs would have similar effects on trout recruitment. Considering the frequency of HFEs alone (Table 4.3-1), average annual rainbow trout recruitment would be expected to be highest under Alternatives C, D, F, and G, and would be lowest under Alternatives A and B. It should be noted, however, that the effects of fall HFEs on trout recruitment are less certain and altering assumptions regarding the strength of the relationship between recruitment levels and fall HFEs could significantly affect the modeled results regarding relative effects of alternatives on average numbers of YOY trout, average numbers of trout emigrating to Marble Canyon, and average abundance of age-1 and older rainbow trout in the Glen Canyon reach during the LTEMP period. Preliminary analyses indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFEs that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015).

Potential increases in rainbow trout recruitment levels due to equalization flows and HFEs could be offset in some years by the proposed testing and implementation of TMFs for all alternatives except Alternative A and F, which do not include TMFs. TMFs are highly variable flows intended to control the number of YOY trout in the Glen Canyon reach (and the associated emigration of trout into Marble Canyon) that would be implemented in years where production of YOY trout is expected to be high. YOY trout tend to occupy shallow habitats near the channel margin (Korman and Campana 2009; Korman and Melis 2011). Based on information from previous studies, raising the flow for a period of days and then suddenly dropping the flow is expected to strand and kill YOY trout, thus controlling numbers and emigration rates (Korman and Melis 2011). As currently envisioned, a typical TMF would consist of several days at a relatively high sustained flow (e.g., 20,000 cfs) followed by a rapid drop to a low flow (e.g., 5,000 cfs), which is held for a brief period (e.g., 6 hr) (Sections 2.2.3.2). This pattern would be repeated for a number of cycles in spring and summer months (May–July). Because of uncertainties about the effectiveness of TMFs, the timing, magnitude, duration, and number of cycles would be tested for efficacy in controlling trout numbers early in the LTEMP period. The number of TMFs that would be expected to occur under each alternative based on modeling are presented in Table 4.9-3 and in Appendix F (Table F-8).

The number of trout emigrating from the Glen Canyon reach into the Marble Canyon reach of the Colorado River was modeled as a function of recruitment levels, which is related to annual volumes, the occurrence of HFEs, the levels of within-day fluctuations during each water year, and whether TMFs are included as a management option for an alternative. The model

estimated that average annual emigration of rainbow trout would be highest under the two steady flow alternatives (Alternatives F [about 72,000 fish/year] and G [about 59,000 fish/year]) and lowest under the alternative with the widest daily fluctuations (Alternative B [about 30,000 fish/year]); the model estimated that Alternatives A, C, D, and E would have intermediate levels of rainbow trout emigration (about 37,000 to 44,000 fish/year) (Figure 4.5-2).

As a measure of the quality of the rainbow trout fishery, the trout model was also used to estimate the average annual number of large rainbow trout (i.e., individuals with total lengths exceeding 16 in.) in the Glen Canyon reach. Among the alternatives, the estimated average number of large rainbow trout in the Glen Canyon reach would range from about 500 to 950 fish (Figure 4.5-3). The estimated average number of large trout present during the 20-year LTEMP period would be greatest under Alternative B (about 870 fish) and lowest under Alternatives F (about 590 fish) and G (about 700 fish), while Alternatives A, C, D, and E would produce intermediate numbers of large trout (about 770, 750, 810, and 830 fish, respectively). In general, growth rates and the number of large rainbow trout in the Glen Canyon reach are expected to be greater in years when overall population abundance is lower due to reduced competition for food and habitat. Because of their effect on recruitment levels and population size, alternatives that

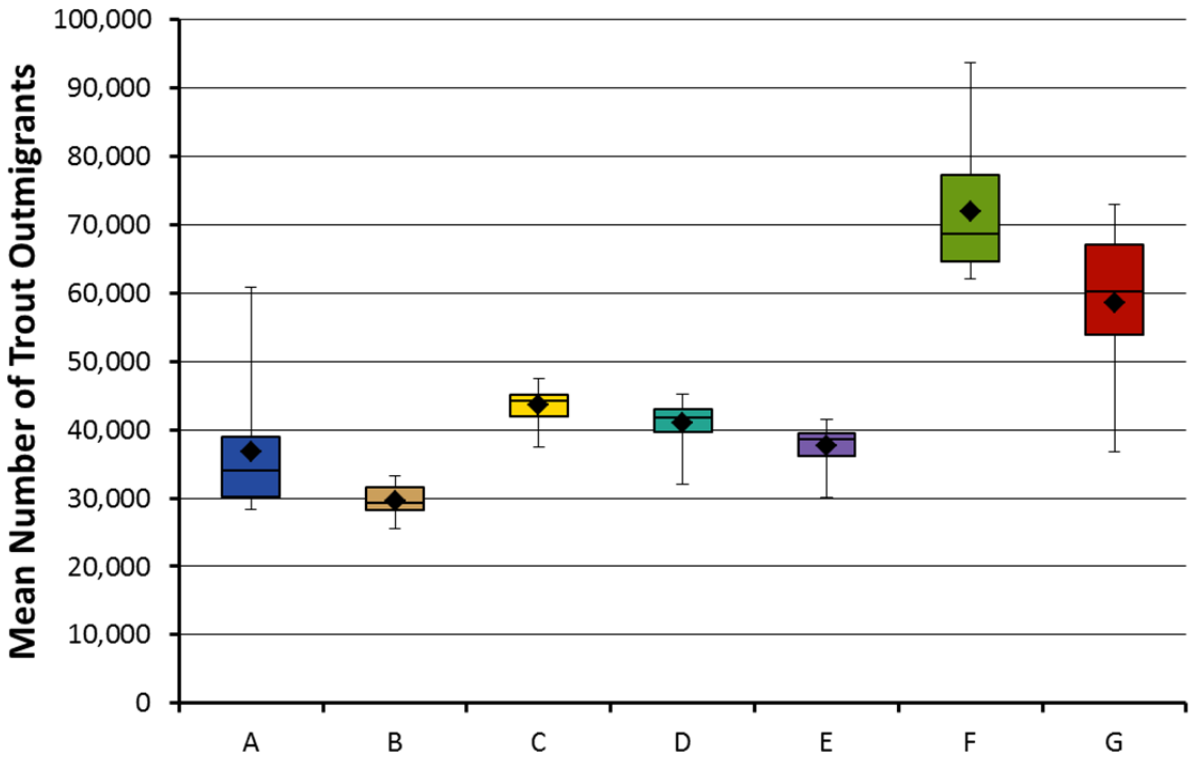

FIGURE 4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

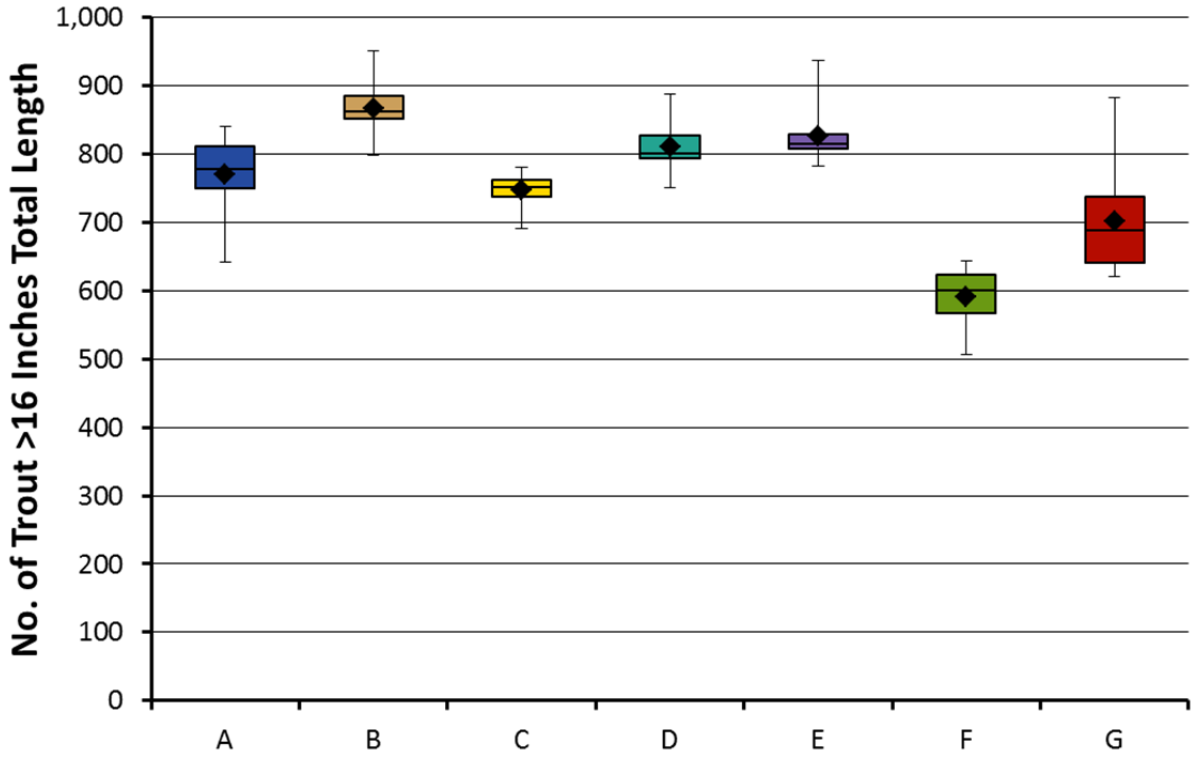

FIGURE 4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

have fewer HFEs (especially spring HFEs), higher daily fluctuations, or implement TMFs are expected to have more large trout.

In general, temperature regimes under all of the alternatives would be suitable, although not optimal, for brown and rainbow trout. Temperature suitability for brown and rainbow trout would be similar among alternatives at most locations downstream of Glen Canyon Dam (Figure 4.5-4), and would be similar to current conditions. However, because of the timing of peak and base flow releases, temperature suitability would be slightly greater under Alternative F than other alternatives at the confluence with the Little Colorado River (RM 61) and lower than other alternatives for locations further downstream. Although main channel temperatures at and downstream of RM 61 would be more suitable for trout than at locations closer to the dam (Figure 4.5-4), the abundance of trout is lower at those locations because other habitat characteristics (e.g., substrate composition and water clarity) are less suitable at these downstream locations.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats. Providing warmer nearshore habitats could promote recruitment and survival of trout that prey

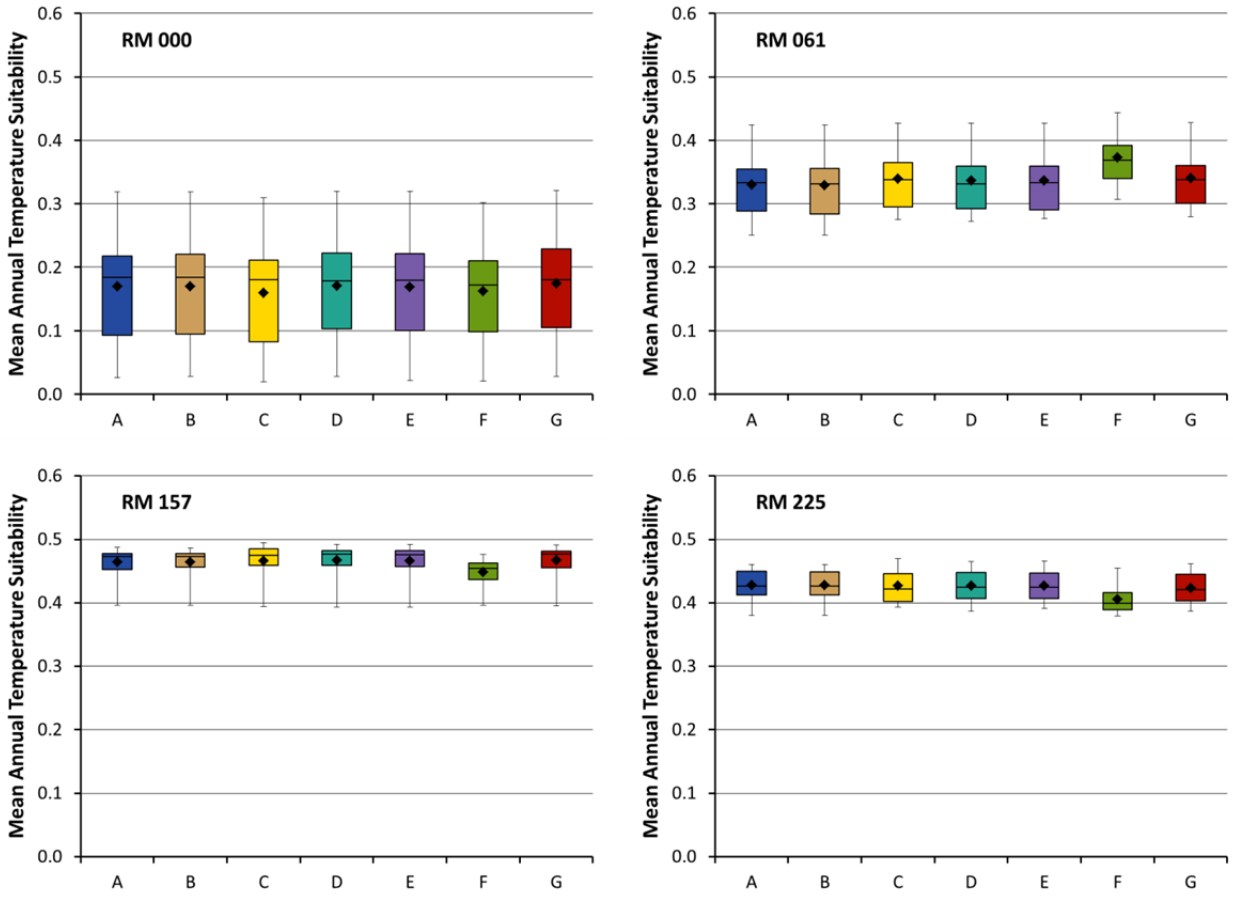

FIGURE 4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

on or compete with native fish species. Because temperature suitability under normal operations is lower than optimal for rainbow and brown trout (Figure 4.5-4), warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach that is important for humpback chub. However, effects on trout and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout and native fish were anticipated.

Impacts on Warmwater Nonnative Fish

As described in Section 3.5.4.2, 17 nonnative warmwater fish species have been documented between Glen Canyon Dam and the inflow to Lake Mead (Table 3.5-2). The distribution and abundance of warmwater nonnative fish could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. As described in Section 4.5.2.1 and Appendix F, alternatives could affect food production for both

native and nonnative fish downstream of Glen Canyon Dam. Changes in sediment regimes and flows under the alternatives could affect the suitability of conditions for warmwater nonnative fish, especially in nearshore habitats (Table 4.5-1).

Temperature suitability was modeled at various main channel locations for four nonnative warmwater species considered to be representative of the warmwater nonnative fish community (smallmouth bass [*Micropterus dolomieu*], green sunfish [*Lepomis cyanellus*], channel catfish [*Ictalurus punctatus*], and striped bass [*Morone saxatilis*]). In general, the estimated average main channel temperature suitability for these nonnative fish did not differ greatly among the alternatives, and was low under all alternatives; the suitability index was below 0.2 on a scale of 0 to 1 for all seven alternatives (Figure 4.5-5). The modeled temperature suitability indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61); this agrees with past surveys that have found more warmwater nonnative fish species in those areas. Relative to current conditions (as exemplified by Alternative A), the temperature suitability model indicated that Alternatives C and F have the greatest potential to improve conditions for warmwater nonnative fish at locations downstream of RM 157, which could result in increased numbers and a greater potential for upstream spread of warmwater nonnative fish species.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats. Providing warmer nearshore habitats could promote recruitment and survival of warmwater nonnative fish species that prey on or compete with native fish species. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. However, effects on warmwater nonnative and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

The Basin Study (Reclamation 2012a) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. Water elevations in Lake Powell could continue to decline, resulting in release of unprecedentedly warm epilimnetic and metalimnetic water through the penstocks. Summer water releases of up to 30°C water could facilitate establishment of detrimental warmwater fish with correspondingly detrimental impacts on native species, including humpback chub, and on the rainbow trout fishery.

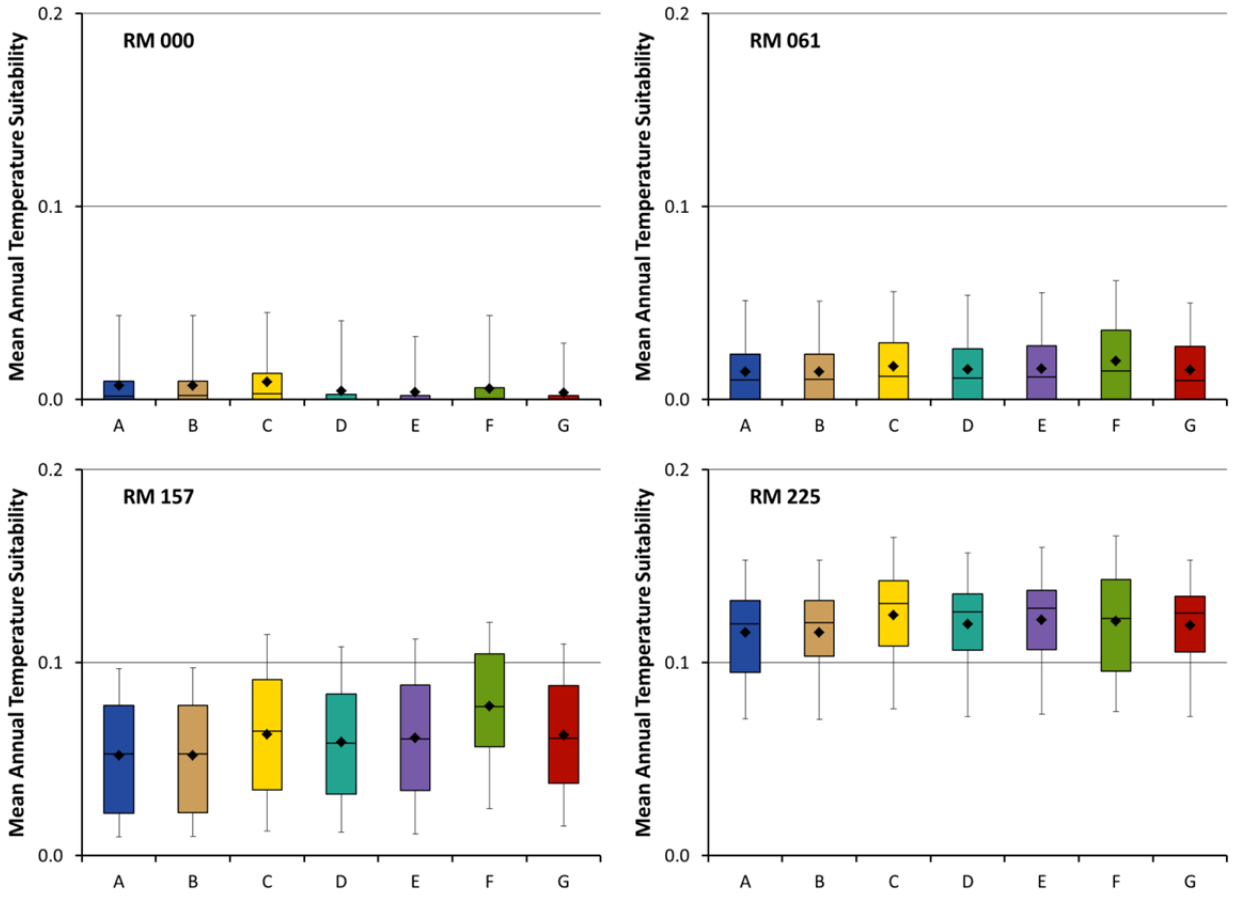

FIGURE 4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish (smallmouth bass, green sunfish, channel catfish, and striped bass) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.5.2.3 Native Fish

Humpback Chub

Relatively little spawning and juvenile rearing of humpback chub occurs in the mainstem of the Colorado River, primarily because of relatively cold water (Andersen 2009). This species requires a minimum temperature of 16°C to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C during the spawning period (Andersen 2009). Drought-induced lower reservoir levels have resulted in warmer releases and mainstem water temperatures since 2003; temperatures have consistently exceeded 12°C in the summer and fall, and may have played a role in the recent observed increase in the humpback chub population (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Although survival of larval and juvenile humpback chub in the mainstem was very rare prior to 2000 (Clarkson and Childs 2000), mainstem conditions since the mid-2000s appear to have been suitable for juvenile growth, survival, and recruitment (Yackulic et al. 2014). Warmer water has been shown in the laboratory to increase hatching success, larval survival, and larval and juvenile growth; to improve swimming ability; and to reduce predation vulnerability from rainbow trout (Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) speculated that when water temperatures are favorable, growth and survival of juveniles in the mainstem will be greater, resulting in increased mainstem recruitment and a larger adult population.

Under all alternatives, main channel water temperature at humpback chub aggregation areas was estimated to continue to be relatively low for spawning and egg incubation during spring and early summer at most locations downstream of Glen Canyon Dam (Figure 4.5-6). Modeled mean annual main channel temperature suitability for humpback chub at RM 61 (the Little Colorado River confluence) was slightly higher under Alternative F than under the other alternatives (Figure 4.5-6), because the low summer and fall flows of this alternative resulted in warmer water during these months. Because the water warms as it travels downstream from the dam, temperature suitability improves with increasing distance. At RM 213, mean annual temperature suitability was highest under Alternatives A, B, D, and G, and slightly lower under Alternatives C and E (Figure 4.5-6), although overall differences were small among these alternatives. Modeled temperature suitability at RM 213 was lowest under Alternative F (Figure 4.5-6), reflecting the higher, colder flows expected to occur under this alternative during spawning and egg incubation periods (April through June). Based on these results, the combined suitability of mainstem temperatures for spawning, egg incubation, and growth by humpback chub in the downstream-most aggregation sites is anticipated to be negatively affected under Alternative F; however, for the other alternatives, this would remain similar to the low historic levels, as represented by the suitability of Alternative A (the No Action Alternative). It should be noted that, historically, there have been years where the magnitude and timing of mainstem water temperatures have likely coincided to allow spawning and egg incubation to occur in some of the downstream aggregation areas; however, the overall average suitability, as measured by the models used in this analysis, has likely been low.

Based on temperature-dependent growth relationships developed by Robinson and Childs (2001), mean total lengths of YOY humpback chub at the end of their first growing season would differ little among the alternatives, although values under Alternative F could be slightly higher than under other alternatives (Figure 4.5-7). In addition, YOY humpback chub that rear in the main channel would be expected to reach a greater mean total length (approximately two times longer) by the end of the first calendar year at the Pumpkin Spring aggregation location (RM 213) than at the confluence with the Little Colorado River (RM 61) due to warming of the water as it travels downstream from Glen Canyon Dam (Figure 4.5-7).

HFEs, TMFs, and low summer flows would be included in many of the alternatives, but none of these flow actions would result in more than a 1 or 2°C change in average monthly water release temperatures or downstream water temperatures during periods of the year considered most important for spawning and egg incubation (i.e., April through June) at any of the humpback chub aggregation locations.

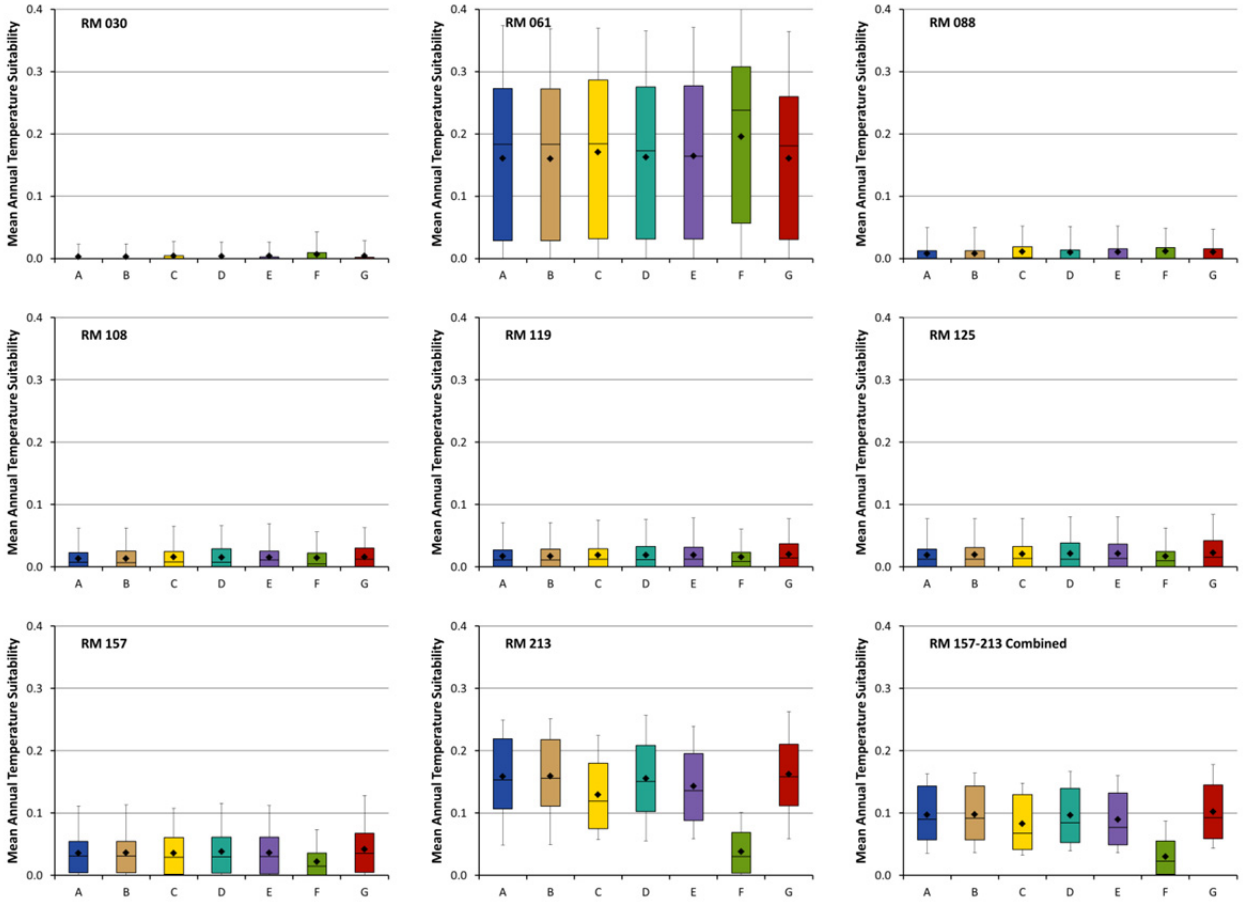

FIGURE 4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations (Temperature suitability is higher at RM 61 because spawning, incubation, and rearing values are based on temperatures in the relatively warm Little Colorado River where these life history elements occur. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Adult humpback chub numbers were modeled for each alternative under a range of hydrologic and sediment conditions. Overall, the minimum population sizes observed among the alternatives during the 20-year simulations ranged from 1,441 to 13,478 humpback chub (Figure 4.5-8). The lowest modeled minimum adult population size (1,441 fish) was observed under Alternative F, although the lowest minimum adult population values were relatively similar among all alternatives (1,441 to 1,912 adult fish). Similarly, the highest minimum numbers of adult humpback chub were similar among all the alternatives, with values exceeding 13,100 adult fish. The modeled average minimum population size ranged from 4,450 fish under Alternative F to 5,392 fish under Alternative B (Figure 4.5-8). The average minimum number of adult humpback chub was highest for Alternatives B, D, and E, slightly lower under Alternatives A and C, and lowest under Alternatives F and G (Figure 4.5-8). These results indicate that although there are small differences among the alternatives with regard to the

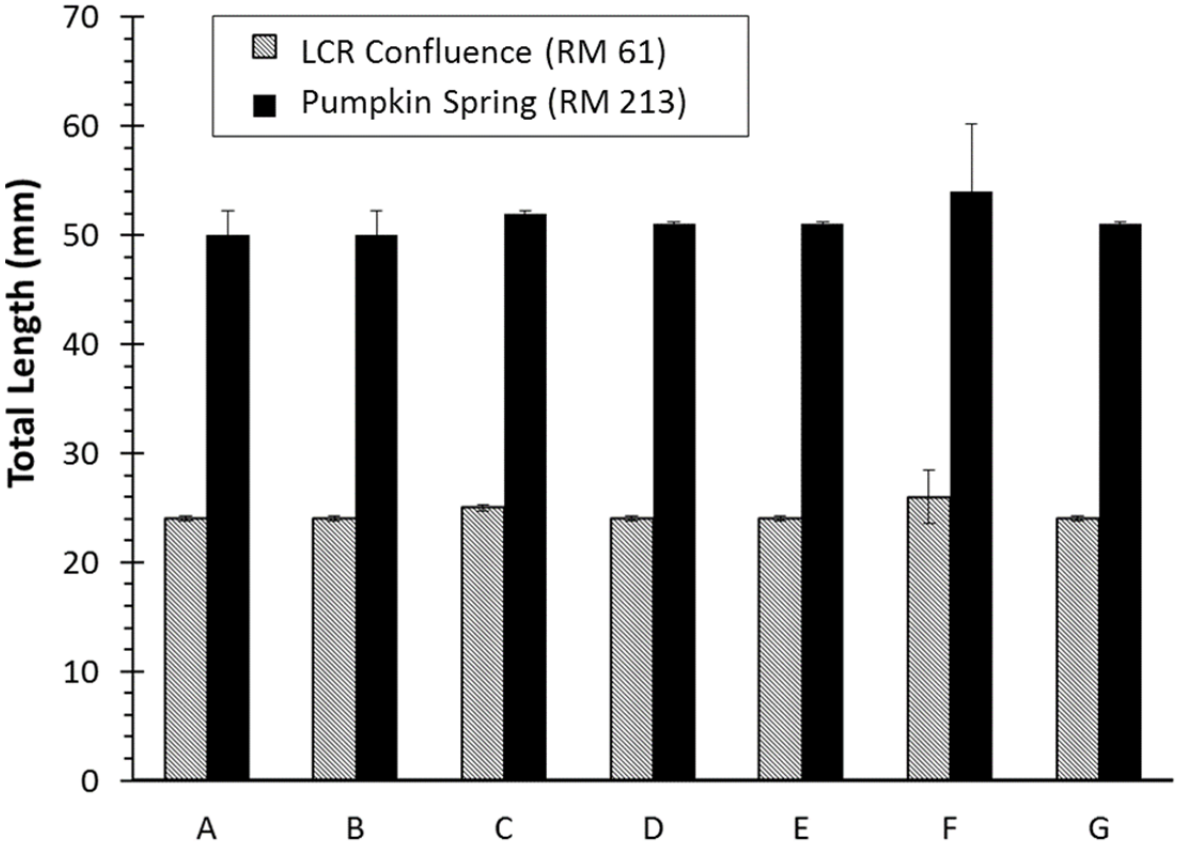

FIGURE 4.5-7 Mean (±1 standard error [SE]) Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence (RM 61) and at Pumpkin Spring (RM 213) under Each Alternative (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all alternatives would maintain the population above at least 1,000 adults throughout the 20-year LTEMP period. The model does not consider the potential effects of alternatives on food base productivity, and thus may underestimate or overestimate the impacts on minimum humpback chub numbers. Predicted increases in humpback chub numbers could be offset by decreases in food base productivity under alternatives with greater fluctuations, such as Alternatives B and E. Predicted increases in humpback chub numbers under Alternative D could be bolstered by improvements in food base productivity resulting from more even monthly volumes and moderate fluctuations.

The differences in estimated minimum numbers of adult humpback chub among the alternatives were related, in part, to the estimated levels of recruitment of rainbow trout in the Glen Canyon reach, and to the resulting emigration of rainbow trout to the Little Colorado River reach where survival of YOY and juvenile humpback chub and subsequent recruitment of adult humpback chub could be affected by increased competition and predation from these trout

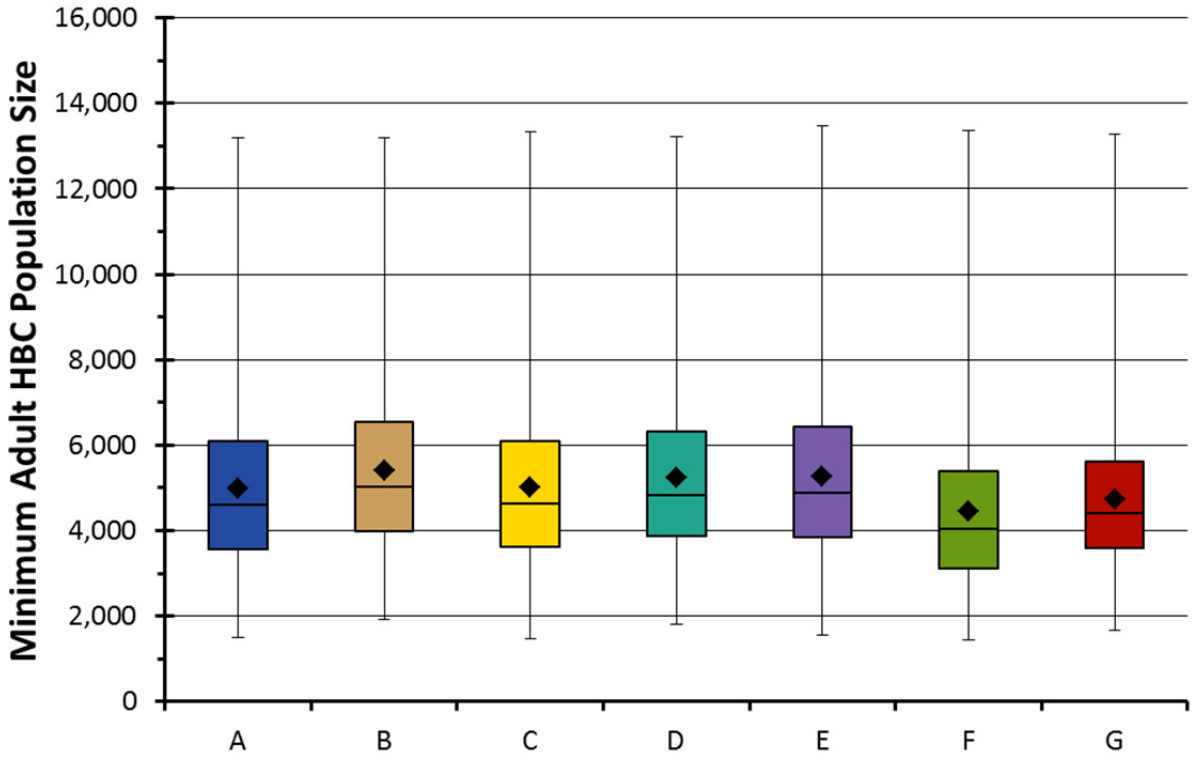

FIGURE 4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

(e.g., Yard et al. 2011). As previously discussed, observations indicate that both rainbow trout recruitment and emigration would increase with implementation of HFEs and with reduced levels of daily fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012). Alternatives with the most HFEs over a 20-year period are Alternatives C (mean of 21 HFEs), D (mean of 21 HFEs), F (mean of 19 sediment-triggered HFEs and an additional 19 non-triggered 45,000 cfs flow spikes in early May), and G (mean of 24 HFEs). Alternatives F and G additionally have no within-day fluctuations in flows and, consequently, are expected to have the lowest minimum population levels for adult humpback chub. Although water temperatures will alter the effect of trout on humpback chub survival and recruitment in some years (e.g., periods when lower reservoir elevations result in warmer releases), the overall differences in temperature regimes among the alternatives over the 20-year periods evaluated are expected to be relatively small. Based on results of laboratory studies on the effects of temperature on predation of humpback chub by trout (Ward and Morton-Starner 2015), the temperature-mediated differences in predation rates by trout among the various alternatives would be negligible.

TMFs are designed to cause mortality in YOY rainbow trout by inundating low-angle, near shore habitats for several days, and then quickly reducing dam discharge which would strand YOY fish. Although TMFs target the Glen Canyon area, where most rainbow trout

production occurs, stage changes from the TMFs also will occur downstream in Marble and Grand Canyons (see discussion in Section 3.2.1.2). Thus, stranding of native fish further downstream could also occur, including the stranding of endangered humpback chub and razorback sucker.

Aquatic habitats along the river margin, including backwaters, and other slack water habitats may be important for juvenile native fish rearing because water temperatures may be warmer than in the main channel, and due to the presence of cover such as inundated roots, and overhanging and rooted vegetation. In monthly sampling of randomly selected larval fish habitats from Lava Falls (approximately RM 180) to Lake Mead between March and September, 2014, Albrecht et al. (2014) found that small-bodied YOY native fish catch rates in slack water and channel margins were highest in June through August. Endangered YOY humpback chub were first captured in May and were captured in all months until September. Larval razorback sucker have been captured in channel margin habitats from April to August (Albrecht et al. 2014; Kegerries et al. 2015). In Marble Canyon near the Little Colorado River inflow, Dodrill et al. (2015) showed that juvenile native fish, including humpback chub, can occur in high densities in backwaters and other channel margin habitats.

The extent of mortality due to stranding of native fish, including endangered species, in a given year in Marble and Grand Canyons as a result of TMFs is unknown, and may depend on the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and abundance of juvenile fish in sensitive habitats, the timing and number of TMFs, and the degree of attenuation of flows downstream. TMFs could be implemented from May through August, which would overlap with the presence of larval fish for many of the native fish species. Given that razorback sucker spawning was recently documented in the study area in 2014 and 2015 (Albrecht et al. 2014; Kegerries et al. 2015) and studies are ongoing, potential impacts on the species are particularly difficult to predict. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected, an unknown number of native fish could also suffer mortality as a result of TMFs, downstream in GCNP. Risk to native fish would likely vary by location depending upon the level of stage changes that would be experienced and the steepness of shallow nearshore areas. Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Low summer flows included under Alternatives C, D, and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitats, potentially benefitting humpback chub. However, providing warmer nearshore habitats also could promote recruitment and survival of nonnative fish species that prey on or compete with humpback chub. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows and offset any benefits to humpback chub. However, effects on nonnative fish and humpback chub would be carefully monitored, and these experiments could be discontinued if adverse impacts on humpback chub were anticipated.

Impacts on Other Native Fish

The distribution and abundance of native fish (other than humpback chub) could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. For the endangered razorback sucker (*Xyrauchen texanus*), suitable water temperatures for spawning, egg incubation, and growth range from 14 to 25°C (FWS 2002a), with estimated optimal temperatures of 18°C for spawning, 19°C for egg incubation, and 20°C for growth (Valdez and Speas 2007). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (AZGFD 2002a). Young razorback suckers require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002a). During 2014 and 2015, razorback sucker larvae were found in the Colorado River as far upstream as RM 173 (upstream of Lava Falls), which is the farthest upstream razorback sucker spawning has been documented in the Grand Canyon (Albrecht et al. 2014; Kegerries et al. 2015). Additional larval sampling in the lower Grand Canyon found razorback sucker larvae to be distributed throughout most shoreline habitats from Lava Falls to Pearce Ferry from May to July and life stages from larvae through subadults are likely occur within these sections of the river. The highest density of razorback sucker larvae were found in isolated pools in 2014 and 2015, although such habitats composed only about 2% of all habitat sampled (Albrecht et al. 2014; Kegerries et al. 2015) (as noted above, TMFs have the potential to strand razorback sucker and other native sucker larvae as well as rainbow trout). Given the need for warm, productive floodplain or backwater habitats for rearing of larval and juvenile native fishes, and the lack or low abundance of nonnative fish found in recent backwater sampling (Albrecht et al. 2014; Kegerries et al. 2015), reduced fluctuations, lower flows, or low summer flows may benefit razorback sucker by providing warm and persistent backwater habitats. Low summer flows would likely increase warming and overall stability in these nearshore habitats, potentially benefitting razorback sucker in the Grand Canyon. Because HFEs and low summer flows affect the creation and maintenance of backwater habitats used by larval or juvenile razorback sucker, these flow actions could benefit razorback sucker. Low summer flows potentially create or maintain warm backwater habitat beneficial to razorback sucker rearing, and spring HFEs may create backwater habitat during a time that may coincide with spawning and emergence of larval razorback sucker.

Two additional species of native suckers—bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*C. latipinnis*)—occur in the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead. Bluehead sucker spawning occurs at water temperatures >16°C (AZGFD 2003a; NPS and GCNP 2013); spawning is primarily limited to tributaries. In the Grand Canyon, flannelmouth suckers spawn at water temperatures ranging from 6 to 18°C in or near a limited number of tributaries, especially the Paria and Little Colorado Rivers (AZGFD 2001b; Weiss et al. 1998; Douglas and Douglas 2000), and Bright Angel Creek (Weiss et al. 1998). Flannelmouth sucker larvae, juveniles, and adults were encountered in the mainstem Colorado River of the lower Grand Canyon during surveys conducted in 2014 (Albrecht et al. 2014). Spawning may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstem Colorado River (Bezzerides and Bestgen 2002). In the tailwaters below Glen Canyon Dam, mainstem water temperatures (8 to 12°C) are either at the lower end of or below those needed for spawning and recruitment of

flannelmouth suckers. Even though some warming does occur downstream, the relatively cold water in summer is thought to limit survival of YOY fish, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Rees et al. 2005; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam of both species was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was an increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). From 2008 through 2014, the numbers of flannelmouth suckers captured in electrofishing surveys was greater in mainstem sample locations downstream of RM 109 (Albrecht et al. 2014), perhaps giving an indication of the point at which water temperatures became more suitable for recruitment. The speckled dace (*Rhinichthys osculus*) is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002c). Within the Grand Canyon, this species occurs within the mainstem Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow; it was captured most commonly in western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010). The speckled dace spawns during the spring to late summer periods (AZGFD 2002c) at temperatures >17°C (NRC 1991).

To examine the potential of each alternative to produce thermal conditions that could improve reproduction, recruitment, and growth of native fish in main channel habitats, temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four native fish species other than humpback chub that occur in the river between Glen Canyon Dam and Lake Mead (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace). In general, the estimated temperature suitability for these species did not differ greatly among the alternatives, was comparable to suitability under current operations (Alternative A), and was low for all four species at most locations (Figure 4.5-9). At RM 225 (Diamond Creek), the mean modeled temperature suitability for native fish was highest under Alternative D and lowest under Alternative F; the mean temperature suitability levels for Alternatives A, B, C, E, and G were similar to each other at RM 225 (Figure 4.5-9). Inclusion of flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by native fish. As a consequence, these flow actions would have minor effects on temperature suitability for native fish and would not alter the relative suitability among alternatives.

Low summer flows included under Alternatives C, D and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitat, potentially benefitting razorback suckers and other native fish. However, providing warmer nearshore habitats could also promote recruitment and survival of nonnative fish species that prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low

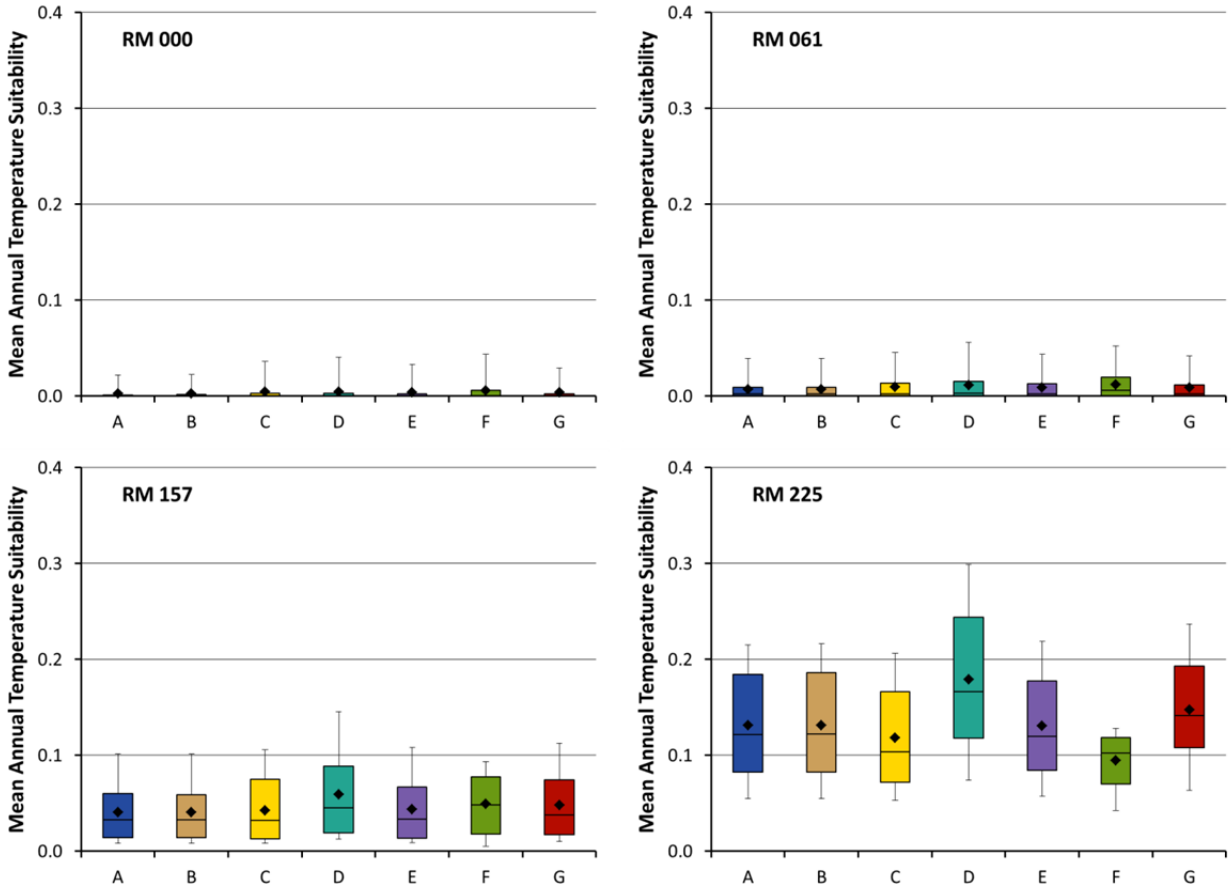

FIGURE 4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

summer flows and offset any benefits to razorback suckers and other native fish. However, the effects on nonnative fish, razorback suckers, and other native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

4.5.2.4 Aquatic Parasites

The distribution and potential for infestation of aquatic parasites could be affected by alternative-specific differences in temperature regimes, sediment dynamics, and flow patterns. Of these factors, only the effects of temperature were considered to potentially be large enough to result in impacts on aquatic parasites. Temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four most important parasite species (Asian tapeworm, anchor worm, trout nematode, and whirling disease). Based on modeling, suitability under all alternatives and all species would generally be very low, would not differ at a biologically significant level among alternatives, and would be comparable to conditions under

current operations as represented by Alternative A (No Action Alternative; Figure 4.5-10). As a consequence, the relative distributions of aquatic parasites in the mainstem or the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current conditions under any of the alternatives.

Low summer flows included under Alternatives C, D and E as an experiment during the LTEMP period would likely increase warming and overall stability in nearshore habitat, potentially increasing the occurrence of aquatic parasites. However, the effects on trout and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated. Under current conditions, population-level effects of parasites on survival and growth of native fish or trout have not been observed.

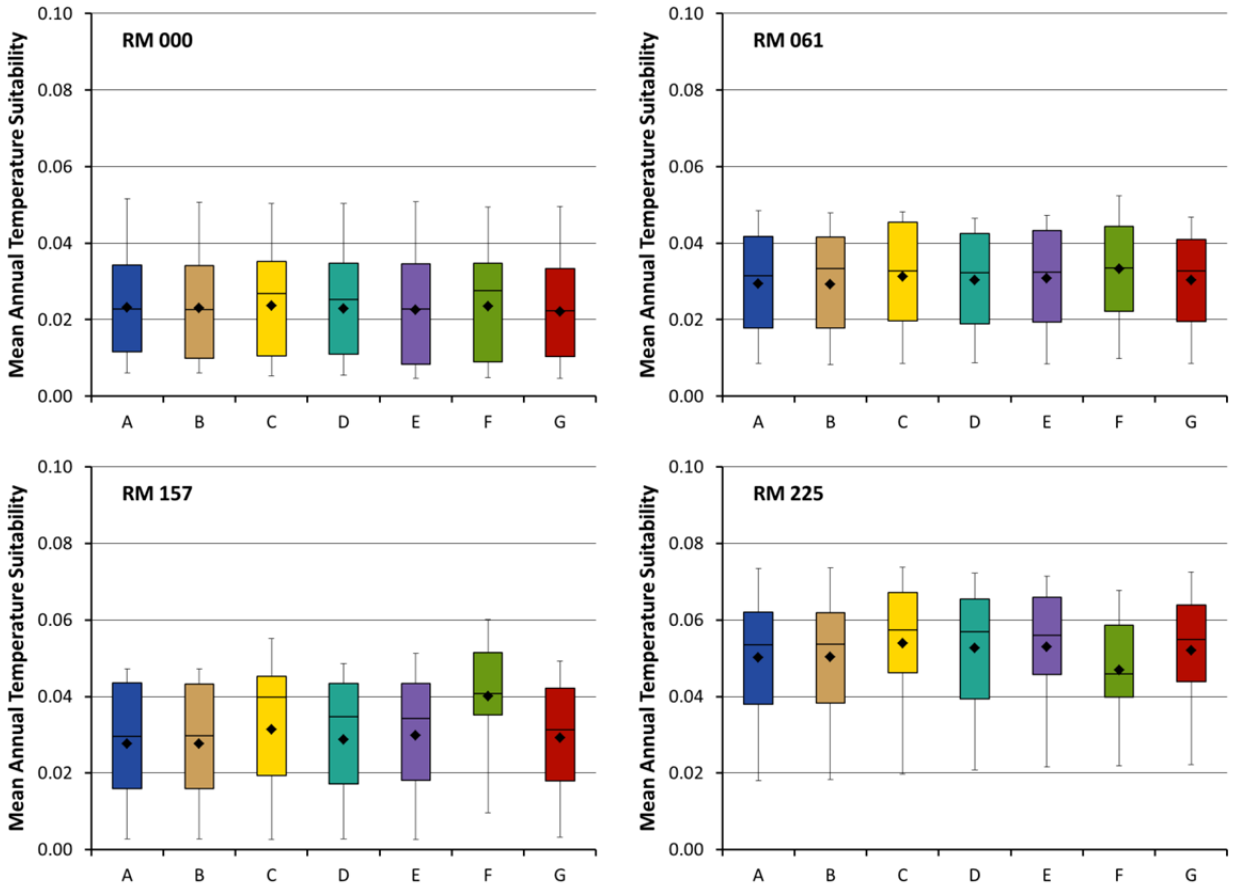

FIGURE 4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites (Asian tapeworm, anchor worm, trout nematode, and whirling disease) at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.5.3 Alternative-Specific Impacts on Aquatic Resources

This section describes alternative-specific impacts on aquatic resources, and focuses on assessment results. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.5.2. As described above, none of the alternatives would be expected to noticeably alter temperature suitability for aquatic parasites, and the relative distributions of aquatic parasites and the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current conditions under any of the alternatives. For this reason, this topic is not discussed below.

As described in the following sections, although differences among alternatives on their effects on humpback chub are expected to be small, Alternatives B, D, and E are expected to result in the highest average minimum number of adult humpback chub during the 20-year LTEMP period, compared to Alternative A, indicating that these alternatives could improve the potential for sustaining this species in the Grand Canyon ecosystem. Alternatives F and G are expected to result in decreases in the average minimum number of adult humpback chub compared to Alternative A. Under Alternatives B and D, temperature suitability and growth for humpback chub are expected to remain similar to those under Alternative A.

4.5.3.1 Alternative A (No Action Alternative)

Impacts of Alternative A on Aquatic Food Base

Alternative A, the No Action Alternative, would continue the implementation of MLFF and other flow and non-flow actions currently in place and, as a consequence, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period. That being said, any significant hydrologic changes over the period or inadvertent introductions of nonnative species could result in unanticipated changes. The future impact of the recent introduction of quagga mussels on the aquatic food base is uncertain.

Dam operations under MLFF have led to increases in the standing mass of food base organisms (i.e., algae and invertebrates) due to steadier flows and greater minimum releases relative to operations prior to 1991. By restricting daily fluctuations in discharge to <8,000 cfs and limiting minimum discharge to 5,000 cfs, the MLFF regime has reduced the size of the varial zone and increased the amount of river bottom that is permanently submerged. Both of these conditions potentially increase the productivity and standing mass of important components of the aquatic food base. Fluctuating flows displace benthic macroinvertebrates into the drift, but they usually recover quickly from such disturbances. The effect of freezing during winter will reduce benthic productivity to the minimum stage level (Shannon et al. 1994; Blinn et al. 1995). The ramping rates for Alternative A would cause a minor increase in drift over the course of a fluctuation, particularly during up-ramping.

For Alternative A, an average of 5.5 HFEs would occur over the 20-year LTEMP period, with a maximum of 14 HFEs not extending past 2020; see Table 4.3-1). Impacts on the aquatic food base from a spring or fall HFE under Alternative A would be similar to those discussed in Section 4.5.2.1 (e.g., benthic scouring, particularly for HFEs of 41,000 cfs or more, and a shift to invertebrate species more prone to drift such as midges and blackflies). Drifting blackflies and midges are important contributors to the diet of trout. HFEs under Alternative A would only occur through 2020. Therefore, the number of HFEs would be less than for the other alternatives (Section 4.2). The cessation of HFEs after 2020 may result in a shift back to a food base community not dominated by midges and blackflies (Reclamation 2011a).

As mentioned in Section 4.5.1.2, trout removal, as would occur under Alternative A, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources.

Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base, under the base operations of Alternative A would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Impacts of Alternative A on Nonnative Fish

Under Alternative A, no change from current conditions is anticipated. Trout would continue to be supported in the Glen Canyon, Marble Canyon, and Little Colorado River reaches. Warmwater nonnative species would continue to be largely restricted to the lower portions of the river nearer to the headwaters of Lake Mead except in areas where warmer inflows from tributaries provide appropriate temperature regimes, or are sources of nonnative fish, from outside GCNP.

Within-day flow fluctuations (between 5,000 and 8,000 cfs) would continue to affect the stability of spawning habitats for rainbow trout and nearshore habitats for other nonnative fish (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011), and would result in trout redd exposure and stranding levels similar to those currently occurring. Implementation of spring and fall HFEs could result in increased recruitment of rainbow trout in the Glen Canyon reach, followed by increased emigration of trout to the Little Colorado River reach (Wright and Kennedy 2011; Korman et al. 2012). These HFEs would not be implemented after 2020 under Alternative A.

Because of the relatively small number of HFEs that would be implemented under this alternative, opportunities for any such increases in trout abundance under Alternative A would be the lowest among all alternatives. TMFs are not included as an explicit element of Alternative A. Mechanical removal of trout at the Little Colorado River confluence, as described in

Reclamation (2011a), would be allowed only up through 2020.[10] Other alternatives would allow these management actions to be implemented throughout the entire LTEMP period if tests are deemed successful (e.g., Alternatives B, C, D, E, and G). The modeled average rainbow trout population size in the Glen Canyon reach during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A.

Impacts of Alternative A on Native Fish

Under Alternative A, within-day flow fluctuations (5,000 to 8,000 cfs), and ramp rates (4,000 cfs/hr up ramp and 1,500 cfs/hr down ramp), would continue to affect the stability and quality of nearshore habitats used by native fish, and would not result in a change in current conditions. Mainstem temperature suitability for humpback chub and other native fish would continue to be relatively low in most years.

Mainstem water temperatures are expected to continue restricting successful reproduction of humpback chub and other native fish to areas warmed by inflows from springs, to tributaries, or to nearshore locations that are far enough downstream for substantial warming to occur (e.g., RM 157 or farther downstream). Under Alternative A, successful spawning, larval survival and growth, and juvenile growth of humpback chub would continue to occur mostly in the Little Colorado River, with possible spawning occurring in Havasu Creek (NPS 2013g) and additional nursery and rearing habitats being used between RM 180 and RM 280 (Albrecht et al. 2014). Successful spawning of razorback sucker has recently been documented as far upstream as Lava Falls in the lower Grand Canyon under current operations (Albrecht et al. 2014; Kegerries et al. 2015) and would be expected to continue to occur under Alternative A, at least in years when temperature regimes are suitable.

The abundance, distribution, reproduction, and growth of native fishes, including humpback chub, are not expected to change appreciably from current conditions as a result of implementing Alternative A. The estimated average minimum number of adult humpback chub under Alternative A is about 5,000 adult fish over the 20-year LTEMP period, which is similar to the estimated minimum adult humpback chub numbers that have occurred during the period from 1989 through 2012 (see Section 3.5.3.1). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period is about 1,500. Under Alternative A, it is estimated that YOY humpback chub would achieve a total length of about 24 mm by the end of their first year at RM 61, and about 50 mm at RM 213 if rearing occurred in main channel habitats; fish of these sizes are unlikely to survive the winter in the mainstem. HFEs that could be implemented under this alternative (an average of 5.5 and a maximum of 14 over a 20-year period) would be similar to existing frequencies, so levels of recruitment of rainbow trout in the Glen Canyon reach of the river and numbers of rainbow trout emigrating to downstream reaches,

[10] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

where they may compete with and prey on humpback chub and other native species, would be expected to be unchanged.

Summary of Alternative A Impacts

Under Alternative A, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period (e.g., increases in the standing mass of food base organisms). The cessation of HFEs after 2020 may shift to a food base community not dominated by midges and blackflies. Drifting midges and blackflies are important contributors to the diet of trout. Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base under the base operations of Alternative A, would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Under Alternative A, there would be no change from current conditions for nonnative and native fish. HFEs (especially spring HFEs) could increase recruitment of rainbow trout in the Glen Canyon reach followed by increased emigration to the Little Colorado reach. However, HFEs would not be implemented after 2020. The modeled average rainbow trout population size during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A. Under Alternative A, the estimated average and absolute minimum number of adult humpback chub under Alternative A is about 5,000 and 1,500 adult fish over the 20-year LTEMP period. It is anticipated that spawning and habitat conditions for razorback sucker would remain similar to current conditions.

4.5.3.2 Alternative B

Impacts of Alternative B on Aquatic Food Base

UnderAlternative B, monthly release volumes would be similar to those under Alternative A, thus providing comparable areas for benthic production. However, the greater allowable daily flow fluctuations under Alternative B would create a wider varial zone and therefore lower benthic production than under Alternative A. More rapid down-ramp rates under Alternative B may result in greater instability and reduced quality of backwater and varial zone habitats. Thus, drift rates and stranding within the varial zone may be somewhat higher for Alternative B compared to Alternative A.

Fluctuating flows (>10,000 cfs/day) can fragment *Cladophora* from its basal attachment and increase its occurrence in the drift. Consuming drifting *Cladophora* (with its attached epiphytes and any invertebrates) allows rainbow trout to expend less energy in searching for food (Leibfried and Blinn 1987). Daily range in flows >10,000 cfs for base operations only occur during December and January (12,000 cfs) for Alternative B.

Slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively). Impacts on the aquatic food base from a spring or fall HFE under Alternative B would be similar to those discussed under Alternative A. However, there would not be more than one (spring or fall) HFE every other year. Less frequent HFEs (e.g., less often than annually) may lower the potential for establishing an aquatic food base that is more adaptable to flood conditions (e.g., an increased shift to blackflies and midges). Alternative B would have relatively few HFEs (Table 4.3-1); however, unlike Alternative A, HFEs would be implemented over the entire LTEMP period.

Hydropower improvement flows, tested experimentally under Alternative B up to four times in years with ≤8.23 maf, could decrease primary and secondary production because of scouring, although macroinvertebrate drift may increase in the short term. Rapid down-ramping may increase stranding of organisms in the varial zone, and this could reduce invertebrate productivity.

Mechanical removal of trout near the Little Colorado River could indirectly increase the availability of invertebrates to native fish because of reduced competition for food resources. Under Alternative B, TMFs would be tested and implemented, if tests are successful. TMFs could increase drift rates and slightly decrease primary production.

Water temperatures in the Colorado River under Alternative B would be similar to current temperature conditions because monthly volumes would be identical to those of Alternative A. Therefore, temperature impacts on the aquatic food base would be similar to those for Alternative A.

Impacts of Alternative B on Nonnative Fish

Under Alternative B, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Under Alternative B, habitat quality and stability may be slightly reduced compared to Alternative A. The higher within-day flow fluctuations (6,000–12,000 cfs), and down-ramp rates (3,000–4,000 cfs/hr) could adversely affect the stability of nearshore main channel habitats. The greater within-day flow fluctuations and faster down-ramp rates could also result in greater levels of exposure of trout redds and stranding of YOY rainbow trout. Stability of nearshore habitats under Alternative B could also be negatively affected by inclusion of testing of hydropower improvement flows, which would include an experimental feature to be employed four times in a 20-year period with wide daily flow fluctuations (up to a 5,000- to 25,000-cfs range) and would allow increased up- and down-ramp rates. Temperature suitability under Alternative B would be similar to that under Alternative A for both coldwater and warmwater nonnative fish.

Although slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively), the estimated abundance and emigration of rainbow trout would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). These lower abundance

and emigration numbers reflect the effect of greater within-day flow fluctuations and ramp rates. The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than under Alternative A. Inclusion of hydropower improvement flows would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (see Appendix F).

TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if the tests were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative B, it is anticipated that TMFs would be triggered in 3 out of 20 years, on average. Alternative B also would allow use of triggered mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period, whereas such removal would cease after 2020 under Alternative A.[11] Modeling indicates that the inclusion of these actions may be able to reduce the abundance of trout in both the Glen Canyon and Little Colorado River reaches and could benefit the humpback chub population in the vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). The modeled average trout population size in Glen Canyon under Alternative B was substantially lower than under Alternative A (Figure 4.5-2).

Impacts of Alternative B on Native Fish

Under Alternative B, higher within-day flow fluctuations and down-ramp rates could result in greater instability and reduced quality of nearshore habitats as compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9) in the mainstem river, as well as estimated growth of YOY humpback chub (Figure 4.5-7), would differ little from suitability and growth under Alternative A.

Higher within-day fluctuations during most periods of the year, limitations on the allowable frequency of HFEs, and implementation of TMFs would be expected to reduce recruitment of rainbow trout and the potential for rainbow trout emigration to the Little Colorado River reach (RM 61) compared to Alternative A, which is expected to reduce competition with and predation by rainbow trout on native fishes in that reach (Yard et al. 2011). Alternative B also includes mechanical trout removal near RM 61 for the entire 20-year period, whereas such removal would cease after 2020 under Alternative A.

Considering the lower trout recruitment that would result from higher within-day fluctuations, low number of HFEs, and implementation of triggered TMFs, the average modeled minimum number of adult humpback chub (about 5,400 adult fish) is higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative B is about 1,900. However, predicted increases in humpback chub numbers could be offset by decreases in food base productivity resulting from higher fluctuations under Alternative B (see discussion of

[11] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

fluctuations in Section 4.5.2.1 and in Appendix F). While indirect benefits of TMFs on native fish (including razorback sucker) as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Summary of Alternative B Impacts

Under Alternative B, the area of main benthic food base production would be similar to Alternative A. HFEs conducted less often than annually may lower the potential to establish a food base adaptable to flood conditions (i.e., one dominated by midges and blackflies). Hydropower improvement flows could decrease benthic primary and secondary food base production, although macroinvertebrate drift may increase in the short term. Temperature impacts on the aquatic food base under Alternative B would be similar to those under Alternative A.

Under Alternative B, habitat quality and stability and temperature suitability for both nonnative and native fish (including humpback chub and razorback sucker) may be slightly reduced compared to Alternative A. The estimated abundance and emigration of rainbow trout under Alternative B would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than the 770 fish estimated under Alternative A. Estimated growth of YOY humpback chub under Alternative B would be similar to Alternative A. The average modeled minimum number of adult humpback chub over the LTEMP period (about 5,400 adult fish) is slightly higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub under Alternative B is about 1,900 compared to 1,500 for Alternative A.

4.5.3.3 Alternative C

Impacts of Alternative C on Aquatic Food Base

Compared to Alternative A, Alternative C has higher monthly release volumes (and thus higher benthic biomass) from December through June, and lower volumes (and thus lower benthic biomass) from August through November. The daily range in flows would be lower under Alternative C compared to Alternative A. Therefore, benthic productivity may be somewhat increased particularly in the Glen Canyon reach because less of the benthic substrate would be exposed during fluctuation cycles. Increased benthic productivity would result in long-term increases in benthic drift (Kennedy, Yackulic et al. 2014).

Impacts on the aquatic food base from a spring or fall HFE under Alternative C would be similar to those discussed under Alternative A. Unlike Alternative A, HFEs would be implemented for the entire LTEMP period, with an average of 21.3 HFEs (maximum 40 HFEs) (Table 4.3-1). The more frequent HFEs are expected to favor blackfly and midge production. Proactive spring HFEs with maximum possible 24-hr release up to 45,000 cfs may be implemented under Alternative C in equalization years (years with annual volumes ≥10 maf) if no other spring HFE occurs in the same water year. Although a proactive spring HFE may scour the benthic community, particularly in the Glen Canyon reach, it would also increase the aquatic food base (e.g., blackflies and midges) available to drift-feeding fishes in the short term and may help control New Zealand mudsnail populations (Rosi-Marshall et al. 2010; Kennedy et al. 2013).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. Fall HFEs longer than 96 hr (i.e., maximum of 137 hr) could be implemented under Alternative C. The HFE volume would be limited to that of a 45,000 cfs, 96-hr flow. Thus, these extended-duration HFEs would be of lower magnitude and would produce less benthic scouring, assuming less shoreline sediment would be affected by flows less than 45,000 cfs. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance, although abundance in the 250-km stretch of river above Lake Mead tends to be more than an order of magnitude less than in the 110-km stretch below Glen Canyon Dam (Shannon, Benenati et al. 2003).

Steady flows would occur just prior to and after spring or fall HFEs under Alternative C. These flows could result in several months of maximized benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters. Benthic productivity in the mainstem should also increase under steady flows.

Tests and implementation of low summer flows would be conducted under Alternative C if conditions warrant it. Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative C, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative C, TMFs would be tested and implemented, if tests are successful. TMFs could temporarily increase drift rates and slightly decrease primary production.

The slightly warmer mean monthly water temperatures under Alternative C at RM 225 may slightly increase benthic production compared to Alternative A as modeled temperatures would be 18.1 and 18.2°C (64.6 and 64.8°F) for August and September, respectively, compared to 17.2 and 17.4°C (63 and 63.3°F). In addition to favoring adnate diatoms over stalked diatoms, these slightly warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. Overall, these changes would be considered detrimental to the aquatic food base (Section 4.5.2.1).

Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative C on Nonnative Fish

Under Alternative C, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish may be higher because of smaller within-day flow fluctuations. However, stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative C was estimated to be similar that under Alternative A for trout at all locations (Figure 4.5-4), but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream compared to Alternative A (Figure 4.5-5).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. The greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, together with reduced fluctuations, could result in higher rainbow trout recruitment and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative C, it is anticipated that TMFs would be triggered in 6 out of 20 years, on average.

Alternative C also would allow use of triggered mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period, whereas such removal would cease after 2020 under Alternative A.[12] Modeling indicates that the inclusion of TMFs and mechanical removal may be able to reduce the abundance of trout in both the Glen Canyon and Little Colorado River reaches and could benefit the humpback chub population in the vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). This alternative has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives, even though implementation of TMFs is included as an element of the alternative.

Low summer flows would be included under Alternative C as an experiment during the entire LTEMP period if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of trout and warmwater nonnative fish that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially

[12] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of the Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

Impacts of Alternative C on Native Fish

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative C than under Alternative A. Within-day flow fluctuations would be scaled according to monthly volumes (3,500 to 6,000 cfs during average hydrologic conditions) and would be less under this alternative than under Alternative A. However, improvements to habitat stability that may result from reduced fluctuations may be offset, in part, by the higher down-ramp rates (2,500 cfs/hr). Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The relatively high number of HFEs under Alternative C would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub could be offset by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish) and slightly less than under Alternatives B, D, and E. The estimated average minimum number of adult humpback chub under Alternative C would be greater than under Alternatives F and G. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative C is about 1,500, the same as Alternative A. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Low summer flows would be included under Alternative C as an experiment during the entire LTEMP period if triggered by low summer water temperatures and low humpback chub numbers, and are expected to increase warming and overall stability of nearshore habitats, which would potentially benefit humpback chub, razorback suckers, and other native fish. Providing

warmer nearshore habitats could promote recruitment and survival of nonnative fish species, including trout, that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species that could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of warmwater nonnative fish species in backwater habitats of the Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Summary of Alternative C Impacts

Under Alternative C, benthic food base productivity may be higher in December through June due to higher flows, but lower from August through November due to lower flows compared to Alternative A. Overall, benthic productivity should be higher under Alternative C than under Alternative A because of reduced fluctuations and a narrower varial zone. The more frequent HFEs compared to Alternative A favor the production of midges and blackflies. Slightly warmer water temperatures for August and September at RM 225 under Alternative D may slightly increase food base production compared to Alternative A, although this could be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Under Alternative C, habitat quality and stability for nonnative and native fish (including humpback chub and razorback sucker) may be higher than under Alternative A because of smaller within-day flow fluctuations. However implementation of TMFs could result in periodic reduction in habitat stability for native fish (e.g., razorback sucker) in nearshore habitats and slightly higher stranding of YOY rainbow trout. Temperature suitability under Alternative C would be similar to Alternative A for trout, native fishes, and growth of YOY humpback chub; but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream from Glen Canyon Dam. The greater number of HFEs, coupled with reduced fluctuations, under Alternative C compared to Alternative A could result in higher rainbow trout recruitment and emigration rates. Alternative C has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish), while the estimated absolute minimum number of adult humpback chub under Alternative C is about the same as Alternative A (1,500 fish). Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer water to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

4.5.3.4 Alternative D (Preferred Alternative)

Impacts of Alternative D on Aquatic Food Base[13]

Under Alternative D, monthly release volumes would be relatively consistent throughout the year compared to Alternative A. This monthly release pattern would produce a more consistent and stable aquatic food base than under Alternative A, and daily range in flows would be similar to Alternative A. Therefore, benthic productivity may be somewhat increased, particularly in the Glen Canyon reach. Stranding within the varial zone may be somewhat lower under Alternative D compared to Alternative A as a result. Increased benthic productivity would increase drift in the long term (Kennedy, Yackulic et al. 2014).

Under Alternative D, there would be an average of 21.1 HFEs (maximum of 38 HFEs) (Table 4.3-1). The more frequent HFEs are expected to favor blackfly and midge production. Spring HFEs may not be tested in years when there appear to be unacceptable risks to key resources including the aquatic food base. Impacts on the aquatic food base from a proactive spring HFE would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative D, up to four of the fall HFEs could be extended-duration HFEs (lasting up to 250 hr). These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. HFEs longer than 96 hr could help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance. The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. Primarily for this reason, sediment-triggered and proactive spring HFEs would not be implemented following an extended-duration fall HFE within the same water year.

Tests of low summer flows would be conducted under Alternative D in the second 10 years of the LTEMP if conditions warrant it (as described in Section 2.2.4). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative D, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative D, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

An aquatic resource–related experiment unique to Alternative D would be to test the effects of macroinvertebrate production flows in May through August on benthic

[13] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on the aquatic food base.

macroinvertebrate production and diversity. It has been demonstrated that the large varial zone created by fluctuating flows limits recruitment of mayflies (order Ephemeroptera), stoneflies (order Plecoptera), and caddisflies (order Trichoptera), collectively referred to as EPT (Ephemeroptera-Plecoptera-Trichoptera), due to high egg mortality. For example, adult females of the mayfly genus *Baetis* land on rocks protruding from the water surface and then crawl underwater to lay their eggs on the underside of the rock. These rocks may become dry for up to 12 hr during a fluctuation cycle, and even brief desiccation (e.g., 1 hour) may result in complete mortality of mayfly eggs (Kennedy et al. 2016). Because EPT taxa deposit eggs principally along river edge habitats, eggs laid during stable low flows over the weekend would not be subjected to drying prior to their hatching, which typically occurs after days to weeks of incubation. Depending on the findings from the first test, this experiment could be repeated during the LTEMP period. In addition to potentially increasing EPT, macroinvertebrate production flows may enhance production of other aquatic food base organisms that have terrestrial adult life stages, such as dragonflies and true flies (including midges and blackflies). Some loss of benthic production is expected in the shoreline areas that remain dewatered over the weekend. If this results in an unacceptable risk to overall benthic production, the experiment might not be repeated.

Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative D on Nonnative Fish[14]

Under Alternative D, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish is expected to be slightly higher because of slightly lower within-day flow fluctuations, especially during the winter. Stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability for trout under Alternative D was estimated to be similar to that under Alternative A at all locations (Figure 4.5-4), but could improve slightly compared to Alternative A for warmwater nonnative fish at the locations farthest downstream (Figure 4.5-5).

Alternative D has a much higher number of HFEs (average of 21.1 HFEs and a maximum of 38 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. This greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, could result in higher rainbow trout abundance and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). This alternative is

[14] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer). The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition, and this reduction in frequency could reduce the number of trout produced under Alternative D. This reduction would not change the ranking of Alternative D relative to other alternatives with regard to effects on trout.

expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A, suggesting that inclusion of TMFs would offset the increased recruitment that would be anticipated with a greater occurrence of HFEs (see Appendix F). However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish) (Figure 4.5.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative D, it is anticipated that TMFs would be triggered in about 4 out of 20 years, on average.

Mechanical removal of nonnative fish would be implemented in the Little Colorado River reach to lessen the effects of competition and predation on humpback chub by nonnative fish (especially trout) if abundance dropped below 7,000 adults (see Appendix O).[15] Once triggered, mechanical removal efforts would cease if a calculated relative predator index declines to 60 rainbow trout per kilometer in the vicinity of the Little Colorado River for 2 years or the number of adult humpback chub increase to more than 7,000. Modeling conducted for the EIS indicated that mechanical removal was effective in controlling trout numbers unless immigration rates into the Little Colorado River reach were high.

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend from May to August). These flows could improve the diversity and production of the aquatic food base for trout in the Glen Canyon reach and for warmwater nonnative fish.

Low summer flows would be included under Alternative D as an experiment during the second 10 years of the LTEMP period if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of nonnative fish species that prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon is currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

15 Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

Impacts of Alternative D on Native Fish[16]

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative D than under Alternative A because within-day flow fluctuations would be slightly less under this alternative than under Alternative A, especially during winter. Mainstem temperature suitability for humpback chub (Figure 4.5-6) and growth of YOY humpback chub under predicted mainstem temperatures (Figure 4.5-7) are expected to differ little from suitability and growth predicted for Alternative A. Temperature suitability for other native fish (including razorback sucker) could improve slightly compared to under Alternative A (Figure 4.5-9) because, under Alternative D, it is predicted that monthly volumes would result in more favorable mainstem temperatures at downstream locations (e.g., RM 225) during early summer months when spawning and egg incubation would benefit.

The relatively high number of HFEs under Alternative D would normally be expected to increase the recruitment levels for trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). As discussed above, even though TMFs that would be implemented (when triggered by high predicted levels of recruitment) throughout the LTEMP period may result in smaller average trout population size in the Glen Canyon Reach, the model indicated that emigration of trout to the Marble Canyon reach under Alternative D would increase, on average, by about 11% compared to Alternative A. This increases the potential for trout to occur in the Little Colorado River reach where humpback chub survival and growth could be affected. The potential for competition with and predation on humpback chub by trout is expected to be partially offset by allowing mechanical removal of trout in the Little Colorado River reach when triggering conditions are met (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Based on modeling, the estimated average minimum number of adult humpback chub under Alternative D (about 5,200 adult fish) would be about 4% higher than under Alternative A; 1 and 3% lower than under Alternatives E and B, respectively; and 11 and 18% higher than under Alternatives G and F, respectively (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative D is about 1,800. Predicted increases in humpback chub numbers under Alternative D could be bolstered by improvements in food base productivity resulting from more even monthly volumes and moderate fluctuations (see Section 4.5.2.1). While indirect benefits of TMFs for native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

16 Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on native fish.

As identified in Section 2.2.4.6 and Appendix O, a number of experimental actions (referred to as Tier 1 actions) designed to improve rearing and recruitment of juvenile humpback chub would be implemented under Alternative D when adult humpback chub abundance declines to 9,000, or if recruitment of subadult humpback chub does not meet or exceed estimated adult mortality. Experimental actions would include expanded translocations of YOY humpback chub to grow-out areas within the Little Colorado River (i.e., above Chute Falls, Big Canyon), or larval humpback chub would be taken to a rearing facility and released in the mainstem Little Colorado River inflow area once they reach 150– 200 mm. Alternatively, YOY would immediately be translocated to areas with few predators for rearing, such as Big Spring or above Chute Falls. Based on past experience successfully translocating fish within the Little Colorado River and to tributaries, where translocated fish experienced high survival and/or growth rates (Healy et al. 2014; Spurgeon et al. 2015; Van Haverbeke et al. 2016), there is a high likelihood of beneficial effects on humpback chub through augmentation of the adult population as a result of these experimental actions. Detrimental effects on humpback chub, including fatality, could occur during handling, transport, or tempering; however, the number of these occurrences is generally low (a few individuals; see Appendix O).

Mechanical removal of nonnative fish would be implemented in the Little Colorado River reach to lessen the effects of competition and predation on humpback chub by nonnative fish, if Tier 1 actions failed to reverse declining trends and adult abundance dropped below 7,000. Past removal efforts appeared to be effective in controlling rainbow trout, and humpback chub recruitment increased; however, the removal effort coincided with a systemwide decline in trout abundance and warmer realeases from Glen Canyon Dam, which confounded results (Coggins et al. 2011).

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend from May to August). These flows could improve the diversity and production of the aquatic food base for native fish.

Low summer flows would be included under Alternative D as an experiment during the second 10 years of the LTEMP period, if triggered by low summer water temperatures and low humpback chub numbers. They are expected to increase warming and overall stability of nearshore habitats, potentially benefitting humpback chub, razorback suckers, and other native fish. Providing warmer nearshore habitats could also promote recruitment and survival of nonnative fish species, including trout, that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species, which could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon are currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Alternative D is the only alternative to include macroinvertebrate production flows (low steady flows every weekend, May–August). As described above, these flows could have both beneficial and adverse effects on the food base, which could either increase or decrease native fish abundance.

Summary of Alternative D Impacts

The relatively similar monthly release volumes under Alternative D compared to Alternative A, and all other alternatives except Alternative G, would produce a more consistent and stable aquatic food base. Fluctuation levels would be comparable to those under Alternative A and would produce comparable varial zone conditions and benthic productivity. The more frequent HFEs under Alternative D are expected to favor midge and blackfly production compared to Alternative A. Macroinvertebrate production flows in May through August under Alternative D would be tested to determine if they increase benthic food base production and diversity including the recruitment of mayflies, stoneflies, and caddisflies (important food base organisms currently rare to absent throughout much of the mainstem below Glen Canyon Dam). Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C.

Under Alternative D, habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A. Temperature suitability for trout, humpback chub, and growth of YOY humpback chub under Alternative D would be similar to that under Alternative A, but could slightly improve suitability for warmwater nonnative fish and other native fish. The high number of HFEs could result in higher rainbow trout abundance and emigration rates. Alternative D is expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A. However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish). The estimated average minimum numbers of adult humpback chub under Alternative D (about 5,200 adult fish) would be higher than under Alternative A (5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the LTEMP period under Alternative D is about 1,800 compared to 1,500 under Alternative A. Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer steadier flows associated with low summer flows to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated. Implementation of Tier 1 experimental actions (e.g., expanded translocations and hatchery rearing and release of fish from the Little Colorado River) and mechanical removal of nonnative fish in the Little Colorado River reach if recruitment or adult populations of humpback chub fall below 7,000 would provide benefits for the humpback chub.

4.5.3.5 Alternative E

Impacts of Alternative E on Aquatic Food Base

More even monthly release volumes would improve aquatic food base productivity compared to Alternative A. However, this benefit could be offset by increased daily fluctuations, which would strand invertebrates within the varial zone. Higher daily fluctuations may also cause short-term increases in drift.

Under Alternative E, fall HFEs would be allowed throughout the 20-year LTEMP period, while spring HFEs would be allowed for the last 10 years of the LTEMP period, with an average of 17.1 HFEs (maximum of 30 HFEs) (Table 4.3-1). The frequent HFEs will favor blackfly and midge production. The number of HFEs would be less than under Alternative C because there would be no spring HFEs in the first 10 years (see Section 2.3). Steady flows would occur after significant sediment inputs prior to fall HFEs under Alternative E. Consequently, there could be several months of improved benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters.

Tests of low summer flows would be conducted under Alternative E in the second 10 years of the LTEMP if conditions warrant (as described in Section 2.2.5). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative E, TMFs would be tested and implemented, if tests are successful. TMFs could increase cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative E on Nonnative Fish

Under Alternative E, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish would be slightly lower due to increased levels of within-day fluctuations during most months. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative E would be similar to suitability under Alternative A for trout at all locations, but would be slightly higher compared to Alternative A for warmwater nonnative fish at the locations farthest downstream. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow

trout recruitment in the Glen Canyon reach. Based on modeling for Alternative E, it is anticipated that TMFs would be triggered in about 3 out of 20 years, on average.

Alternative E has more HFEs (average of 17.1 HFEs and a maximum of 30 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B, but fewer than the other alternatives. This greater number of HFEs is expected to result in relatively high rainbow trout abundance and emigration rates (see discussion of effects of HFEs in Section 4.5.2.2), although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish (Figure 4.5-1), but slightly higher levels of emigration (about 38,000 fish/yr) compared to Alternative A (see discussion of effects of removal actions in Section 4.5.2.2). Slightly more large rainbow trout are expected (on average about 830 fish) than under Alternative A based on modeling results (Figure 4.5-3).

Low summer flows would be included under Alternative E as an experiment during the second 10 years of the LTEMP period, if triggered by low summer water temperatures and low humpback chub numbers. Providing warmer nearshore habitats could promote recruitment and survival of trout and warmwater nonnative fish that prey on or compete with native fish. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach, which is important for humpback chub. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of Grand Canyon is low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of nonnative fish by warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

Impacts of Alternative E on Native Fish

Under Alternative E, habitat quality and stability for native fish would be slightly lower due to increased levels of within-day fluctuations during most months compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), is expected to differ little from suitability and growth predicted for Alternative A.

Alternative E allows no spring HFEs for the first 10 years, but it has relatively similar numbers of fall HFEs compared to Alternatives C, D, F, and G. The relatively high number of HFEs under Alternative E would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2) with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub is expected to be partially controlled by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to

ongoing emigration from areas upstream in Marble Canyon. The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) was about 6% higher than under Alternative A (about 5,000 fish) (Figure 4.5-8), reflecting the combined effects on growth and survival of humpback chub associated with slightly higher emigration rates for trout from the Glen Canyon reach, slightly warmer mainstem temperatures at the confluence with the Little Colorado River, and implementation of mechanical removal of trout in the Little Colorado River reach when triggering criteria are met. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600. However, predicted increases in humpback chub numbers could be offset by decreases in food base productivity resulting from higher fluctuations under Alternative E. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources.

Low summer flows included under Alternative E as an experiment after the first 10 years of the LTEMP period would likely increase warming and overall stability of nearshore habitats, potentially benefitting humpback chub, razorback suckers, and other native fish in the Grand Canyon. Providing warmer nearshore habitats could promote recruitment and survival of nonnative fish species, including trout, which prey on or compete with native fish species. Warmer temperatures in Glen Canyon or Marble Canyon could increase recruitment and growth of trout, especially brown trout in the Little Colorado River reach. Farther downstream in the Grand Canyon, warmer conditions in nearshore habitats such as backwaters could benefit a variety of warmwater nonnative fish species that could alter suitability for razorback sucker. Recent sampling has indicated that the abundance and presence of nonnative fish species in backwater habitats of the Grand Canyon are currently low (Albrecht et al. 2014; Kegerries et al. 2015), but these fish could increase with warmer water temperatures during low summer flows. There is also a potential for warmer water to promote infestation of native fish by warmwater fish parasites. Effects on parasites, nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on native fish were anticipated.

Summary of Alternative E Impacts

Under Alternative E, relatively even monthly release volumes would increase aquatic food base productivity, but this increase could be offset by increased daily fluctuations. The number of HFEs under Alternative E would favor midge and blackfly production, though the number of HFEs would be less than under Alternative C. Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C.

Under Alternative E, habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A due to increased levels of within-day fluctuations during most months; implementation of TMFs could result in additional periodic reductions in habitat stability for native fish (e.g., razorback sucker) in nearshore areas. Stranding of YOY rainbow

trout may also be slightly higher than under Alternative A. Temperature suitability for trout, native fish, and growth of YOY humpback chub under Alternative E would be similar to that under Alternative A; but would be slightly higher for other warmwater nonnative fish species at locations farthest downstream from Glen Canyon Dam. The high number of HFEs under Alternative E is expected to result in relatively high rainbow trout abundance and emigration rates compared to Alternative A; although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish but slightly higher levels of emigration compared to Alternative A. Slightly more large rainbow trout (830) are expected than under Alternative A (770). The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) is slightly higher than under Alternative A (about 5,000 fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600, compared to 1,500 under Alternative A. Experimental low summer flows could benefit humpback chub, razorback suckers, and other native fish that utilize nearshore habitats. There is also a potential for warmer water to increase the number of trout, warmwater nonnative fish, and warmwater fish parasites. Effects on parasites, trout, warmwater nonnative fish, and native fish would be carefully monitored, and these experiments could be discontinued if adverse impacts on trout or native fish were anticipated.

4.5.3.6 Alternative F

Impacts of Alternative F on Aquatic Food Base

Compared to all other alternatives, Alternative F would have lower flow volumes, and therefore potentially less benthic biomass, from July through the following March. Seasonally adjusted steady flows would minimize the adverse effects of desiccation and dewatering that occurs in a varial zone (Reclamation et al. 2002). Flow stabilization may allow for very high snail densities, especially for the New Zealand mudsnail (Reclamation et al. 2002). In addition, reduced drift rates occur under mildly fluctuating or steady flows (Shannon et al. 1996; Rogers et al. 2003). Lower benthic productivity may also cause decreased drift over the long term (Kennedy, Yackulic et al. 2014). Higher volumes in April through June may increase benthic biomass compared to Alternative A, and would somewhat mimic pre-dam conditions with increased flows during spring and early summer. Increased benthic productivity during this period may also increase drift (Kennedy, Yackulic et al. 2014).

Under Alternative F, the 24-hr, 45,000-cfs high flows in early May in years without sediment-triggered spring HFEs, together with the May and June period of sustained high flows and the week-long 25,000 cfs release at the end of June, would scour the benthos, particularly within the Glen Canyon reach. This could improve the aquatic food base by reworking sediments and removing fines that can limit production of benthic organisms. Alternative F would have an average of 38.1 HFEs (maximum of 40 HFEs) (Table 4.3-1). The frequent HFEs will favor blackfly and midge production. Sustained high flows and HFEs would also decrease the density of New Zealand mudsnails.

No trout management actions would occur under Alternative F, but the rapid drop from high flows in June to low flows in July could have similar effects to those of TMFs. If these flow changes did not mimic the effects of TMFs, there would be continued competition for aquatic food base resources between trout and other fish species.

The warmer mean monthly water temperatures under Alternative F at RM 225 may slightly increase benthic production compared to all other alternatives, as modeled monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) for July through August. In addition to favoring adnate diatoms over stalked diatoms, these warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. These changes would be considered detrimental to the aquatic food base (Section 4.5.2.1). Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative F on Nonnative Fish

Because there would be no within-day flow fluctuations, Alternative F is expected to have positive effects on nonnative fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Although the results of the temperature suitability modeling show only small differences among the alternatives in overall suitability for trout, temperature suitability under Alternative F would be slightly greater, compared to Alternative A, at RM 61 and slightly lower at RM 157 and RM 225 (Figure 4.5-4). For warmwater nonnative fish, mainstem temperature suitability is expected to improve slightly, compared to Alternative A, at RM 61and RM 157 (Figure 4.5-5). The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A.

Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach (Figure 4.5-1), and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. These numbers reflect the more stable habitat conditions and very high number of HFEs (an average of 39 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) of this alternative that are expected to result in increased production and survival of YOY rainbow trout (see discussion of effects of HFEs in Section 4.5.2.2). Because this alternative does not include implementation of TMFs or mechanical removal, there is no offset to conditions that would be likely to increase recruitment, resulting in larger numbers but lower growth rates for trout in the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives (Figure 4.5-3). The modeled results for Alternative F are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011).

Impacts of Alternative F on Native Fish

Under Alternative F, there would be no within-day fluctuations in flow, resulting in a high degree of nearshore habitat stability. The 24-hr, 45,000-cfs peak flow in May, extended high flows of 20,000 cfs in May and June, and 7-day 25,000-cfs high flow at the end of June may improve forage for native fish by reworking sediments and removing fines that can limit production of benthic organisms. Compared to Alternative A, temperature suitability would be slightly higher at RM 61 and lower at RM 213. Temperature suitability for native fish would be lower at RM 225 (Diamond Creek) compared to other alternatives (Figure 4.5-9). Under Alternative F, modeling estimated that YOY humpback chub would achieve a total length of about 26 mm by the end of their first year at RM 61, and about 54 mm at RM 213 if rearing occurred in main channel habitats; this level of growth is slightly higher than that estimated for all other alternatives (Figure 4.5-7).

The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives (Figure 4.5-8). This lower estimated population size results from the high number of HFEs, low summer flows, and lack of within-day fluctuations that promote production of rainbow trout in the Glen Canyon reach and subsequent high emigration to the Marble Canyon reach (see Section 4.5.3.2), as well as the lack of TMFs or mechanical removal that could offset increases in trout. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative F is about 1,400. Frequent spring HFEs would also contribute to the periodic reworking of sediments and creation of backwater habitat in the lower Grand Canyon during a time that may coincide with spawning and emergence of larval razorback sucker.

Historically, there have been few opportunities to study the effects of steady-flow operations on fish resources downstream of Glen Canyon Dam, especially the effects of long-term steady flow operations. During the spring and summer of 2000, a series of steady discharges of water from Glen Canyon Dam were used to evaluate effects of aquatic habitat stability and water temperatures on native fish growth and survival, with a particular focus on the humpback chub (Ralston 2011). The hydrograph implemented for the experiment achieved steady discharges at various levels that lasted for periods of 4 days to 8 weeks. The steady flows did not appear to result in increased growth rates by humpback chub or other native fish, although there was some evidence that nonnative fish species that could compete with or prey upon native fish species (fathead minnow, plains killifish, and rainbow trout) experienced population increases associated with reduced fluctuations and/or warmer water temperatures that occurred during the experimental period (Ralston 2011). However, the short-term nature of the experiment makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have. Given the need for warm, productive nearshore (including backwater) habitats for rearing of larval and juvenile native fishes, and the lack or low abundance of nonnative fish found in recent backwater sampling (Albrecht et al. 2014; Kegerries et al. 2015), reduced fluctuations during spring and summer months may be beneficial for razorback sucker by providing warm and persistent backwater habitats.

Summary of Alternative F Impacts

Under Alternative F, food base biomass from July through the following March would be potentially less compared to all other alternatives due to comparatively lower flow volumes. Flow stabilization may allow for high benthic densities of New Zealand mudsnails, while reduced benthic productivity is expected to reduce drift. Higher flow volumes in April through June may increase benthic food base biomass and drift compared to Alternative A. The frequent HFEs will favor blackfly and midge production. The warmer water temperatures for August and September at RM 225 under Alternative F may slightly increase food base production even more than Alternative D, although this could similarly be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Alternative F is expected to have positive effects on nonnative and native fish (including humpback chub and razorback sucker) and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Temperature suitability for nonnative and native fish under Alternative F would be slightly higher than Alternative A at RM 61 and slightly lower at sites further downstream. The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A. Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach, and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives. The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives. The estimated absolute minimum number of adult humpback chub under Alternative F is about 1,400.

4.5.3.7 Alternative G

Impacts of Alternative G on Aquatic Food Base

Under Alternative G, changes in monthly release volumes would be limited only to those necessary to adjust to changes in runoff forecasts. The benthic community would benefit from these even monthly volumes and the steady within-day flows of this alternative. This would allow somewhat consistent and stable aquatic food base conditions to persist throughout the year. In addition, benthic community biomass would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher under Alternative G. However, the year-round stable conditions may favor dominance by less-desirable species such as the New Zealand mudsnail. Increased benthic production could result in long-term increases in drift (Kennedy, Yackulic et al. 2014).

Alternative G would have an average of 24.5 HFEs (maximum of 40 HFEs) (Table 4.3-1). The frequent HFEs are expected to favor blackfly and midge production. HFEs

would also decrease the density of New Zealand mudsnails. Impacts on the aquatic food base from proactive spring HFEs would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative G, there could be fall HFEs of up to 45,000 cfs that could last as long as 336 hr. These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance.

The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-duration HFE, could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. For this reason, implementation of a spring HFE in years that follow an extended-duration fall HFE would be carefully considered.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative G, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative G on Nonnative Fish

Under Alternative G, there would be no within-day fluctuations, and monthly volumes would only vary as a result of changes in runoff forecasts. As a result, habitat stability would be greater under this alternative than under any of other alternatives. Under this alternative, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to occur in the lower portions of the river and tributaries. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative G, it is anticipated that TMFs would be triggered in about 11 out of 20 years, on average.

The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). The relatively high abundance and emigration rate reflect, in part, the high number of HFEs that could occur with

this alternative (an average of 24.5 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period), including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, and the absence of within-day fluctuations. However, TMFs and mechanical removal of trout, which are included as operational elements in this alternative, are expected to partially mitigate the increased trout production.[17] Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length) (Figure 4.5-3). The modeled results for nonnative fish under Alternative G are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011). However, the short-term nature of the experiment that was conducted makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have.

Impacts of Alternative G on Native Fish

Under Alternative G, habitat stability for native fish (including humpback chub and razorback sucker) would be greater than under any of the other alternatives. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The high number of HFEs under Alternative G is expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation of humpback chub are expected to be partially offset by mechanical removal (when triggering criteria are met) of trout in the Little Colorado River reach. However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Modeling indicated that the average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives and would be approximately 6% lower than under Alternative A (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative G is about 1,700. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish (including razorback sucker) would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on humpback chub, razorback suckers, other native fish, and other resources. For information regarding past studies of the effects of steady-flow operations on native fish downstream of Glen Canyon Dam, refer to Section 4.5.3.6.

[17] Several Tribes have expressed concerns regarding nonnative fish management actions that they regard as having an adverse impact on their Tribal communities. These concerns are detailed in Tribal Perspectives section of Section 3.5.3 and in Section 4.9.1.3.

Summary of Alternative G Impacts

Under Alternative G, somewhat consistent and stable aquatic food base conditions to persist throughout the year. Benthic food base biomass and drift would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher. However, stable flows may favor dominance by the New Zealand mudsnail. Potentially higher drift rates from spring flows under Alternative F would not occur under Alternative G. The frequent HFEs are expected to favor blackfly and midge production. Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C.

Habitat stability for nonnative and native fish (including humpback chub and razorback sucker) would be greater under Alternative G than under any of the other alternatives. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats; whereas, temperature suitability for native fishes, as well as growth of YOY humpback chub, are expected to differ little from Alternative A. The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length). The average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives. The estimated absolute minimum number of adult humpback chub under Alternative G is about 1,700.

4.6 VEGETATION

This section presents an evaluation of the impacts of the LTEMP on riparian vegetation of the Colorado River corridor between Glen Canyon Dam and Lake Mead. Glen Canyon Dam operations affect river flow and stage, which in turn affect the disturbance regime, soil moisture, and ultimately the distribution of vegetation species and communities in the river corridor. In addition to the effects of operations on vegetation communities, the effects on vegetation of non-flow actions were evaluated, including vegetation treatments. Analysis methods, a summary of anticipated impacts, and alternative specific impacts are presented.

4.6.1 Analysis Methods

Issue: How do alternatives affect riparian vegetation in the project area as a result of dam operations?

Impact Indicators:

- Changes in habitat of special status plant species
- Changes in cover of wetland community types
- Changes in the composition of the New High Water Zone and wetland vegetation as indicated by four metrics: (1) change in cover of native community types; (2) change in diversity of native community types; (3) change in the ratio of native to nonnative community types; and (4) change in the arrowweed community type
- Change in the composition of plant communities in the Old High Water Zone

Three sources of information were evaluated in order to analyze the impacts of the alternatives on plant communities. First, information found in studies on vegetation done to date was examined. Secondly, a model based on published studies and collected data was used to predict potential effects. Third, the combined information from the studies and model was evaluated to analyze the potential effects of the alternatives over the period of the LTEMP. The studies allowed an assessment of effects that go beyond the limitations of the model.

The model enabled an evaluation of effects by predicting four characteristics of vegetation. The metrics that reflect these characteristics were calculated using the results of an existing model for Colorado River riparian vegetation downstream of the Paria River (Ralston et al. 2014). Seven vegetation states were used in the model to represent plant community types found along the river on sandbars and channel margins in the New High Water Zone and Fluctuation Zone (Section 3.6). Species associated with a particular state respond similarly to Colorado River hydrologic factors such as depth, timing, and duration of inundation. These states and the plant species associated with each are given in Table 4.6-1. The model and data used to calculate performance metrics are based on vegetation studies conducted within GCNP (see citations in Ralston et al. 2014). Although the model is a simplification of the complexities of the riparian ecosystem, it is a valuable tool for assessing potential changes in riparian vegetation under a variety of flow regimes. Model details are described in Ralston et al. (2014). The four metrics are:

1. Relative change in cover of native-dominated vegetation community types (other than arrowweed) on sandbars and channel margins using the total percentage increase in native states (change in native cover = $cover_{final}/cover_{initial}$; a result >1 is a beneficial change).

2. Relative change in diversity of native vegetation community types (other than arrowweed) on sandbars and channel margins using the Shannon Weiner index for richness/evenness (change in diversity = $diversity_{final}/diversity_{initial}$; a result >1 is a beneficial change).

TABLE 4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels

Vegetation States	Primary Plant Species	Additional Species	Submodel/Landform
Bare Sand	<1% vegetation cover		All submodels
Common Reed Temperate Herbaceous Vegetation (Marsh)	Common reed (*Phragmites australis*), cattail (*Typha domingensis, T. latifolia*)	Common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower Reattachment Bar
Coyote Willow-Emory Seep Willow Shrubland/ Horsetail Herbaceous Vegetation (Shrub Wetland)	Horsetail (*Equisetum laevigatum*), coyote willow (*Salix exigua*), *Baccharis emoryi*, *Schoenoplectus pungens*	*Eleocharis palustris, Muhlenbergia asperifolia*	Lower Channel Margin, Lower Reattachment Bar
Tamarisk Temporarily Flooded Shrubland	Tamarisk (*Tamarix* spp.)		All submodels
Cottonwood/Coyote Willow Forest[a] (Cottonwood-willow)	Coyote willow, cottonwood (*Populus fremontii*)	*Salix gooddingii, Baccharis salicifolia, Distichlis spicata, Muhlenbergia asperifolia, Phragmites australis*, *Equisetum spp., Juncus* spp., *Carex* spp., *Elaeagnus angustifolia, Tamarix* spp., *Agrostis stolonifera, Melilotus* spp.	Lower Channel Margin, Lower Separation Bar
Arrowweed Seasonally Flooded Shrubland (Arrowweed)	Arrowweed (*Pluchea sericea*)	*Baccharis* spp., mesquite (*Prosopis glandulosa*), coyote willow	Lower Reattachment Bar, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin
Mesquite Shrubland (Mesquite)	Mesquite (*Prosopis glandulosa* var. *torreyana*)	*Baccharis* spp., *Pluchea sericea*	Lower Channel Margin, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin

[a] Although an element of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

Source: Ralston et al. (2014).

3. Relative change in the ratio of native- (other than arrowweed) to nonnative-dominated vegetation community types on sandbars and channel margins (change in native/nonnative ratio = $ratio_{final}/ratio_{initial}$; a result >1 is a beneficial change).

4. Relative change in the arrowweed community type on sandbars and channel margins using the total percentage decrease in the arrowweed state (change in arrowweed = $arrowweed_{initial}/arrowweed_{final}$; a result >1 is a beneficial change). Because the desired change is a decrease in arrowweed, this metric is calculated as initial/final, unlike the other metrics.

These performance metrics were developed from the resource goal for riparian vegetation downstream of Glen Canyon Dam: *Maintain native vegetation and wildlife habitat in various stages of maturity that are diverse, healthy, productive, self-sustaining, and ecologically appropriate*.

The vegetation model has several limitations that should be noted when considering the modeling results. The model was designed as a conceptual as opposed to a predictive model; therefore, the results are used in this analysis carefully and in combination with the literature because the model is a simplification with limitations in the ability to assess on-the-ground changes. However, it is the best available tool for impact analysis, when used in conjunction with field studies and literature.

Several issues that could not be addressed by the model are discussed qualitatively or quantitatively based on literature from field studies in this section below. These include the dynamics of the tamarisk leaf beetle (*Diorhabda* spp.) on tamarisk distribution and abundance; the overall decrease in area of the Old High Water Zone and the mortality of species within that zone; the increase or decrease of open sand that could not be captured in this model, as it could not be coupled with the sediment models; the effects from NPS's experimental vegetation treatment program (common to most alternatives); and the fact that the model considers hypothetical sandbars and was not spatially explicit in relation to current and potential future conditions.

The vegetation model was developed to compare the effects of various flow regimes on Colorado River riparian vegetation. The model consists of six geomorphic submodels based on landforms that are known to influence vegetation floristics and structure: Lower Separation Bar, Upper Separation Bar, Lower Reattachment Bar, Upper Reattachment Bar, Lower Channel Margin, and Upper Channel Margin. The upper and lower landform surfaces are separated at the 25,000-cfs stage elevation (see Section 3.3.1.1 for a description of these landforms).

The four vegetation states dominated by native plant species are marsh (Common Reed Temperate Herbaceous Vegetation), shrub wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation), cottonwood-willow (Cottonwood/Coyote Willow Forest), and mesquite (Mesquite Shrubland). Although arrowweed is a native species, prior to the dam's construction, it was strongly controlled by spring flooding and was not common, but with cessation of spring floods it has invaded many sandbars and formed monocultures. Because of

this tendency to form monocultures under these conditions, arrowweed (Arrowweed Seasonally Flooded Shrubland) states are excluded from the desired native states in the metrics. One nonnative state, tamarisk (Tamarisk Temporarily Flooded Shrubland), is included in the model. Bare Sand is also included as one of the possible states in the model. As described in Section 3.6, a number of other plant community types also occur within the riparian area downstream of Glen Canyon Dam (see also Table H-3). These plant community types vary somewhat by river reach, in the Old High Water Zone, New High Water Zone, and Fluctuation Zone.

In the model, the magnitude and timing of various important hydrologic events were identified for each model run and evaluated for the potential effects on vegetation (see Table G-2 in Appendix G for a listing and description of these hydrologic events). The model uses the daily maximum flow for the evaluation of each alternative. Important hydrologic events included spill flows (>45,000 cfs), spring HFEs (>31,500 to 45,000 cfs), fall HFEs (>31,500 to 45,000 cfs), extended low flows (daily maximum ≤10,000 cfs for at least 30 consecutive days), extended high flows (daily maximum ≥20,000 cfs for at least 30 consecutive days), and flows that can fluctuate up to 25,000 cfs, (i.e., the absence of spill flows or extended high or extended low flows). Although periodic spill flows (>45,000 cfs) could occur based on historic hydrologic conditions within the 20-year period of this evaluation, these would likely be infrequent and would occur at equal frequency under all alternatives. These spill flows are non-discretionary emergency actions and are not part of the alternatives, but were part of the hydrologic modeling. The timing of these events relative to the growing season (May–September) or non-growing season (October–March) was also determined. Growing seasons vary depending on the reach, but were generalized to these months for the model.

Daily fluctuation patterns generally produce the extended high and extended low flows. For example, Alternative B, with relatively large fluctuations, has a higher frequency of daily maxima ≥20,000 cfs for at least 30 consecutive days, and therefore more extended high flows; Alternatives F and G, two alternatives with no fluctuations, have a higher frequency of extended low flows. Monthly release volumes also affect these events. Alternative C, for example, has relatively small fluctuations but also low release volumes August through November, resulting in a higher frequency of extended low flows than Alternative G.

The model predicts transitions from one state to another, based on a set of rules that considers the frequency and duration of hydrologic events. The transition rules for the upper portions of the bars and channel margin are the same because of the similarity of plant community types and responses to flow characteristics. These transition rules are based on the effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species. HFEs result in sediment deposition, but scouring is minor and limited to low-elevation wetland species (Kearsley and Ayers 1999; Ralston 2010; Stevens et al. 2001). HFEs transport seeds of nonnative as well as native species (Kennedy and Ralston 2011; Ralston 2011; Spence 1996). Repeated extended high flows (i.e., flows with daily maximum ≥20,000 cfs for at least 30 consecutive days) result in removal of vegetation by drowning and scouring, primarily on lower elevation surfaces (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010). Increased soil moisture at upper elevations from extended high flows can increase vegetation growth and seedling establishment (Waring 1995; Sher et al. 2000; Mortenson et al. 2012). The germination of seeds transported by HFEs or extended high flows is promoted by extended low

flows (e.g., elevated base flows) that reduce disturbance, expose lower elevation surfaces, and maintain soil moisture at lower elevations, all of which are conducive to seedling growth (Porter 2002; Ralston 2011). Extended low flows (i.e., flows with daily maximum ≤10,000 cfs for at least 30 consecutive days) also can result in the lowering of groundwater levels, thus increasing the depth to groundwater and the reduction of soil moisture, creating conditions that favor the growth of more drought-tolerant species (Porter 2002; Stevens et al. 1995).

Model results include the total number of years each state occurs for the 20-year period of the model run according to each potential starting state in each submodel. For example, the reattachment bar submodel uses five different starting states for each hydrologic trace: bare sand, marsh, shrub wetland, tamarisk, and arrowweed. Model results were used to calculate the metrics for each alternative using the sum of each of the states for all six models. This value was then compared to the number of years each state would have accumulated, if the current condition was maintained, i.e., if no transitions occurred and each of the seven states remained the same for the full 20 years of the model run. This proportion was multiplied by the acreage of mapped cover types from the NPS Vegetation Map of GCNP (Kearsley et al. 2015) corresponding to the seven model states in order to provide a sense of the relative spatial scale of potential changes under each Alternative (Table 4.6-2). Because, as noted above, the model considers hypothetical sandbars due to the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area, and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

The results for the four metrics were then summed to derive a final score for each alternative. Alternatives with higher scores were considered to have come closer to achieving the resource goal. Several factors other than the operational characteristics considered by the models have a strong influence on the riparian vegetation below the dam, however, due to a lack of information on these potential effects and for the purposes of this analysis, it is assumed that these effects would apply equally across all alternatives. These include changes in precipitation, defoliation of tamarisk by the tamarisk leaf beetle and other insects, and experimental vegetation management activities implemented by the NPS to reduce invasive plant populations and increase local populations of desired native plants (Figure 4.6-1). The impacts of these factors were assessed in light of the potential vegetation changes shown by the state and transition model.

4.6.2 Summary of Impacts

Impacts on plant communities of the Old High Water Zone, New High Water Zone, and wetlands for the 20-year LTEMP period are summarized below. Table 4.6-3 provides an overview of the anticipated impacts by alternative, as well as the important flow characteristics associated with the effects of each alternative. Although the presence of the dam affects the vegetation community in the Colorado River Ecosystem via changes in maximum annual flows

TABLE 4.6-2 Vegetation States and Corresponding Mapped Vegetation Types

Vegetation States	Mapped Vegetation Classes[a]	Area (ac)
Bare Sand	Unvegetated Surfaces and Built Up Areas	112
Marsh (Common Reed Temperate Herbaceous Vegetation)	*Phragmites australis* Western North America Temperate Semi-Natural Herbaceous Vegetation	4.4
Shrub Wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation)	Arid West Emergent Marsh	0.2
Tamarisk (Tamarisk Temporarily Flooded Shrubland)	*Tamarix* spp. Temporarily Flooded Semi-Natural Shrubland	273.7
Cottonwood-Willow (Cottonwood/Coyote Willow Forest[b])	*Baccharis* spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	177.3
Arrowweed (Arrowweed Seasonally Flooded Shrubland)	*Baccharis* spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	177.3
Mesquite (Mesquite Shrubland)	*Prosopis glandulosa* var. *torreyana* Shrubland	137.1

[a] Kearsley et al. (2015), which mapped RM 0-278; vegetation classes and area are based on 2007 and 2010 aerial photography and do not necessarily reflect current conditions. This mapping was limited to GCNP and did not include Glen Canyon.

[b] Although a component of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

and sediment supply, the analysis conducted for the EIS indicated that vegetation areal cover, species composition, and diversity in the New High Water Zone are related to dam operations.

Figure 4.6-2 compares the predicted effects of each alternative on vegetation characteristics as measured using four metrics. A score of 1 indicates no change from initial conditions; values >1 indicate an improvement relative to current conditions (increase in native cover, native diversity, or native/nonnative diversity; decrease in arrowweed); values <1 indicate a decline relative to current conditions (decrease in native cover, native diversity, or native/nonnative ratio; increase in arrowweed), and Figure 4.6-3 presents the overall impacts under the LTEMP alternatives. In this case, a total score of 4.0 calculated by summing the scores for each of the 4 metrics under each alternative indicates no change from initial conditions; values >4 indicate an improvement relative to current conditions; and values <1 indicate a decline relative to current conditions. See Appendix G for additional details regarding the application of the vegetation model in the analysis of impacts.

TABLE 4.6-3 Summary of Impacts of LTEMP Alternatives on Vegetation

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Overall index = 3.66, reflecting an adverse impact relative to current condition resulting from: narrowing of Old High Water Zone; an expected decrease in New High Water Zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Compared to Alternative A, 6% increase in overall index reflecting an improvement in vegetation conditions (but a decline under hydropower improvement flows); impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, increase in arrowweed, increase in native diversity (decrease under hydropower improvement flows), increase in native/nonnative ratio (decrease under hydropower improvement flows), and decrease in wetland community cover.	Compared to Alternative A, 13% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone; decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover.	Compared to Alternative A, 8% increase in overall index reflecting an improvement in vegetation conditions; impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, increase in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover; lowest impact of alternatives.	Compared to Alternative A, 3% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of the Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, increase in arrowweed, and decrease in wetland community cover.	Compared to Alternative A, 14% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative), decrease in arrowweed, and decrease in wetland community cover; highest impact of alternatives.	Compared to Alternative A, 7% decrease in overall index reflecting a decline in vegetation conditions; impacts include a narrowing of Old High Water Zone, decrease in New High Water Zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, decrease in arrowweed, and decrease in wetland community cover.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Old High Water Zone							
	Relative to current conditions, continued narrowing of zone due to lack of sufficiently high flows.	Same as Alternative A.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transiton between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but annual spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.	Compared to Alternative A, continued narrowing of zone, but more frequent spring HFEs may result in greater survival of plants at the transition between the New High Water Zone and the Old High Water Zone.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a]							
Relative change in cover of native vegetation community types (final cover/ initial cover)	Native cover index = 0.827, reflecting a 17% (55.2 ac[a]) overall decrease in native plant community cover over the LTEMP period relative to current conditions, resulting from few spring HFEs, occasional fall HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows; 28% (1.3 ac) decrease in wetland community cover resulting from extended high flows.	Compared to Alternative A, 3% increase in native cover index reflecting a smaller overall decrease (15%, 48.3 ac) in native plant community cover (47% decrease under hydropower improvement flows) resulting from few spring HFEs, more fall HFEs, slightly more extended high flows; 20% (0.9 ac) decrease in wetland community cover (83% [3.8 ac] decrease under hydropower improvement flows) resulting from extended high flows.	Compared to Alternative A, 24% decrease in native cover index reflecting a greater overall decrease (37%, 117.7 ac) in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 75% (3.4 ac) decrease in wetland community cover resulting from extended low flows and extended high flows (highest impact of all alternatives).	Compared to Alternative A, 6% increase in native cover index reflecting a smaller overall decrease (12%, 39.5 ac) in native plant community cover, resulting from more HFEs, more seasons without extended high or low flows, frequent extended high flows; 16% (0.8 ac) decrease in wetland community cover resulting from extended high flows (lowest impact of all alternatives).	Compared to Alternative A, 3% decrease in native cover index reflecting a greater overall decrease (20%, 63.5 ac) in native plant community cover, resulting from more fall HFEs, slightly more growing-season extended low flows; 38% (1.7 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Compared to Alternative A, 15% decrease in native cover index reflecting a greater overall decrease (30%, 95.0 ac) in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 86% (4.0 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Compared to Alternative A, 15% decrease in native cover index reflecting a greater overall decrease (29%, 93.7 ac) in native plant community cover, resulting from more HFEs, more extended low flows, occasional extended high flows; 58% (2.6 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in diversity of native vegetation community types (final diversity/ initial diversity)	Diversity index = 0.983, reflecting a 2% decrease in native diversity over the LTEMP period relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities resulting from occasional growing-season extended low flows.	Compared to Alternative A, 4% increase in diversity index reflecting an increase (3%) in native diversity relative to current conditions due to an increase in relative evenness of community types resulting from a small (<1 ac) decrease in wetlands (9% decrease under hydropower improvement flows) (lowest impact of all alternatives).	Compared to Alternative A, 6% decrease in diversity index reflecting a greater decrease (8%) in native diversity relative to current conditions, due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in response to fewer seasons without extended high or low flows, more extended low flows.	Compared to Alternative A, 3% increase in diversity index reflecting an increase (2%) in native diversity relative to current conditions, due to an increase in relative evenness of community types resulting from a small (<1 ac) decrease in wetlands.	Compared to Alternative A, <1% decrease in diversity index reflecting a slightly greater decrease (2%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in response to slightly more growing-season extended low flows.	Compared to Alternative A, 8% decrease in diversity index reflecting a greater decrease (9%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities in reponse to fewer seasons without extended high or low flows, more extended low flows (highest impact of all alternatives).	Compared to Alternative A, 2% decrease in diversity index reflecting a greater decrease (3%) in native diversity relative to current conditions due to a decrease in relative evenness of native community types resulting from a large (>1 ac) decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in the ratio of native- to nonnative-dominated vegetation community types (final ratio/initial ratio)	Native-nonnative index = 1.051, reflecting a 5% increase in ratio over the LTEMP period relative to current conditions reflecting a 58.4-ac decrease in tamarisk over the LTEMP period resulting from frequent extended high flows, few extended low flows, and spring HFEs. Tamarisk leaf beetle may increase benefit, but lack of experimental vegetation treatment provided under other alternatives would not provide benefit.	Compared to Alternative A, 9% increase in index (decrease under hydropower improvement flows), reflecting a 48.3-ac decrease in native cover but a larger 71.4 ac decrease in tamarisk (107 ac decrease under hydropower improvement flows) resulting from few spring HFEs, slightly more extended high flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk further. Lowest impact of alternatives.	Compared to Alternative A, 57% decrease in ratio, reflecting a 117.7 ac decrease in native cover and a 104-ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk.	Compared to Alternative A; 9% decrease in ratio, reflecting a 39.5 ac decrease in native cover and a smaller 22.4-ac decrease in tamarisk resulting from extended high flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk further.	Compared to Alternative A; 9% decrease in ratio, reflecting a 63.5 ac decrease in native cover and a smaller 45.7-ac decrease in tamarisk resulting from more fall HFEs, slightly more growing-season extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A, 64% decrease in ratio, reflecting a 95 ac decrease in native cover and a 231-ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk. Highest impact of alternatives.	Compared to Alternative A; 43% decrease in ratio reflecting a 93.7 ac decrease in native cover and a 46.4-ac increase in tamarisk resulting from more HFEs, more extended low flows. Tamarisk leaf beetle and non-flow vegetation treatment activities may decrease tamarisk.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in the arrowweed community type (initial acres/final acres)	Arrowweed index = 0.799, reflecting a 25% (44.5 ac) increase in arrowweed over the LTEMP period relative to current conditions resulting from few spring HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows. Highest impact of alternatives.	Compared to Alternative A, 5% increase in arrowweed index, reflecting a smaller increase (19%, 33.3 ac) in arrowweed relative to current conditions resulting from more extended high flows (24% increase under hydropower improvement flows). Non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A, 46% increase in arrowweed index, reflecting a decrease (14%, 25.1 ac) in arrowweed relative to current conditions resulting from repeated extended low flows and extended high flows. Non-flow vegetation treatment activities may increase benefit. Lowest impact of alternatives.	Compared to Alternative A, 39% increase in arrowweed index, reflecting a decrease (10%, 17.1 ac) in arrowweed relative to current conditions resulting from repeated extended high flows, frequent fall HFEs, and few growing season extended low flows. Non-flow vegetation treatment activities may increase benefit.	Compared to Alternative A; <1% change in arrowweed index, reflecting an increase (25%, 44.0 ac) increase in arrowweed relative to current conditions resulting from more HFEs, more growing-season extended low flows, and frequent growing-season extended high flows. Non-flow vegetation treatment activities may decrease adverse impact.	Compared to Alternative A; 43% increase in arrowweed index, reflecting a decrease (13%, 22.2 ac) in arrowweed relative to current conditions resulting from more HFEs, repeated extended high flows. Non-flow vegetation treatment activities may increase benefit.	Compared to to Alternative A; 41% increase in arrowweed index, reflecting a decrease (11%, 20.1 ac) in arrowweed relative to current conditions resulting from more HFEs, growing-season extended low flows, fewer growing-season extended high flows. Non-flow vegetation treatment activities may increase benefit.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Special status plant species[b]	No change from current conditions in terms of impacts on species of active and inactive floodplains; potential impact on wetland species resulting from continuing loss (28%, 1.3 ac) of wetland habitat.	Compared to Alternative A, no change from current conditions in terms of impacts on species of active and inactive floodplains; less impact on wetland species because less wetland habitat would be lost (20%, 0.9 ac).	Compared to to Alternative A, potential impacts on active floodplain species from extended-duration HFEs, greater impact onwetland species from 75% (3.4 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.	Compared to Alternative A, potential impacts on active floodplain species from extended-duration HFEs, less impact on wetland species from 16% (0.8 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.	Compared to Alternative A, similar impact on active floodplain species; greater impact on wetland species from 38% (1.7 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs (lowest impact of alternatives).	Compared to Alternative A, potential impacts on active floodplain species from annual HFEs; Lake Mead shoreline species from high reservoir levels; greater impact on wetland species from 86% (4.0 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs (highest impact of alternatives).	Compared to Alternative A,, potential impacts on active floodplain species from extended-duration HFEs; greater impact onwetland species from 58% (2.6 ac) decrease in habitat; potential benefit for inactive floodplain species from spring HFEs.

[a] Changes in area are presented for each community type; however, because of the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

[b] Details regarding special status plant species are provided in Table 4.6-6.

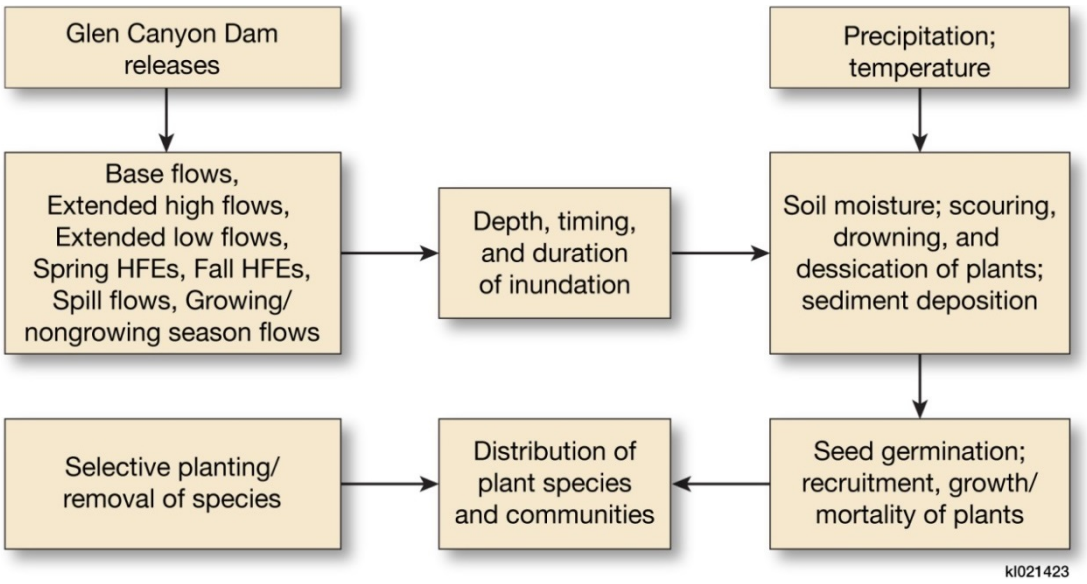

FIGURE 4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam

4.6.2.1 Impacts on Old High Water Zone Vegetation

The riparian vegetation that became established along the Colorado River channel margin in response to annual peak flows prior to the construction of Glen Canyon Dam is located at high flow stage elevations (above 60,000 cfs, but primarily from about 100,000 to approximately 200,000 cfs), well above the level of current dam operations. The Old High Water Zone plant communities are described in Section 3.6. Mortality of riparian plants within this zone, along with a lack of seedling establishment for some species, such as mesquite and hackberry, have been occurring for decades, because of a lack of sufficiently high flows and nutrient-rich sediment (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Dam operations, other than HFEs, do not exceed 31,500 cfs flows (although all alternatives have a normal maximum operating flow of 25,000 cfs), and HFEs do not exceed 45,000 cfs. None of the alternatives considered would include flows sufficient to maintain these pre-dam plant communities. HFEs could provide soil moisture to the deep root systems of some Old High Water Zone plants that are at the lower edge, close to the New High Water Zone, providing occasional soil moisture. Studies indicate that dam releases can affect water availability to plants at elevations up to approximately 15,000 cfs above flow levels (Melis et al. 2006; Ralston 2005). Alternatives with more frequent spring HFEs, such as Alternatives C, D, E, F, and G, may result in higher survival rates of plants at lower elevations of the Old High Water Zone than Alternative A due to increased moisture within the root zone. The differences between alternatives are expected to be minor in terms of effects on the lower margin of the Old High Water Zone. Several alternatives include extended-duration HFEs (longer than 96 hr; e.g., up to 250 hr under Alternative D); however, because these HFEs only occur during the fall (the non-growing season), their contribution to higher survival rates would likely be limited.

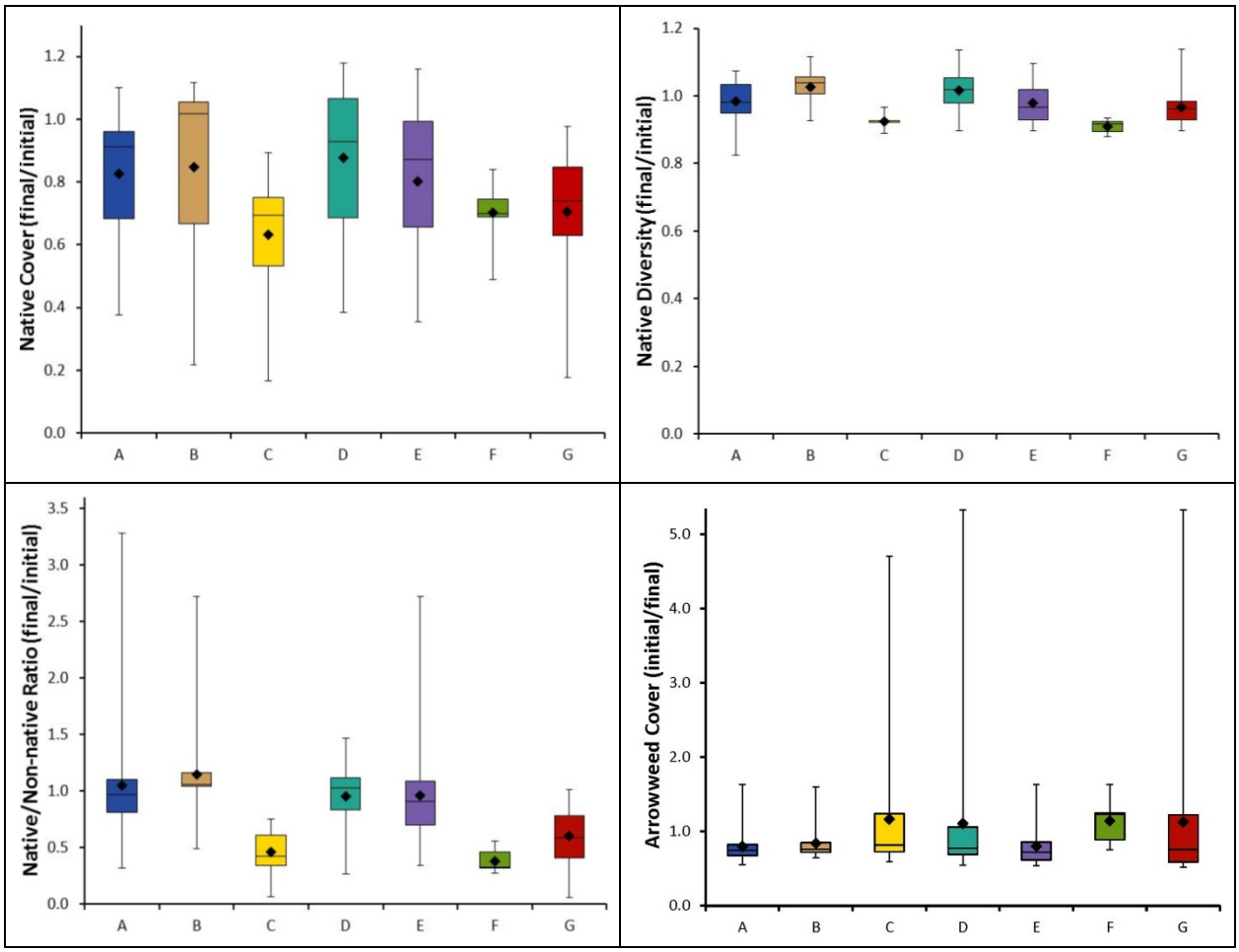

FIGURE 4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an improvement relative to current conditions; values <1 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Because of generally continued low soil moisture and lack of recruitment opportunities under all alternatives, the upper margins of this zone would be expected to continue moving downslope, with a continued narrowing of the riparian zones. Desert species occurring on the pre-dam flood terraces and windblown sand deposits above the Old High Water Zone would increasingly establish within this zone, depending on climate and precipitation. Overall, all alternatives would result in a decline in upper margins Old High Water Zone plant communities, because none feature regular flows >45,000 cfs. The likelihood of these very high flows, which would occur only under emergency dam operations, is considered very low, and would be the same for all alternatives. Therefore, the narrowing of the Old High Water Zone is outside the scope of the LTEMP impact analysis.

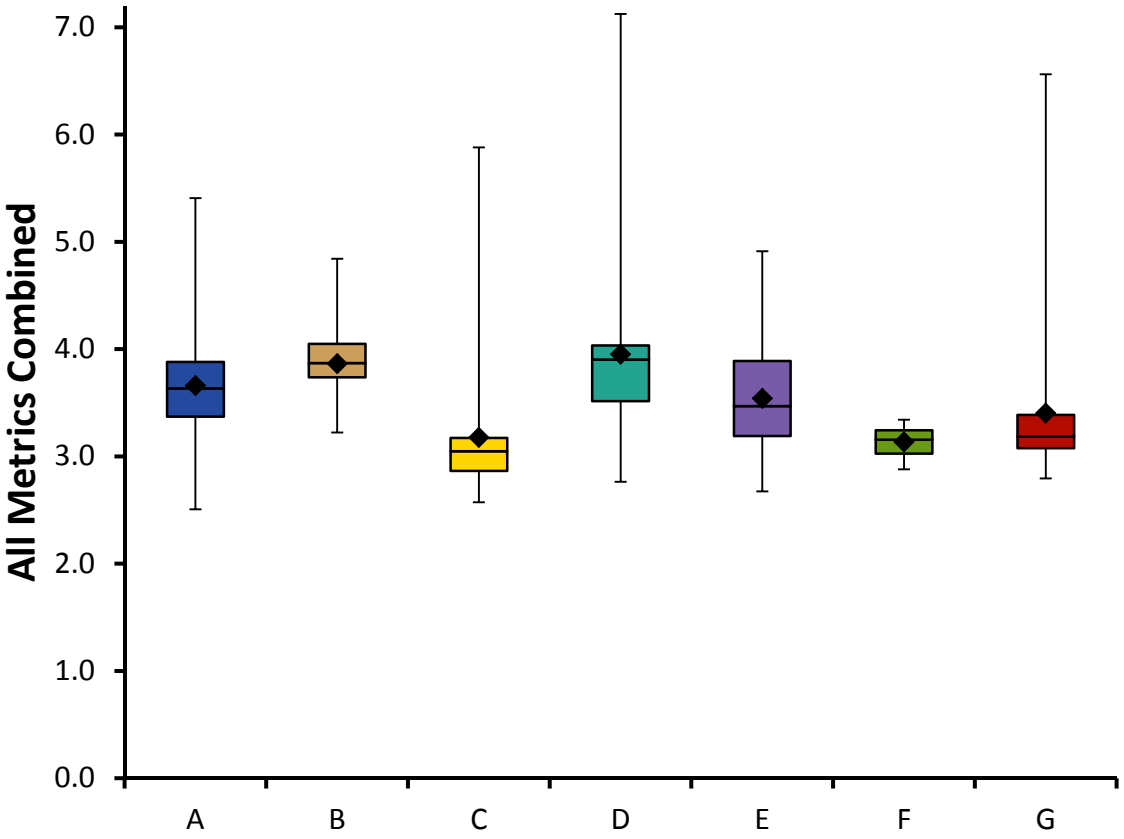

FIGURE 4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 4 indicate no change over the LTEMP period; values >4 indicate an improvement relative to current conditions; values <4 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.6.2.2 Impacts on New High Water Zone

Plant community types that have developed in the New High Water Zone in response to Glen Canyon Dam operations include cottonwood-willow and mesquite communities, both native species-dominated community types, as well as tamarisk (a nonnative species-dominated community type) and arrowweed (an invasive native species-dominated community type) (Ralston et al. 2014). Two native species-dominated wetland community types, marsh and shrub wetland, that occur in the Fluctuation Zone are discussed in Section 4.6.2.3. Transitions between plant community types, or to bare sand, are driven by specific flow events that vary among the alternatives. Spring HFEs, fall HFEs, spill flows, extended low flows, extended high flows, and seasons without extended high or low flows occurring during the growing or non-growing season result in changes in the distribution and cover of New High Water Zone plant communities.

HFEs alone do not result in transitions but generally act in combination with other flow events. Colorado River flows affect the composition, structure, and distribution of riparian vegetation communities through the effects of drowning, scouring, sediment deposition, desiccation, and maintaining alluvial groundwater levels (Sankey, Ralston et al. 2015; Ralston et al. 2014; Ralston 2005, 2010, 2012; Kennedy and Ralston 2011; Kearsley et al. 2006; Porter 2002; Kearsley and Ayers 1999; Stevens et al. 1995). HFEs result in sediment deposition and increased water availability at higher stage elevations but little scouring, extended high flows drown and scour plants and maintain ground-water levels, while extended low flows can desiccate plants, especially seedlings, while providing a consistent water supply to plants at very low stage elevations. Transitions and initiating flows are presented in Table G-3, in Appendix G.

Flows that result in increases or decreases in cottonwood-willow and mesquite communities are given in Table 4.6-4. Alternatives with greater occurrence of transitions from bare sand to native plant communities and/or maintenance of those communities (i.e., a lack of transitions to bare sand) would result in greater native community cover. However, repeated seasons of extended high flows, extended high flows above 50,000 cfs, or spill flows transition native communities to bare sand through the processes of drowning, scouring, and burial (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). All of the alternatives would result in a decrease in native plant community cover (see discussions below under individual alternatives). However, annual hydrology has a greater effect on the change in native community types than the operational characteristics of the alternatives.

Flows that result in increases or decreases in tamarisk are given in Table 4.6-4. The overall cover of tamarisk-dominated communities would be expected to increase under Alternatives C, F, and G, each of which are expected to produce frequent transitions to tamarisk communities, in large part because they frequently have extended high flows, extended low flows, and spring HFEs. This combination of flows encourages transitions to tamarisk because tamarisk increases when high flows coincide with seed release during spring and early summer, followed by lower flows, all of which results in establishment of seedlings above the elevation of subsequent floods (Mortenson et al. 2012; Stevens and Siemion 2012). Also, under these alternatives, various community types frequently shift to bare sand, which then shifts to tamarisk. Each of these alternatives has more extended low flows and more spring HFEs than the other alternatives. The overall cover of the tamarisk is expected to decrease under Alternatives A, B, D, and E. Each of these alternatives has frequent extended high flows, which result in consecutive seasons and consecutive years of extended high flows. Two or more years of extended high flows are required for tamarisk to be removed by drowning, leaving a bare sand lower reattachment bar, or two consecutive seasons (growing and non-growing) on a lower separation bar (Kearsley and Ayers 1999; Stevens and Waring 1986a).

The presence of the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.) along much of the Colorado River below Glen Canyon Dam has resulted in defoliation of tamarisk in many areas, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Considerable uncertainty still exists regarding the long-term effects of the beetle and weevil on the tamarisk population below the dam and subsequent effects on ecosystem dynamics within the New High Water Zone. The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics. Tamarisk may

TABLE 4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Increase New High Water Zone Natives			
Bare sand	Cottonwood-willow	Lower separation bar	Growing season and non-growing season without extended high or low flows the same year (7 yr; slowed by non-growing-season extended high flow with growing season without extended high or low flow the same year) (Waring 1995; Ralston et al. 2008).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow next growing season (Ralston 2010).
Tamarisk	Mesquite	Upper bars/channel margin; lower channel margin	Spring HFE with growing season without extended high or low flow or extended high flow the same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Decrease New High Water Zone Natives			
Cottonwood-willow	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high plus growing-season extended high same year; or growing-season extended high followed by non-growing-season extended high the next year.(Stevens and Waring 1986a)
Cottonwood-willow	Bare sand	Lower channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Mesquite	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a] or any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Transitions That Increase Wetland			
Bare sand	Marsh	Lower reattachment bar	Growing season without extended high or low flow (2 yr; slowed by growing season with extended high flow) (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010).
Bare sand	Shrub wetland	Lower channel margin	Non-growing season without extended high or low flow plus growing season without extended high or low flow (4 yr, can be slowed by growing season with extended low flow or HFE; extended high flow starts process over) (Stevens and Waring 1986a; Porter 2002).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Wetland			
Marsh, shrub wetland	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012).
Marsh, shrub wetland	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow next growing season; growing season with extended high flow followed by a non-growing season with extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Shrub wetland	Bare sand	Lower channel margin	Any season with extended high flow over 25,000 cfs (Stevens and Waring 1986a).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow the next growing season (Ralston 2010).
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Transitions That Increase Tamarisk			
Marsh, shrub wetland, arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002).
Bare sand	Tamarisk	Lower separation bar; lower channel margin	Non-growing season with extended high flow, or spring HFE plus growing season with extended low flow the same year (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000).
Bare sand	Tamarisk	Lower reattachment bar	Growing season with extended low flow (Stevens and Waring 1986a; Porter 2002; Sher et al. 2000).
Bare sand	Tamarisk	Upper bar/channel margin	Spring HFE plus growing season with extended high flow the same year (Sher et al. 2000; Mortenson et al. 2012).
Transitions That Decrease Tamarisk			
Tamarisk	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high flow plus growing-season extended high flow same year; or growing-season extended high flow followed by non-growing-season extended high flow the next year (Stevens and Waring 1986a).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Tamarisk (Cont.)			
Tamarisk	Bare sand	Lower reattachment bar	Spill flow[a]; 4 consecutive seasons of non-growing-season extended high flow plus growing-season extended high flow; growing-season extended high flow (4 consecutive years) (Stevens and Waring 1986a; Kearsley and Ayers 1999).
Tamarisk	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a]; any season extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Tamarisk	Mesquite	Lower channel margin; upper bar/channel margin	Spring HFE with growing season without extended high or low flow or extended high same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Increase Arrowweed			
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Bare sand	Arrowweed	Upper bar/channel margin	Non-growing season with extended low flow, or seasons without extended high or low flow, or non-growing season with extended high flow, plus growing season with extended low flow, or seasons without extended high or low flow, or growing season with extended high flow; same year (3–6 yr, extended high flows increase the rate, slowed by fall HFE) (Waring 1995).
Transitions That Decrease Arrowweed			
Arrowweed	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow the next growing season; growing season with extended high flow followed by a non-growing season extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Arrowweed	Bare sand	Upper bar/channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002).

[a] Spill flows are releases through the spillway and are non-discretionary emergency actions that do not vary among alternatives.

Source: Ralston et al. (2014).

not establish as readily on bare sand substrates, or transition from other community types, as in the past (and described above) if seed sources are reduced. Additionally, tamarisk communities may become less stable and more easily removed by high flows than in the past. Therefore, increases in tamarisk that would be expected to result under Alternatives C, F, and G, may be less than expected, and decreases of tamarisk under Alternatives A, B, D, and E may be greater than expected.

Flows that would result in increases or decreases in arrowweed are given in Table 4.6-4. The overall cover of the arrowweed community type would be expected to increase under Alternatives A, B, and E; under these alternatives, bare sand would transition to arrowweed rather than tamarisk because there are few spring HFEs and/or few growing-season extended high flows, both of which promote the establishment of tamarisk on bare sand, and, except in Alternative B, arrowweed would transition from marsh because of growing-season extended low flows (Porter 2002). Once established, arrowweed would tend to remain for many years under these alternatives. HFEs alone are not effective at reducing arrowweed as burial typically results in resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth occurs (Ralston 2012). Arrowweed would decrease under Alternatives C, D, F, and G, usually by transitioning to bare sand with repeated extended high flows (Ralston 2010; Stevens and Waring 1986a), but often by transitioning to tamarisk under Alternatives C, F, and G. The hydrology of the river (e.g., wet years vs. dry years), however, has a greater effect on the change in arrowweed than the characteristics of the alternatives. Drier years tend to have fewer extended high flows resulting in more arrowweed due to fewer transitions to bare sand or tamarisk.

Given that under all alternatives vegetation condition degrades to some degree, experimental riparian vegetation treatments are planned under all alternatives except for Alternative A. These activities are expected to modify the cover and distribution of plant communities along the Colorado River and improve the vegetation conditions. These vegetation treatments include removal of nonnative plants, revegetation with native species, clearing of undesirable plants from campsites, and management of vegetation to assist with cultural site protection. All vegetation treatments would occur only within the Colorado River Ecosystem, which could be influenced by dam operations. Native species, such as Goodding's willow and cottonwood, would be planted to increase and maintain populations of these species. Native plant materials would be developed for replanting through partnerships and use of regional greenhouses; this would include the collection of propagules (seeds, cuttings, poles, or whole plants) from riparian areas in both the river corridor and side canyons. Removal of nonnative plants would include mechanical means (e.g., cutting), smothering, spot burning, or use of herbicides. Monitoring of riparian areas subsequent to the implementation of any alternative would direct the specific locations and degree of implementation of non-flow actions. Nonnative species targeted for removal would be those affected by dam operations that are considered the greatest threat to park resources and having a high potential for successful control (Table 4.6-5). Control and removal of the native arrowweed would be conducted where this species is encroaching on campsites where camping area has been lost. In addition to ongoing removal of selected nonnative plant species in the river corridor, targeted vegetation treatment at priority sites or sub-reaches would include systematic removal of tamarisk and replanting and seeding of natives. The acreage that would be targeted for priority treatment would vary by alternative, depending on expected changes in riparian community types. An estimate of the change in

TABLE 4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor

Scientific Name	Common Name
Rhaponticum repens	Russian knapweed
Alhagi maurorum	camelthorn
Brassica tournefortii	Sahara mustard
Convolvulus arvensis	black bindweed
Cortaderia selloana	Pampas grass
Echinochloa crus-galli	barnyardgrass
Eragrostis curvula	weeping love grass
Elaeagnus angustifolia	Russian olive
Lepidium latifolium	perennial pepperweed
Malcolmia africana	African mustard
Phoenix dactylifera	date palm
Saccharum ravennae	Ravenna grass
Salsola tragus	Russian thistle
Schedonorus arundinaceus	tall fescue
Sisymbrium altissimum	tumble mustard
Sisymbrium irio	London rocket
Solanum elaeagnifolium	silverleaf nightshade
Sonchus asper	spiny sowthistle
Sonchus oleraceus	common sowthistle
Tamarix aphylla	athel
Tamarix spp.	salt cedar
Tribulus terrestris	puncture vine
Ulmus pumila	Siberian elm

acreage of tamarisk or arrowweed under each of the alternatives is given in Section 4.6.3. Alternatives that result in greater increases in these species would be expected to also result in a greater extent of targeted vegetation treatment. Therefore, differences among alternatives in changes of tamarisk or arrowweed may be somewhat less than indicated by flow effects alone. Vegetation treatments would be expected to occur at limited locations, and these areas would likely only comprise a small proportion of the riparian area below Glen Canyon Dam.

4.6.2.3 Wetlands

Wet marsh communities of flood-tolerant herbaceous species that occur on low elevation areas of reattachment bars within the Fluctuation Zone (i.e., the range of normal operational fluctuations between the elevations of 5,000 and 25,000 cfs flows) have developed in response to frequent inundation (daily for at least part of the year) (Stevens et al. 1995; Ralston 2005, 2010). These marsh communities (with common reed and cattail the dominant species) occur on fine-grained silty loam soils in low-velocity environments on lower areas of eddy complex sandbars, which, although easily scoured by high flows, can redevelop quickly. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Native flood-adapted

species increase in low-elevation areas following growing-season steady high flows, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Shrub wetland communities (with coyote willow, seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000 cfs stage, that are less frequently inundated. Mortality of horsetail occurs at higher elevations above the water table during growing-season low steady flows (Porter 2002). Large daily fluctuations increase the area of saturated soil, and thus the sandbar area available for wetland species establishment (Stevens et al. 1995; Carothers and Aitchison 1976; Kearsley et al. 2006). The reduction of daily fluctuations may increase the establishment of wet marsh species at lower elevations and promote the transition of higher elevation marshes to woody phreatophyte species such as tamarisk or arrowweed (Stevens et al. 1995). Periodic flooding and drying tends to increase diversity and productivity in wetland communities (Reclamation 2011b; Stevens et al. 1995). Although low-elevation plants in marshes in Marble Canyon and Grand Canyon, such as cattail, common reed, and willow, may become buried with coarse sediment, recovery generally occurs within 6–8 months (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Low steady flows can cause some wetland patches to dry out, resulting in considerable mortality (Porter 2002). Sustained high releases reduce wetland vegetation cover to less than 20% on lower reattachment bars, allowing tamarisk to occupy open space, if sustained low releases occur in the next growing season (Ralston et al. 2014; Sher et al. 2000). Extended high flows typically scour herbaceous vegetation; however, most woody plants often remain (Ralston et al. 2014). Thus, extended high flows followed by extended low flows in the following growing season result in a transition from shrub wetland to a cottonwood-willow community on channel margins because of an increase in overstory cover and a decrease in herbaceous understory plants (Ralston 2010).

Flows that result in increases or decreases in marsh or shrub wetland communities are given in Table 4.6-4. A transition from marsh to shrub wetland occurs on lower reattachment bars with 4 years of consecutive seasons of low fluctuating flows or non-growing-season sustained low flows (Ralston et al. 2014; Stevens et al. 1995). A fall or spring HFE delays the transition for 1 year; however, an extended high flow before the transition removes the established plants (Ralston et al. 2014).

Wetland communities generally transition only from bare sand or other wetlands (Ralston et al. 2014; Stevens et al 1995); they can transition back to bare sand or to arrowweed, tamarisk, or cottonwood-willow communities (Mortenson et al 2012; Ralston 2010; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a). A greater occurrence of transitions from bare sand to wetlands and/or maintenance of wetlands (lack of transitions to other community types) would result in greater wetland cover. Alternatives that include frequent extended low flows, such as annually for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases for Alternative F. The relative change in cover (final based on model results/initial) of wetland community types is presented in Figure 4.6-4.

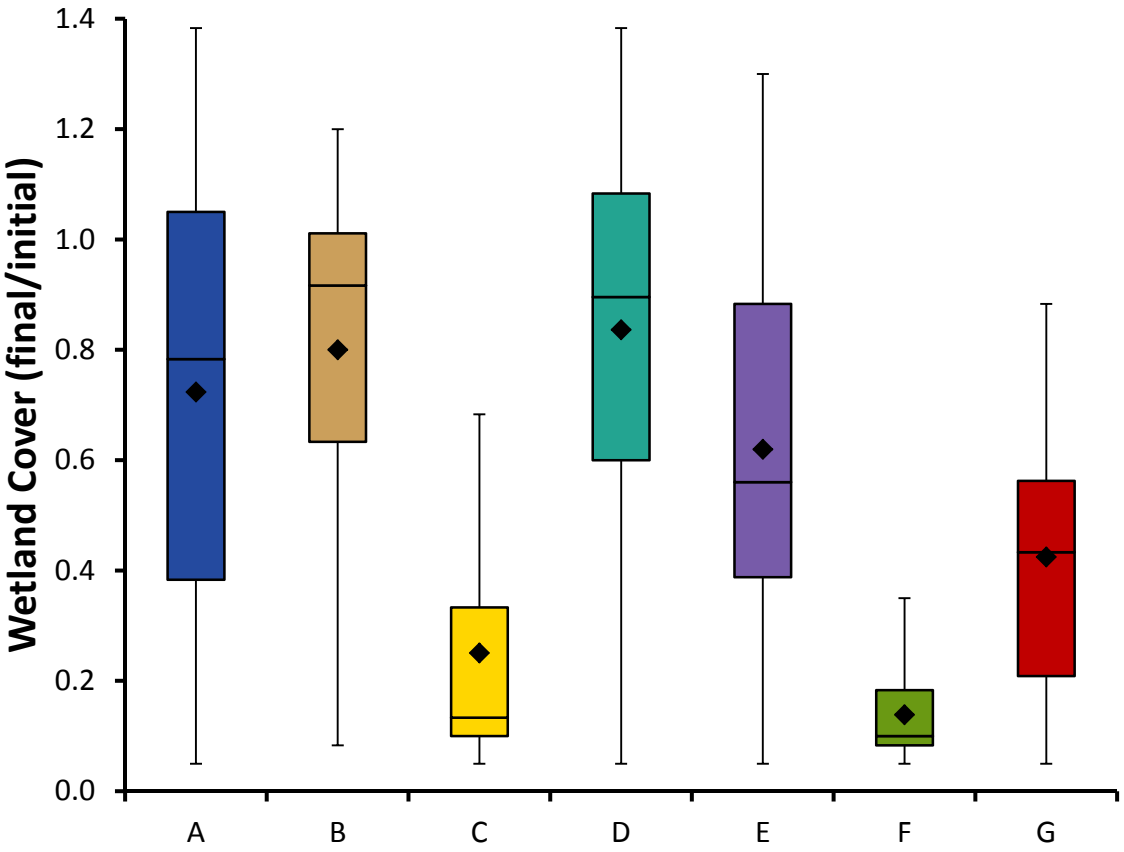

FIGURE 4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model (Metric represents the proportion of the estimated amount of wetland vegetation types at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an increase; values <1 indicate a decrease. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.6.2.4 Special Status Plant Species

Impacts on special status plant species that are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead are summarized in Table 4.6-6. Scientific names, listing status, and habitat are presented in Section 3.6, Table 3.6-2. The analyses of impacts for special status plant species is similar to the analysis for other vegetation and relies on an evaluation of impacts on the habitat associated with each species.

Species of active floodplains occur above the elevation of daily releases (25,000 cfs) but within the stage elevation of HFEs (45,000 cfs). These include Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), and may include giant helleborine (*Epipactis gigantea*). These species are generally not affected by HFEs because of their short duration, however, Alternatives C, D, and G include extended-duration HFEs (up to 250 hr under

TABLE 4.6-6 Summary of Impacts of LTEMP Alternatives on Special Status Plant Species

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Species of active floodplains (25,000–45,000 cfs) Grand Canyon evening primrose (*Camissonia specuicola* ssp. *Hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), giant helleborine (*Epipactis gigantea*)	No impact from current operations; located above the level of daily operations.	Same as Alternative A.	Compared to Alternative A, small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Compared to Alternative A, small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Same as Alternative A.	Compared to Alternative A, small potential for temporary impacts from high frequency of HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.	Small potential for temporary impacts from extended-duration HFEs. Recovery expected based on life history and recolonization from nearby unaffected habitats.
Species of the Lake Mead shoreline sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), Las Vegas bear poppy (*Arctomecon californica*)	No impact on species from current operations.	No impact.	No impact.	No impact.	No impact.	Minor increase in April–June in Lake Mead shoreline elevation inundating habitat (highest impact of alternatives).	Similar to Alternative A.
Species of inactive floodplains (>45,000 cfs) Marble Canyon spurge (*Euphorbia aaron-rossii*), hop-tree (*Ptelea trifoliata*)	No impact from current operations; located above dam operational effects.	Same as Alternative A.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from spring HFEs.	Compared to Alternative A, small potential for benefit from annual spring HFEs (lowest impact of alternatives).	Same as Alternative A.

TABLE 4.6-6 (Cont.)

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Species of fluctuation zones and wetlands satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), American bugleweed (*Lycopus americanus*)	No change from current conditions; potential impact resulting from continuing loss (28%, 1.3 ac) of wetland habitat.	Compared to Alternative A, less impact resulting because less wetland habitat would be lost (20%, 0.9 ac).	Compared to Alternative A, greater impact resulting from 75% (3.4 ac) decrease in habitat.	Compared to Alternative A, less impact because less wetland habitat would be lost (16%, 0.8 ac) decrease in habitat (lowest impact of alternatives).	Compared to Alternative A, greater impact resulting from 38% (1.7 ac) decrease in habitat.	Compared to Alternative A, greater impact resulting from 86% (4.0 ac) decrease in habitat (highest impact of alternatives).	Compared to Alternative A, greater impact resulting from from 58% (2.6 ac) decrease in habitat.

Alternative D and 336 hr under Alternative G), while Alternative F has annual spring HFEs. A slightly increased potential for burial from these HFEs could result in a temporary increase in impacts on special status species because of their small populations. These impacts of inundation and burial are expected to be temporary because the Grand Canyon evening primrose, lobed daisy, and giant helleborine are floodplain species adapted to flooding disturbance. The main populations of the primrose, helleborine, and daisy are in springs up tributaries away from the river, and the Mohave prickly pear is also found in sandy flats above the 45,000-cfs stage elevation. These areas would be unaffected by HFEs, and could serve as sources for recolonization of floodplain habitats.

Species of the Lake Mead shoreline include sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*). These species are generally not affected by fluctuations in the Lake Mead surface elevation, as under current operations. However, alternatives that raise the reservoir surface elevation, such as the minor elevation increase in April–June under Alternative F (see Figure 4.2-4), inundate the shoreline habitat for these species, potentially resulting in drowning of individuals below the highest shoreline elevation. These effects are expected to be offset by increases in germination, growth, and reproduction of individuals above that level, which would benefit from increases in soil moisture.

Species of inactive floodplains, Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*), occur above the stage elevation of HFEs (45,000 cfs) but below the elevation of the desert scrub community. These species are not directly affected by dam operations; however, alternatives with more frequent spring HFEs, such as Alternatives C, D, E, F, and G, potentially provide a slight benefit to these species through frequent increases in soil moisture.

Species of the fluctuation zone are inundated by daily operations and are typically associated with wetland communities. These include satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*). The loss of wetland community cover under all alternatives would result in a loss of habitat for these species; Alternatives B and D would result in a decrease impacts on these species compared to Alternative A, while Alternatives C, E, F, and G would result in an increase in impacts. Alternative D would have the least impact of any alternative; Alternative F would have the highest impact.

4.6.3 Alternative-Specific Impacts

The resources addressed in this section include the riparian plant communities of the New High Water Zone and the Fluctuation Zone. The mechanisms underlying New High Water Zone vegetation changes associated with hydrologic events, and the associated research supporting those mechanisms, are described in Section 4.6.2. Details of the model and calculation of the performance metrics can be found in Appendix G. Although the model is not spatially explicit and, therefore, cannot predict changes to plant communities on individual sandbars and channel margin depositional features, acreage changes that are calculated from the currently mapped

extent of each of the modeled community types are presented in this section, based on the modeled increase or decrease in each type.

As noted in Section 4.6.2.2, experimental vegetation treatments would also be implemented that would result in modifications to the riparian vegetation communities in the New High Water Zone. Although these areas may be a relatively small proportion of the riparian area below Glen Canyon Dam, implementation of non-flow actions would result in the reduction of nonnative species populations, including tamarisk, and increases in native species populations on sandbars and channel margin areas. Consequently, the native/nonnative ratios (as well as changes in tamarisk) identified for each alternative in this section would likely be higher with the implementation of non-flow actions under those alternatives. Similarly, the arrowweed metric presented for each alternative would likely be higher with the implementation of non-flow actions under those alternatives.

4.6.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), base operations (i.e., the intervening flows that occur between HFEs or other experimental flow manipulations) are MLFF, the flow regime that was put in place by the 1996 ROD (Reclamation 1996) for the 1995 Glen Canyon EIS (Reclamation 1995). This alternative includes sediment-triggered spring and fall HFEs through 2020 (no spring HFEs until 2016) that would be implemented according to the HFE protocol developed and evaluated in the HFE EA (Reclamation 2011b). Alternative A has higher monthly volumes in the high electricity demand months of December, January, July, and August than in other months. This alternative has fewer spring and fall HFEs than other alternatives, occasional extended low flows, and more frequent extended high flows than most other alternatives, the latter being particularly frequent in the growing season.

Frequent extended high flows would result in a decrease in the native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a). Repeated seasons of extended high flows have been observed to cause the transition of native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). This is supported by modeling results which indicate a 17% (55.2 ac) overall decrease in native plant community cover and 28% (1.3 ac) decrease in wetland community cover.

The frequent extended high flows and few extended low flows (along with few spring HFEs) would tend to remove tamarisk and would be accompanied by a reduced level of establishment of tamarisk (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a), resulting in an overall decrease in tamarisk-dominated communities. Because the decrease in tamarisk modeled (58.4 ac) exceeds the decrease in native community types (55.2 ac), the ratio of native to nonnative community types would be expected to increase by about 5% under Alternative A.

Frequent extended high flows, few spring HFEs, and occasional fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on

results of modeling, Alternative A is expected to result in a 25% (44.5 ac) increase in the arrowweed community type.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3.

In summary, Alternative A would result in beneficial changes associated with an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (5% increase in ratio, 58.4 ac decrease in tamarisk). These benefits could be greater than anticipated, depending on the effects of the tamarisk leaf beetle in the area, but the lack of experimental vegetation treatments included under other alternatives would not provide benefits. However, Alternative A is also expected to result in adverse effects associated with a decrease in native cover (17% overall decrease in native plant community cover; 28% decrease in wetland community cover) and native diversity (2% decrease in native diversity over the LTEMP period due to decrease in wetland communities), and an increase in arrowweed cover (25% increase in cover). Several special status species could be impacted as a result of the continuing decrease in wetland community cover (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing. It is expected that Alternative A would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.2 Alternative B

Alternative B includes spring and fall HFEs (the number of HFEs not to exceed one every other year), with few spring HFEs, similar to Alternative A, but slightly more fall HFEs compared to Alternative A. TMFs are also included in this alternative. This alternative has the same monthly pattern in release volume as the Alternative A; however, due to the large daily fluctuations, Alterative B has no extended low flows and has frequent extended high flows, at a slightly greater frequency compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a); however, the decrease, including wetland decrease, is less (statistically significant) than under Alternative A. Repeated seasons of extended high flows transition native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). This is supported by modeling results which indicate a 15% (48.3 ac) overall decrease in native plant community cover and 20% (0.9 ac) decrease in wetland community cover. Although the amount of native cover would be expected to decrease under this alternative, the diversity of native community types is expected to increase 3%. This alternative would result in a greater area of wet marsh than Alternative A primarily because of a lack of extended low flows that would contribute to a loss of marsh (Sher et al. 2000; Porter 2002).

The frequent extended high flows would result in a tendency to remove tamarisk through repeated effects (consecutive seasons or years) of drowning, limited growth, and depleted energy reserves (Kearsley and Ayers 1999; Stevens and Waring 1986a), and a lack of extended low flows (along with few spring HFEs) would result in a reduced level of tamarisk seedling establishment (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000), resulting in an overall decrease in tamarisk-dominated communities, with there being more of a decrease than under Alternative A. Because of the large decrease in tamarisk-dominated communities modeled (71.4 ac) and smaller decrease in native cover (48.3 ac), the ratio of native to nonnative community types under this alternative would increase 15% and is significantly higher (statistically significant) than that for Alternative A.

Frequent extended high flows, few spring HFEs, and more fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of modeling, Alternative B is expected to result in a 19% increase (33.3 ac) in arrowweed, although at a level less than under Alternative A (however, the difference is not statistically significant).

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. One experimental element, hydropower improvement flows, results in a considerable increase in the frequency of extended high flows, resulting in a greater decrease in native community types (150.1 ac) and tamarisk (107.0 ac) and a slightly greater increase in arrowweed (41.9 ac) (although not a statistically significant difference).

In summary, Alternative B would result in beneficial changes associated with an increase in native diversity (3% increase over the LTEMP period, a higher diversity than Alternative A), and an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (a 15% increase in ratio, a higher ratio than under Alternative A; 71.4 ac decrease in tamarisk, a greater decrease than under Alternative A). These benefits could be greater than anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation treatment restoration experiments. However, Alternative B is also expected to result in adverse effects associated with a decrease in native cover (15% overall decrease in native plant community cover, 20% decrease in wetland community cover; both less of a decrease than under Alternative A) and an increase in arrowweed cover (19% increase in cover, less than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, although the decreases would be less than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing. Although the vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative B would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk. Alternative B would result in higher fluctuation flows, although flows prior to the 1996 ROD (Reclamation 1996) had a much greater daily range than Alternative B (28,500–30,500 cfs; Reclamation 1995). The shift from those flows to MLFF resulted in a general reduction of marsh habitat and an increase in tamarisk and arrowweed, particularly in the upper elevations of the former Fluctuation Zone (Ralston 2005). An increase in fluctuations would not necessarily reverse those trends but would be expected to result in greater marsh area (Stevens et al. 1995)

and potentially less tamarisk and arrowweed than under MLFF of Alternative A. These increases would not be realized under experimental hydropower improvement flows.

4.6.3.3 Alternative C

Alternative C includes spring and fall HFEs that could be triggered by Paria River sediment inputs in all years during the LTEMP period and proactive spring HFEs (24 hr, 45,000 cfs HFE) that would be tested in April, May, or June in high-volume years. Lower fluctuation levels conserve more sediment, and therefore result in more triggered HFEs. As a result, this alternative has a far greater frequency of fall and spring HFEs compared to Alternatives A and B (see Section 4.2). TMFs are also included in this alternative. Alternative C has highest monthly release volumes in December, January, and July, and lower volumes from August through November; volumes in February through June would be proportional to power contract delivery rates. This alternative has a higher frequency of extended low flows compared to Alternative A and far fewer growing or non-growing seasons without extended high or low flows. Although Alternative C generally has fewer growing-season extended high flows than Alternative A, it has a slightly greater frequency of non-growing-season extended high flows.

Repeated high flows have been observed to shift vegetation communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in a lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than that under Alternative A. This alternative has the greatest decrease in native cover of all the alternatives and the second greatest decrease in wetlands (only Alternative F is greater). Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 37% (117.7 ac) overall decrease in native plant community cover and 75% (3.4 ac) decrease in wetland community cover. The diversity of native community types decreases 8% under this alternative is lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) and promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000). Consequently, tamarisk-dominated communities would be expected to increase considerably under Alternative C (104.0 ac, only Alternative F has a greater increase). Because of the large decrease in native community types (117.7 ac), the ratio of native to nonnative community types under this alternative decreases 54% and is significantly lower (statistically significant) than under Alternative A, and is the largest difference between the two alternatives.

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010), while extended low flows contribute to tamarisk replacing arrowweed (Sher et al. 2000; Stevens and Waring 1986a; Porter 2002). Arrowweed would therefore decrease 14 % (25.1 ac) based on results of modeling, under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows and TMFs. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs, combined with proactive spring HFEs, result in twice the tamarisk increase (more bare sand becoming tamarisk rather than arrowweed) and a decrease in arrowweed.

In summary, Alternative C would result in a beneficial change associated with a decrease in arrowweed cover (14% decrease in cover, less cover than the increase under Alternative A). This benefit could be greater than anticipated depending on the effects of the vegetation treatments. However, Alternative C is also expected to result in adverse effects associated with a decrease in native cover (37% overall decrease in native plant community cover, 75% decrease in wetland community cover; both greater decreases than under Alternative A), decrease in native diversity (8% decrease, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (54% decrease in ratio, a lower ratio than under Alternative A; 104 ac increase in tamarisk, greater tamarisk cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover; this is expected to be a larger effect than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative C would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.4 Alternative D (Preferred Alternative)[18]

This alternative includes a variety of HFE types throughout the LTEMP period including: sediment-triggered spring (March–April) and fall (October–November) HFEs; proactive spring HFEs (24 hr, 45,000 cfs) would be tested (April, May, or June) in high-volume years; no spring HFEs in the first two years; and extended-duration fall HFEs (up to 250 hr duration, up to 45,000 cfs), up to four in 20-year period. More even monthly volumes conserve more sediment and therefore result in more triggered HFEs. As a result, Alternative D has a considerably greater frequency of fall and spring HFEs compared to Alternatives A and B (Section 4.3). TMFs are also included in this alternative. This alternative has very few growing-season extended low flows, as well as slightly fewer non-growing-season extended low or high flows, due to the monthly pattern of flows as well as the amount of daily fluctuations. Alternative D has frequent growing-season extended high flows but fewer than under Alternative A. Seasons without extended low or high flows are frequent, especially non-growing seasons.

Frequent extended high flows would result in a decrease in native community types, including wetlands, although less (statistically significant) of a decrease than under Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. A greater frequency of HFEs would tend to slow establishment of shrub wetland on bare sand; extended high flows prevent establishment of this community type (Stevens and Waring 1986a; Porter 2002) and establishment of wet marsh (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010). However, few extended low flows during the growing season would limit the occurrence of wetland communities shifting to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). This is supported by modeling results, which indicate a 12% (39.5 ac) overall decrease in native plant community cover and 16% (0.8 ac) decrease in wetland community cover. The diversity of native community types, a 2% increase, is significantly greater (statistically significant) under this alternative than under Alternative A because of a greater degree of evenness in native community types, as this alternative would result in a greater area of wet marsh than under Alternative A, which has more frequent extended high flows.

Repeated extended high flows, as occur under this alternative, can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. The low number of growing-season extended low flows would limit tamarisk establishment (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). However, spring HFEs and growing-season extended high flows can promote the establishment of tamarisk (Sher et al. 2000; Mortenson et al. 2012). Because the decrease in native community types is greater than the decrease in tamarisk (22.4 ac) based on results of modeling, the ratio of native to nonnative community types under this alternative decreases and is lower than under Alternative A (the difference is statistically significant).

[18] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on vegetation.

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010). The establishment of arrowweed on upper elevation areas is slowed by fall HFEs (Waring 1995). In addition, the low number of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed (Porter 2002). Based on results of modeling arrowweed would therefore decrease 10% (17.1 ac) under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2, 4.6-3, and 4.6-8. Experimental elements of this alternative include low summer flows, TMFs, and low flows for benthic invertebrate production. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs would result in a slightly greater reduction in native cover due to a loss of marsh to arrowweed from occasional extended low flows. Benthic invertebrate production flows do not result in any statistically significant differences in performance metrics.

In summary, Alternative D would result in a beneficial change associated with an increase in native diversity (2% increase, greater diversity than under Alternative A) and decrease in arrowweed cover (10% decrease, lower cover than under Alternative A). These benefits could be greater than anticipated depending on the effects of vegetation treatments. However, Alternative D is also expected to result in adverse effects associated with a decrease in native cover (12% overall decrease in native plant community cover, 16% decrease in wetland community cover; both decreases less than under Alternative A) and a decrease in the ratio of native to nonnative community types (5% decrease in ratio, a lower ratio than under Alternative A; 22.4 ac decrease in tamarisk, less of a decrease than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover (Figure 4.6-4), although this effect would be smaller than under Alternative A. Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation treatment experiment may decrease these adverse effects to some extent, it is expected that Alternative D would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.5 Alternative E

This alternative includes sediment-triggered spring and fall HFEs implemented according to the HFE protocol (Reclamation 1995) with the exception that no spring HFEs would be implemented in first the 10 years. As a result, Alternative E has a greater frequency of HFEs,

particularly fall HFEs, than Alternative A (Section 4.2). TMFs are also included in this alternative. Lower monthly water volumes would occur in August, September, and October. This alternative has frequent growing-season extended high flows but fewer than under Alternative A, and slightly more growing-season extended low flows. The non-growing season frequently has no extended high or low flows.

Frequent extended high flows would result in a decrease in the native community types including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) including wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. These flows, in combination with extended low flows, can result in wetlands transitioning to tamarisk (Sher et al. 2000; Mortenson et al. 2012). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a,b; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 20% (63.5 ac) overall decrease in native plant community cover and 38% (1.7 ac) decrease in wetland community cover. The diversity of native community types under this alternative would decrease and is similar to that under Alternative A.

Repeated extended high flows can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. Because the decrease in native community types modeled (63.5 ac) is greater than the decrease in tamarisk (45.7 ac), the native to nonnative ratio under this alternative decreases 4% and is lower than under Alternative A.

Growing-season extended low flows can result in wetlands becoming replaced by arrowweed (Porter 2002), and non-growing seasons without extended high or low flows combined with growing-season extended low or extended high flows allow arrowweed to become established on bare sand (Waring 1995). Based on results of modeling arrowweed-dominated communities would be expected to increase 25% (44.0 ac) under this alternative, similar to the increase under Alternative A.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows, TMFs, and HFEs. Low summer flows result in a slight increase in extended low flows, as well as a slight increase in extended high flows (due to redistribution of water during other months). However, the effects on riparian vegetation are small and often undetectable in the model results, since low summer flows are relatively infrequent, and do not have a large effect relative to other components of the alternatives. TMFs have little effect on results of this alternative, and HFEs, when absent, result in a smaller decrease in native community types, a greater decrease in tamarisk, and a greater increase in arrowweed (arrowweed establishment on bare sand is slowed by fall HFEs; Waring 1995).

In summary, Alternative E would result in an adverse change associated with a decrease in native cover (20% overall decrease in native plant community cover, 38% decrease in wetland

community cover; both decreases greater than under Alternative A), decrease in native diversity (2%, similar to Alternative A), decrease in the ratio of native to nonnative community types (4% decrease in ratio, a lower ratio than under Alternative A; 45.7 ac decrease in tamarisk, less of a decrease than under Alternative A), and an increase in arrowweed cover (25%, similar to Alternative A). These adverse effects could be less than anticipated, depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation treatment experiment. Several special status species could be impacted as a result of the decrease in wetland community cover, and this effect would be greater than that under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur as a result of HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation treatment experiment within the New High Water Zone (or close to the New High Water Zone where roots may be watered by HFEs) may decrease these adverse effects to some extent, it is expected that Alternative E would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.6 Alternative F

This alternative includes a much greater frequency of spring and fall HFEs than Alternative A and any other alternative (see Section 4.2). Alternative F also features higher volumes than Alternative A in April, May, and June, and lower volumes than Alternative A in other months, with low flows from July through January. This alternative has a far greater number of extended low flows than Alternative A, few seasons without extended high or low flows, and frequent growing-season extended high flows, with slightly fewer extended high flows compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types, including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in lack of establishment of native community types, including wetlands (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 30% (95.0 ac) overall decrease in native plant community cover and 86% (4.0 ac) decrease in wetland community cover. Alternative F results in a greater loss of wetlands than any other alternative due to the frequent extended high flows, the far greater number of extended low flows, and the small number of seasons without extended high or low flows. The diversity of

native community types under this alternative is expected to decrease 9% and is lower (statistically significant) than that under Alternative A and lower than any other alternative, primarily due to the large decreases in wetland community types.

Growing-season extended low flows resulting from low steady flows from July through October can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) as wetlands dry and arrowweed colonizes former wetland areas. Wetlands transition to tamarisk with growing-season extended high flows in combination with extended low flows (Sher et al. 2000; Mortenson et al. 2012). The frequent extended high flows often shift all states to bare sand, which then shifts to tamarisk. Spring HFEs and growing-season extended high and low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002; Mortenson et al. 2012). In addition, tamarisk communities are not expected to transition to other community types under this alternative, and as a result, this alternative would result in the greatest increase in tamarisk of any alternative (230.7 ac). Because of the large decrease in native community types (95.0 ac), the native to nonnative ratio under this alternative decreases 62% and is lower (statistically significant) than under Alternative A.

Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). Extended low flows combined with extended high flows result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Based on results of modeling, Alternative F would result in a 13% (22.2 ac) decrease in the arrowweed community type, with arrowweed cover being lower (statistically significant) than under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative F would result in a beneficial change associated with a decrease in arrowweed (13%, lower cover than under Alternative A). This benefit could be greater than anticipated, depending on the effects of vegetation treatments. However, Alternative F is also expected to result in adverse effects associated with a decrease in native cover (30% overall decrease in native plant community cover, 86% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (9%, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (62% decrease in ratio, a lower ratio than under Alternative A; 230.7 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, and this decrease would be far greater than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain and Lake Mead shoreline special status species and benefit to inactive floodplain special status species. The Old High Water Zone would continue narrowing, although annual

spring HFEs could result in higher survival rates of plants at lower elevations of the zone compared to Alternative A. Although the vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative F would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.7 Alternative G

This alternative includes sediment-triggered spring and fall HFEs, extended-duration fall HFEs (up to 336-hr, 45,000-cfs releases), and proactive spring HFEs in high volume years. Equal monthly volumes and steady flows conserve more sediment, and therefore result in more triggered HFEs. As a result, Alternative G has a far greater frequency of fall and spring HFEs compared to Alternative A and most other alternatives (Section 4.2). Because monthly volumes would be approximately equal, this alternative has a far greater number of extended low flows and fewer extended high flows compared to Alternative A.

Occasional extended high flows (although less frequent than under Alternative A) would result in a decrease in native community types through scouring and drowning, including wetlands, with there being more (statistically significant) of a decrease than under Alternative A. A greater frequency of HFEs and far more extended low flows would result in lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008;Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than under Alternative A. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 29% (93.7 ac) overall decrease in native plant community cover and 58% (2.6 ac) decrease in wetland community cover. The diversity of native community types under this alternative would be expected to decrease 3%, and would be lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows along with an extended high flow can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). Growing-season extended low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs in combination with growing-season extended low flows can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012) or spring HFEs in combination with a growing-season extended high flow (Sher et al. 2000; Mortenson et al. 2012). Consequently, tamarisk-dominated communities would be expected to increase under Alternative G, a 46.4 ac increase based on results of modeling. Because of the large decrease in native community types (93.7 ac), the native to

nonnative ratio under this alternative would decrease (40% decrease) a lower ratio (statistically significant) than under Alternative A.

Extended low flows can contribute to wetlands becoming replaced by arrowweed (Porter 2002), and extended low flows combined with extended high flows can result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002), and growing-season extended high flows contribute to the loss of arrowweed, resulting in bare sand (Kearsley and Ayers 1999; Ralston 2010). Based on the results of modeling, Alternative G would result in a 11% (20.1 ac) decrease in the arrowweed community type, with arrowweed cover being significantly lower (statistically significant) than for Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation camping goals.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative G would result in a beneficial change associated with a decrease in arrowweed (11%, lower cover than under Alternative A). This benefit could be greater than anticipated depending on the effects of the vegetation treatments. However, Alternative G is also expected to result in adverse effects associated with a decrease in native cover (29% overall decrease in native plant community cover, 58% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (3% decrease in native diversity over the LTEMP period, lower than under Alternative A), and reduction in the ratio of native to nonnative community types (40% decrease in ratio, a lower ratio than under Alternative A; 46.4 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover, and this reduction would be greater than under Alternative A (Figure 4.6-4). Temporary impacts on special status floodplain species could occur from HFEs, but the main populations of these species are in habitats away from the river, and recolonization of affected areas is likely. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than under Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although vegetation treatments may decrease these adverse effects to some extent, it is expected that Alternative G would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.7 WILDLIFE

This section addresses the effects of the LTEMP alternatives on wildlife, including special status species.

Issue: How do alternatives affect wildlife species in the project area?

Impact Indicators:

- Change in riparian and wetland wildlife habitats
- Change in aquatic habitats and food base used by wildlife
- Direct effects of HFEs and other flow and non-flow actions on wildlife

4.7.1 Analysis Methods

Models of the effects of alternatives on wildlife populations were not available for use in this analysis. This is, in part, a reflection of the relatively limited amount of quantitative data available on wildlife of Glen and Grand Canyons, which would serve as the basis of such models. Impact assessments are based on previous studies of wildlife in the project area and on the assessments conducted for aquatic ecology (Section 4.5) and vegetation (Section 4.6), because these assessments reflect impacts on terrestrial wildlife habitat and food production upon which wildlife species depend.

Impacts of LTEMP alternatives were evaluated for the following wildlife species groups (impacts on fish and other aquatic species are discussed in Section 4.5):

- Terrestrial invertebrates,
- Amphibians and reptiles,
- Birds,
- Mammals, and
- Special status species.

Impacts of each alternative on these species groups were evaluated based on the following impact indicators:

- Change in riparian and wetland wildlife habitats,
- Change in aquatic habitats and food base, and
- Direct effects of HFEs and other flow and non-flow actions on wildlife.

Other factors that could contribute to impacts on wildlife species and their habitats, such as climate change, defoliation of tamarisk by the tamarisk leaf beetle (*Diorhabda* spp.), noise, and uranium mining, are addressed as cumulative impacts (in Section 4.17.3.6).

4.7.2 Summary of Impacts

As described in Section 3.7, terrestrial wildlife populations in Glen and Grand Canyons are influenced by the availability of suitable habitat, food, and water resources. Of most importance for the analysis of the effects of LTEMP alternatives are those species dependent on riparian, wetland, and aquatic habitats, because these habitats could be directly and indirectly affected by LTEMP alternatives. Habitats above the riparian zone (mostly desert scrub) and the wildlife that inhabit those areas would be unaffected by LTEMP alternatives.

Water release patterns associated with both daily and monthly base operations, and experimental elements, particularly HFEs, are important factors that determine the coverage and characteristics of riparian vegetation and wetlands. Section 4.6 describes the anticipated changes in the characteristics of riparian vegetation communities over the LTEMP period; however, the anticipated impacts of the alternatives on vegetation relate to transitions among plant community types, not to increases or decreases in the amount of riparian and wetland vegetation coverage. None of the alternatives are expected to result in important structural changes in riparian habitat or overall riparian habitat coverage that could have population-level effects on terrestrial wildlife species. As noted in Section 4.5, there has been a net increase in vegetation since construction of the dam and none of the alternatives are expected to reverse these gains. In addition, many of the terrestrial wildlife species that occur in Glen and Grand canyons utilize a variety of terrestrial habitats and are not solely dependent on riparian habitat in general, or on the specific types of riparian vegetation that occur along the river. These factors reduce the potential for impacts of LTEMP alternatives on terrestrial wildlife.

Direct impacts of LTEMP alternatives on terrestrial wildlife species are possible, but these are likely to be short term. Although HFEs could displace less mobile species such as invertebrates, amphibians, and reptiles (Reclamation 2011b), these species can quickly recolonize disturbed areas from adjacent areas; most vertebrate animals that occupy riparian habitats are mobile enough to move in response to fluctuations in flow, and would return shortly after the HFE is over.

A summary of impacts of the LTEMP alternatives on various wildlife groups is presented in Table 4.7-1 and discussed below.

4.7.2.1 Terrestrial Invertebrates

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on terrestrial invertebrates. Invertebrates contribute to the diversity of the riparian corridor of the Colorado River and perform important ecological functions as decomposers, herbivores, predators, and pollinators. In addition, this diverse community of animals is an important component of the prey base of insectivorous vertebrates including fish, frogs, toads, lizards, snakes, songbirds, small mammals, and bats.

TABLE 4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts on wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows; less decline of wetland habitat, however hydropower improvement flows would cause a greater decline of wetland habitat.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat compared to Alternative A.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; least decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; increased production of aquatic insects due to more even monthly volumes could benefit species that eat insects or use nearshore areas, but benefits may be offset by higher within-day flow fluctuations.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas; greatest decline of wetland habitat of any alternative.	Compared to Alternative A, negligible impacts on most terrestrial wildlife species; greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas; greater decline of wetland habitat.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Terrestrial invertebrates	No change from current conditions.	Compared to Alternative A, potentially lower production of insects with aquatic and terrestrial life stages due to higher daily flow fluctuations. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages due to more uniform monthly flows from December through August, lower daily range in flows. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages due to more uniform monthly flows; experimental macroinvertebrate production flows may also increase insect production and diversity. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential slight increase in production due to more uniform monthly flows, but any increase could be offset by higher within-day flow fluctuations. No effect on other terrestrial invertebrates.	Compared to Alternative A, potential increase in production of insects with aquatic and terrestrial life stages resulting from steady flows and relatively high spring flows. No effect on other terrestrial invertebrates.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages of all alternatives. No effect on other terrestrial invertebrates.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians and reptiles	Negligible impact on amphibians and reptiles; some decrease in wetland habitat from current condition, but no change in the stability of nearshore habitats that support adult and early life stages of amphibians and serve as food production areas for amphibians and reptiles. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, potentially lower insect production due to higher daily flow fluctuations. Second lowest wetland loss of any alternative. Hydropower improvement flows would have larger adverse effects on wetlands and food production than Alternative A. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to reduced daily fluctuations. Second highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to relatively even monthly release volumes; experimental macroinvertebrate production flows may increase insect production and diversity. Lowest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Negligible impact, similar to Alternative A.	Compared to Alternative A, increase in habitat stability and insect production in nearshore habitats due to steady flows. Highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. Third highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect terrestrial birds over the long term. HFEs would occur outside of the breeding season of most birds.	Compared to Alternative A, larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on insect-eating birds and waterfowl using nearshore areas. HFEs would occur outside of the breeding season of most birds.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to reduced daily fluctuations. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to more even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.	Similar to Alternative A.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to steady flows. Annual 45,000 cfs spike flow would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.	Compared to Alternative A, conditions would improve for insect-eating birds and waterfowl using nearshore areas due to steady flows and even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season of some species (May), and could affect nesting birds in elevations below 45,000 cfs.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Mammals	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect mammals over the long term. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on semi-aquatic mammals and other mammals using nearshore areas. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Compared to Alternative A, conditions would improve for semi-aquatic mammals and other mammals using nearshore areas due to steady flows and even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

Most invertebrates in the riparian zone obtain their food from terrestrial sources, but the diets of some species (e.g., ground beetles, ants, and spiders) are also subsidized by emerging aquatic insects or by drifting aquatic organisms that become stranded in the varial zone (Paetzold et al. 2006). Some changes in the characteristics of vegetation communities (e.g., changes in diversity) and aquatic habitats may cause localized changes in terrestrial invertebrates (Anderson, B.W. 2012). Terrestrial invertebrates in the riparian zone recovered from the impacts of natural annual historic flood events, and are expected to recover quickly from HFEs (Reclamation 2011b). None of the LTEMP alternatives are expected to result in long-term population-level changes to terrestrial invertebrates.

Differences in the monthly and daily flow patterns of alternatives could affect the production of insects with aquatic and terrestrial life stages (e.g., blackflies, midges, and dragonflies) by affecting the stability of nearshore habitats and the amount of wetted area that supports these insects. Alternatives with more stable flows (Alternatives C, F, and G) and those with more even monthly release volumes (Alternatives C, D, E, and G) are expected to have higher production of these insects because of greater habitat stability; however, any differences among alternatives are expected to be relatively small (Section 4.5). The year-round steady flows of Alternative G are likely to result in the greatest production of these insects, and experimental macroinvertebrate production flows under Alternative D also target increased production and diversity. Although these experimental flows have not been tested, on a conceptual basis, providing steadier flows during important production months should produce more insects.

Experimental actions being considered under different alternatives also could adversely affect or benefit terrestrial invertebrates in the Colorado River corridor. For instance, experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to terrestrial invertebrates. Low summer flows under Alternatives C, D, E, and F could increase production of aquatic insects with terrestrial adult stages. TMFs under Alternatives B, C, D, E, and G are expected to have minor adverse effects on the production of aquatic insects with terrestrial life stages because very low flows that temporarily expose substrates would be very short lived (less than 1 day during a TMF cycle).

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would result in noticeable or measurable changes in invertebrates with only terrestrial life stages. However, alternatives with reduced fluctuations (Alternatives C, D, F, and G) or more even monthly release volumes (Alternatives C, D, E, and G) would have greater nearshore habitat stability, and could result in an increase in the production of insects with both aquatic and terrestrial life stages. Section 4.7.3 addresses the potential impacts on invertebrates under each LTEMP alternative.

4.7.2.2 Amphibians and Reptiles

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on amphibians and reptiles. Glen Canyon Dam operations may affect amphibians (including their aquatic larval stages) and reptiles along the Colorado River corridor, primarily though alterations of riparian

and wetland habitats and effects on aquatic insect production (Dettman 2005). The effects of alternatives on amphibians (frogs and toads) could result from potential changes to wetland habitat and nearshore habitat that supports both adult and early life stages and serves as production areas for aquatic invertebrate prey. The effects of alternatives on reptiles (snakes and lizards) could result from potential changes in riparian vegetation and terrestrial invertebrate prey production. In addition, raised water levels from HFEs may drown some amphibians and reptiles that are unable to escape the rising water (Dettman 2005), or flood habitats used by amphibians and reptiles.

Amphibian and reptile populations along the river have increased under the modified Colorado River flow regime created by operation of Glen Canyon Dam (Section 3.7.2). Operations since completion of the dam have reduced the magnitude of spring floods and subsequently allowed an increase in riparian vegetation colonizing areas previously scoured by annual floods, and allowing the formation of wetlands under variable daily flows, but more consistent monthly flows (Reclamation 1995). Effects of alternatives on these habitats and the amphibians and reptiles supported by them are expected to be relatively small compared to these larger changes from pre-dam conditions.

Amphibians could be affected by the predicted decreases in wetland habitat area over the 20-year LTEMP period. Wetland area along the river corridor downstream of Glen Canyon Dam is limited (approximately 5 ac), making any loss potentially important for species dependent on wetland areas. Based on vegetation modeling presented in Section 4.6, wetland habitat is expected to decline over the LTEMP period under all alternatives, but impacts would be greater under alternatives with steadier flows (Alternatives C, F, and G) than alternatives with higher fluctuations (Alternatives A, B [except with experimental implementation of hydropower improvement flows], D, and E), which provide daily watering of habitats in the varial zone.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect amphibians or reptiles over the long term. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (alternatives with lower within-day fluctuations, such as Alternatives C, F, and G, or more even monthly release volumes, such as Alternatives C, D, E, and G). Lower fluctuations would also result in potential benefits for the survival of amphibian eggs and tadpoles; however, as discussed in the previous paragraph, these alternatives also support less wetland habitat, which is important to amphibians. Lizards and snakes would benefit less from increases in aquatic-based food production because these reptiles are less dependent on these food sources than are amphibians.

In addition to these habitat and food-based impacts, HFEs can directly affect amphibians by disrupting breeding activities and by flushing egg masses and tadpoles from backwaters depending on the time of year in which they occur. Breeding and egg deposition occurs between April and July, with metamorphosis to adult occurring between June and August (Dettman 2005). Thus, any HFEs conducted between April and August (e.g., sediment-triggered spring

HFEs or proactive spring HFEs) are likely to result in some disruption of reproduction and/or mortality (Reclamation et al. 2002). Rising waters have the potential to trap lizards and snakes that are resident below the elevation of HFE flows and drown them or their buried eggs (Warren and Schwalbe 1985). In addition, possible reductions in riparian vegetation (e.g., from scouring) and direct mortality of prey items could lead to a decrease in prey availability (Dettman 2005; Reclamation et al. 2002). These effects are expected to be temporary and not to result in long-term effects on amphibian and reptile populations, because the area affected by scour would be small (below the elevation of 45,000 cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and amphibian and reptile populations in adjacent unaffected areas is expected to occur. Prior to construction of the dam, flooding was an annual natural event in the Grand Canyon from which amphibians and reptiles recovered. Thus, they are expected to quickly recover from individual HFEs (Reclamation 2011b).

Other experiments being considered under different alternatives also could affect amphibians and reptiles in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to amphibians and reptiles. Activities associated with these treatments could disturb amphibians and reptiles in and adjacent to treatment areas, but this should be temporary unless individuals were inadvertently killed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates; this could in turn affect amphibians and reptiles that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on amphibians and reptiles because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on amphibians or reptiles.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect amphibian and reptile populations. However, alternatives could produce changes in nearshore aquatic and wetland habitats occupied by some amphibian and reptile species, and those that serve as important food production areas for them (Table 4.7-1). Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore habitat areas, but these alternatives would provide less support for wetlands than would alternatives with higher fluctuations (Alternatives A, B, and E). Direct impacts from HFEs on amphibians and reptiles are expected to be negligible and temporary. Periodic flooding is a natural phenomenon along rivers; amphibian and reptile species have adapted to flooding and, from an ecosystem maintenance perspective, they are dependent on it. Section 4.7.3 addresses the potential impacts on amphibians and reptiles under each LTEMP alternative.

4.7.2.3 Birds

Riparian birds, many of which are protected under the Migratory Bird Treaty Act, have increased along the river corridor downstream of Glen Canyon Dam in response to an increase in riparian vegetation under dam operations (Brown et al. 1983; LaRue et al. 2001). In general,

birds that use the Grand Canyon corridor temporarily during migration are not affected by Glen Canyon Dam operations; however, birds that breed or overwinter in the riparian zone can be directly and indirectly affected by operations. Table 4.7-1 summarizes the potential effects of LTEMP alternatives on birds.

Changes in riparian and wetland plant coverage can alter foraging and nesting habitats. Even the loss of less desirable vegetation such as tamarisk may have potential negative effects on bird species unless replaced promptly by native woody vegetation (Yard et al. 2004; see also Section 4.17.3.6). The structural complexity of riparian vegetation (e.g., tree, shrub, and ground vegetation layers) and the ecological function they provide is particularly important for many nesting birds (Sogge et al. 1998). Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period, but none of the alternatives are expected to result in significant structural changes in riparian habitat or vegetation productivity that could affect bird populations over the long term.

Differences in the monthly and daily flow patterns of alternatives could affect nearshore foraging areas used by waterfowl and wading birds. As discussed in Section 4.7.2.1, insects with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (those with lower within-day fluctuations or more even monthly release volumes such as Alternatives C, D, F, and G). These changes in food production could result in very minor adverse impacts on birds, in part because most birds forage over broad areas that include habitats outside of the river corridor.

In general, the potential for direct impacts of flows on birds would be greatest during the nesting period when nests could be inundated. Impacts of normal operating flows (between 5,000 and 20,000 cfs) are expected to be negligible because few birds nest in these areas (Sogge et al. 1998), and Brown and Johnson (1985) reported that flows up to 31,000 cfs do not affect the nests of riparian birds. Only flows above the normal operating range, such as HFEs, could affect nesting birds, and only if they occurred during the peak nesting period (May through August) because active nests could be destroyed by these high flows. For shrub-nesting songbirds such as Bell's vireo (*Vireo bellii*) and common yellowthroat (*Geothlypis trichas*), inundation of the ground below nests begins to occur at flows of about 36,000 cfs, and nest losses of 50% or more begin to occur from 40,000 to 62,000 cfs. These species can renest as long as high waters do not persist (Brown and Johnson 1985). The nests of some ground-nesting waterfowl species such as mallards (*Anas platyrhynchos*), gadwalls (*A. strepera*), and American wigeon (*A. americana*) could be more susceptible to HFEs than those of songbirds that nest in riparian vegetation, in part because these species breed earlier in the year when spring HFEs would be implemented. Sediment-triggered spring and fall HFEs would occur outside of the main nesting period for most birds, although proactive spring HFEs considered for testing under Alternatives C, D, and G could occur during the nesting period (April through June). Alternative F features an annual 45,000 cfs spike flow that would occur in May. HFEs outside of the nesting period are expected to only temporarily displace birds within the flood zone, and they are expected to use flooded areas once the high flows recede. Overall, riparian bird populations were unaffected by prior HFEs, so no effects are expected from proposed HFEs (Reclamation 2011b).

Waterfowl that winter in Glen and Grand Canyons would not be present during the months when spring and fall HFEs would most likely occur (March through June and October or November, respectively). Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl.

Other experiments being considered under different alternatives also could adversely affect or benefit birds in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to birds. Activities associated with these treatments could disturb birds in and adjacent to treatment areas, but this should be temporary unless nests were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, which could in turn affect birds that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on birds because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*) and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

In summary, none of the LTEMP alternatives are expected to produce changes in aquatic and riparian habitats that would result in long-term, population-level impacts on riparian bird populations. However, alternatives could produce changes in nearshore habitats that could affect waterfowl and wading birds; Alternatives C, D, F, and G would produce more stable nearshore habitat for these species. Direct impacts from HFEs on birds would be minimal, mostly because the timing of HFEs would occur outside of the peak breeding season. Under Alternatives C, D, and G, proactive spring HFEs would occur in high-volume release years (≥10 maf); these could occur during the peak nesting season (April through June) and result in the loss of some nests. Alternative F also could affect nesting birds, because it features an annual 45,000-cfs spike flow that would occur in May. Section 4.7.3 addresses the potential impacts on birds under each LTEMP alternative.

4.7.2.4 Mammals

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on mammals. Section 4.6 describes changes in the riparian vegetation community types over the LTEMP period, but these are not expected to result in important structural changes in riparian habitat or vegetation productivity that could affect mammal populations over the long term. Differences in the monthly and daily flow patterns of alternatives could have differential effects on the habitat stability of nearshore areas used by semi-aquatic mammals and other mammals using nearshore areas. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives and those with both aquatic and terrestrial

life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in very minor effects on insect-eating mammals, such as shrews, mice, and bats. Riparian vegetation changes during the LTEMP period are not expected to have adverse impacts on habitat or food resources for herbivorous mammals that occupy riparian habitats.

HFEs may have direct impacts on some mammals. Less mobile species such as shrews, mice, and other small mammals may drown, but some individuals would be able to move upslope away from floodwaters. Recolonization of flooded areas would be expected to occur rapidly. Ground nests also could be destroyed. Many small mammals produce multiple litters each year, which may compensate for small mammal losses from an individual HFE (Dettman 2005). No long-term population-level impacts on these mammals are anticipated.

Along the Colorado River, American beavers (*Castor canadensis*) inhabit and raise their young in bank dens, which they create near the water's edge; the lack of high flows allows them to build their dens lower down in the banks. HFEs may drown young or adults in their bank dens (Dettman 2005; Reclamation et al. 2002). HFEs affect muskrats (*Ondatra zibethicus*) similarly (Reclamation 2011b). Young born prior to a spring or proactive spring HFE may drown if they are located below the flood stage and are unable to leave the lodge. Fall HFEs are unlikely to impact the American beaver or muskrat because they would be able to leave their dens and swim to safety (Reclamation 2011b). These species regularly occur in riverine habitats subjected to regular flood flows, and are adapted to these conditions both in terms of their ability to respond to increases in flow and to recolonize areas affected by HFEs.

Large carnivores such as the cougar (*Puma concolor*) would experience minimal impacts from dam operations because they generally have large ranges and can obtain prey from both riparian and upland (desert) communities. Similarly, bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) are highly mobile and use a variety of habitats within the Grand Canyon, including non-riparian habitats (Dettman 2005).

Other experiments being considered under different alternatives also could adversely affect or benefit mammals in the Colorado River corridor. Experimental vegetation treatments (common to most alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to mammals. Activities associated with these treatments could disturb mammals in and adjacent to treatment areas, but this should be temporary unless individuals, nests, or roosts were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect mammals that consume terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on mammals because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on mammals.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect mammal populations. Direct impacts from HFEs on mammals would be negligible and temporary, and no long-term population-level impacts are expected. Section 4.7.3 addresses the potential impacts on mammals under each LTEMP alternative.

4.7.2.5 Special Status Species

Eleven special status wildlife species, listed under the Endangered Species Act, Bald and Golden Eagle Protection Act, or the State of Arizona, are known to occur or could occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead (Section 3.7). Potential impacts on these species from LTEMP alternatives are summarized in Table 4.7-2 and discussed below. A Biological Assessment (BA; see Appendix O) has been prepared for three of these species that are currently listed under the Endangered Species Act (ESA) and that may be impacted by LTEMP operations: Kanab ambersnail (*Oxyloma haydeni kanabensis*), Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*), and southwestern willow flycatcher (*Empidonax traillii extimus*).

The effects of dam operations and HFEs under the LTEMP alternatives are discussed for each special status species below. Other experiments being considered under different alternatives also could adversely affect or benefit these species in the Colorado River corridor. Experimental vegetation treatments (common to all alternatives except Alternative A) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to special status species. Activities associated with these treatments could disturb special status birds and bats in and adjacent to treatment areas, but this should be temporary unless nests or roosts were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect special status species that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on special status species because the flows would last for a 3-month period during the growing season while the low flows of TMFs would be of short duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species.

Section 4.7.3 addresses the potential impacts on the special status species under each LTEMP alternative, including potential impacts of condition-dependent and experimental elements of the alternatives. For species listed under the ESA, Appendix O presents the BA prepared for Section 7 consultation with the U.S. Fish and Wildlife Service (FWS).

TABLE 4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Losses of habitat and individuals of Kanab ambersnail. Decrease in potential wetland habitat for northern leopard frog and Ridgway's rail (Yuma). Sediment-triggered spring HFEs could adversely affect nests of Ridgway's rail (Yuma). No impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar; similar decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma), but greater potential decrease under hydropower improvement flows; sediment-triggered spring HFEs could adversely affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma) compared to Alternative A; proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; least wetland loss of any alternative would minimize habitat loss for northern leopard frog and Ridgway's rail (Yuma); proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma). No impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency could inhibit rebound of the population; similar decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration annual high flow in May could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); annual extended-duration high flow in May could occur during the nesting period of southwestern willow flycatcher; spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.	Compared to Alternative A, losses of habitat and individuals of Kanab ambersnail would be similar, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population; greater decrease in wetland habitat for northern leopard frog and Ridgway's rail (Yuma); proactive spring HFEs could occur during the nesting period of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Ridgway's rail (Yuma); no impacts on other special status wildlife species.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Invertebrates							
Kanab ambersnail (*Oxyloma haydeni kanabensis*) ESA-E; AZ-SGCN	No change from current conditions. The average of 5.5 HFEs and maximum of 14 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise through the early portion of the LTEMP period (HFEs would expire in 2020); some rebound between HFEs and after 2020 would be expected; no impacts would occur on the Elves Chasm population.	The average of 7.2 HFEs and maximum of 10 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the low frequency of HFEs would allow some rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 21.3 HFEs and maximum 40 HFEs could cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 21.1 HFEs and maximum 38 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 17.1 HFEs and maximum 30 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 38.1 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and the annual extended-duration high flow in May would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.	The average 24.5 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population. Riparian vegetation treatments could also contribute to impacts.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians							
Northern leopard frog (*Lithobates pipiens*) AZ-SGCN	Species may already be extirpated downstream of Glen Canyon Dam. Negligible change from current condition. Some decrease in wetland habitat, but no change in the stability of nearshore habitats that support adult and early life stages and serve as food production areas.	Compaed to Alternative A, potentially lower insect production due to higher daily flow fluctuations; hydropower improvement flows would have larger adverse effects on wetlands and food production.	Compared to Alternative A, potential benefit due to an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations, but these benefits could be offset by greater wetland losses.	Compared to Alternative A, potential benefit due to lowest wetland habitat loss and an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations and relatively even monthly release volumes; experimental macroinvertebrate production flows may also increase insect production and diversity.	Compared to Alternative A, potentially lower insect production due to higher daily flow fluctuations; greater wetland loss.	Compared to Alternative A, potential benefit due to an increase in habitat stability and insect production in nearshore habitats due to steady flows, but these benefits could be offset by greater wetland losses.	Compared to Alternative A, year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives; these benefits could be offset by greater wetland losses
Birds							
American peregrine falcon (*Falco peregrinus*) AZ-SGCN	No change from current conditions related to food or habitat availability for the American peregrine falcon.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Bald eagle (*Haliaeetus leucocephalus*) BGEPA; AZ-SGCN	No change from current conditions related to food or habitat availability for the bald eagle.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
California condor (*Gymnogyps californianus*) ESA-EXPN; AZ-SGCN	No change from current conditions related to food or habitat availability for the California condor.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Golden eagle (*Aquila chrysaetos*) BGEPA; AZ-SGCN	No change from current conditions related to food or habitat availability for the golden eagle.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Osprey (*Pandion haliaetus*) AZ-SGCN	No change from current conditions related to food or habitat availability for the osprey.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Ridgway's rail (Yuma) (*Rallus obsoletus yumanensis*) ESA-E; AZ-SGCN	No change from current conditions. Unlikely that nests or suitable habitat would be close enough to the river to be impacted by sediment-triggered spring HFEs that coincide with the nesting period (April and May). Fall HFEs would not occur during the nesting season.	Same as Alternative A.	Compared to Alternative A, greater wetland loss.	Same as Alternative A.	Compared to Alternative A, greater wetland loss.	Compared to Alternative A, greatest wetland loss could adversely affect this species.	Compared to Alternative A, greater wetland loss.
Southwestern willow flycatcher (*Empidonax traillii extimus*) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered HFEs would not occur during the nesting period.	Same as Alternative A.	Proactive spring HFEs could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.	Proactive spring HFEs could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.	Same as Alternative A.	Annual 45,000-cfs high flow could occur during the nesting period, but nests in the Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period. Annual low summer flows could affect the species by drying riparian habitat.	Proactive spring HFEs could occur during the nesting period, but nests inthe Grand Canyon typically located above 45,000-cfs flows; sediment-triggered HFEs would not occur during the nesting period.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) ESA-T(DPS); AZ-SGCN	No impact on the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Mammals							
Spotted bat (*Euderma maculatum*) AZ-SGCN	No impact on current conditions related to food or habitat availability for the spotted bat.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

[a] AZ-SGCN = Arizona Wildlife Species of Greatest Conservation Need; BGEPA = Protected under the Bald and Golden Eagle Protection Act; ESA-E = Endangered Species Act-Endangered; ESA-EXPN = Endangered Species Act-Experimental Population, Non-Essential; ESA-T(DPS) = Endangered Species Act-Threatened (Distinct Population Segment).

Kanab Ambersnail (*Oxyloma haydeni kanabensis*)

Within the Grand Canyon, populations of the Kanab ambersnail occur at Vasey's Paradise and Elves Chasm. Because the Elves Chasm population is located above the 100,000 cfs stage (FWS 2008), this population would not be affected by any of the LTEMP alternatives. At Vasey's Paradise, very little Kanab ambersnail habitat and only a few individuals occur below the 25,000-cfs stage (Meretsky and Wegner 2000; Sorensen 2009). Most Kanab ambersnail habitat is located above the 33,000 cfs stage (Reclamation 2011b). HFEs may scour or inundate portions of Kanab ambersnail habitat (Kennedy and Ralston 2011). The November 1997 test flow of 31,000 cfs scoured 1% (7 m^2) of Kanab ambersnail habitat (FWS 2008). HFEs of 45,000 cfs cause a temporary loss of as much as 17% (119 m^2) of Kanab ambersnail habitat (FWS 2008). Surveys conducted after HFEs revealed no population-level declines in the Kanab ambersnail population (Kennedy and Ralston 2011). Kanab ambersnails can survive up to 32 hours underwater in cold, well-oxygenated water (FWS 2011c); so as long as they are not washed away, they could survive inundation from the short-term HFEs. The effects of extended-duration HFEs (up to 250 hr in length) proposed under Alternatives C, D, and G, and the extended-duration high flow in May under Alternative F are not known, but they could pose a greater threat to Kanab ambersnail habitat within the area affected by 45,000-cfs flows.

Recovery of ambersnail habitat scoured by HFEs can take 2.5 years (Sorensen 2009). Therefore, frequent HFEs or extended-duration HFEs may result in long-term loss of ambersnail habitat that occurs below the 45,000-cfs flow level (FWS 2011c). However, the snails survived and persisted through natural pre-dam floods and the 1983 high flows (Reclamation 1995), which were much larger in magnitude and duration than HFEs proposed under the LTEMP, so HFEs may not represent a substantial threat to the persistence of the Kanab ambersnail (Kennedy and Ralston 2011).

Northern Leopard Frog (*Lithobates pipiens*)

Only one population of northern leopard frogs, located within the Glen Canyon National Recreation Area (GCNRA), has been recorded along the Colorado River between Glen Canyon Dam and Lake Mead. However, individuals have not been observed at this location since 2004 (Drost 2005), and it is possible this population has been extirpated.[19] If the species still occurs in Glen Canyon, operations and experiments under the LTEMP alternatives could affect it by affecting the extent of wetland habitat, production of terrestrial invertebrates, or the stability of nearshore habitats potentially used by adults and early life stages. As discussed in Section 4.6.2.2, alternatives could produce changes in nearshore aquatic and wetland habitats. Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore areas and provide higher quality habitats for adults and early life stages of the leopard frog, but Alternatives C, E, F, and G would provide less support for wetlands than

[19] In 2013, GCNRA, Grand Canyon Wildlands Council, FWS, and AZGFD began collaborating to restore northern leopard frog habitat at Leopard Frog Marsh (RM -9.0). In 2016, a northern leopard frog reintroduction plan was developed and may be implemented in the next 1–2 years.

would alternatives with higher fluctuations (Alternatives A and B) or Alternative D, which would result in the least wetland loss of any alternatives.

American Peregrine Falcon (*Falco peregrinus*)

Any impacts on the American peregrine falcon from dam operations are likely to be indirect, possibly through influences on the distribution and abundance of aquatic and terrestrial macroinvertebrate populations, which in turn would influence the availability of prey such as swifts, other songbirds, bats, and—in winter—waterfowl (Holmes et al. 2005). However, based on the evaluations presented in Sections 4.7.2.1 (invertebrates) and 4.7.2.3 (birds), differences among alternatives are expected to be small and not affect the abundance of food available to peregrine falcons. No effects of alternatives on foraging habitats (riverine, riparian, and desert areas) or roosting and nesting habitats (cliffs) are anticipated.

Bald Eagle (*Haliaeetus leucocephalus*)

Bald eagles migrate through and overwinter in Marble Canyon and the upper half of the Grand Canyon. There is no evidence that bald eagle abundance is directly affected by river flows (Holmes et al. 2005). During low river flows, bald eagles can capture and scavenge proportionally more prey from isolated pools and nearshore habitats. Inundation of these habitats during high flows reduces or eliminates prey availability (Brown et al. 1989). During the winters of 1990 and 1991, bald eagle foraging in the river, nearshore, and isolated pool habitats of the Colorado River decreased to 0% at flows >20,000 cfs; foraging in adjacent creek habitat increased to 100% (Brown et al. 1998). These observations demonstrate the ability of eagles to respond to changes in foraging conditions by moving to more favorable areas nearby. Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of eagles to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on the bald eagle, because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. Alternatives would have no effect on habitats used for roosting (cliffs or trees). Wintering and migrant bald eagles are generally not present during the months in which spring and fall HFEs would occur (Sogge et al. 1995).

California Condor (*Gymnogyps californianus*)

California condors are opportunistic scavengers that consume carcasses of mammals, birds, and fishes. Along the Colorado River corridor in Glen and Grand Canyons, they utilize cliff locations for roosting, and beaches when drinking, resting, preening, and feeding (Section 3.7). No impacts on the California condor are anticipated from LTEMP activities.

Golden Eagle (*Aquila chrysaetos*)

Golden eagles are rare to uncommon residents and rare fall migrants throughout the region (Gatlin 2013). None of the alternatives are expected to impact golden eagles, because they nest on cliff edges and primarily feed on upland terrestrial wildlife. Indirect effects of LTEMP alternatives on the abundance of mammals and other prey items within the narrow riparian zone would be negligible, because the home range of the golden eagle can be over 300 km^2 (NatureServe 2014). No impacts on the golden eagle are anticipated from LTEMP activities.

Osprey (*Pandion haliaetus*)

Ospreys typically occur along the Colorado River during their fall migration (August–September), although a nesting pair successfully fledged young in 2014, 2015, and 2016 near the dam (Section 3.7). Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of osprey to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. There would be no effect of alternatives on habitats used for roosting (cliffs or trees) or nesting. Section 4.7.3 addresses the potential impacts on the osprey under each LTEMP alternative.

Ridgway's Rail (Yuma) (*Rallus obsoletus yumanensis*)

The Ridgway's rail (Yuma) inhabits marshes dominated by emergent plants. Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrushes along margins of shallow ponds with stable water levels (FWS 2014c). It is only a casual visitor to marshy mainstem riparian habitats along the Colorado River downstream of Separation Canyon (e.g., RM 227 and 246 and near Burnt Springs). The only confirmed nesting was reported in 1996. Its occurrence along the Colorado River in the affected area only was documented once suitable habitat was created through dam construction (FWS 2014c). Other than predation, the main threats to the rail include habitat destruction, primarily due to stream channelization and drying and flooding of marshes resulting from water flow management (FWS 2014c). Sediment-triggered spring or proactive spring HFEs under Alternatives C, D, and G, and annual 45,000-cfs releases under Alternative F could cause inundation of rail nests or habitat, although it is unlikely that nests or habitat would be close enough to the river to be affected. All alternatives would have spring HFEs, but these are expected to be less frequent for Alternatives A, B, and E. Fall HFEs would not coincide with the nesting period of the Ridgway's rail (Yuma). Low summer flow experiments under Alternatives C, D, and E are not expected to have long-term effects on potential Ridgway's rail (Yuma) habitat. Wetland habitat loss under Alternatives C, E, F, and G could affect this species.

Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The southwestern willow flycatcher nests and forages in habitats ranging from dense, multi-storied riparian vegetation (such as cottonwood/willow stands with a mix of trees and shrubs) to dense tamarisk stands with little layering of vegetation. However, changes in the availability of suitable habitat may not necessarily translate into changes in the southwestern willow flycatcher populations. Despite the abundance of woody riparian vegetation (e.g., tamarisk) since construction of the Glen Canyon Dam, numbers of nesting southwestern willow flycatchers in the Grand Canyon have declined since the 1980s and no nests have been confirmed in the Grand Canyon since 2007. Nest surveys conducted between Lees Ferry and Phantom Ranch and between Diamond Creek and Pearce Ferry in 2008 detected no nests. No other nest surveys were conducted between 2008 and 2012 (Stroud-Settles et al. 2013).

The effect of HFEs on the southwestern willow flycatcher depends on whether the HFE enhances or substantially reduces riparian habitat at potential breeding sites (Holmes et al. 2005). All alternatives include sediment-triggered spring HFEs; Alternatives C, D, and G include proactive spring HFEs in May or June that coincide with the nesting period of the southwestern willow flycatcher. Alternative F features an annual 45,000-cfs spike flow that also coincides with the nesting period. However, southwestern willow flycatchers nests in the Grand Canyon have typically been located above the elevation of 45,000-cfs flows (Gloss et al. 2005), and thus may not be affected by the HFEs that would be implemented under the LTEMP alternatives. Most spring HFEs would occur prior to nest initiation for the southwestern willow flycatcher and would have no direct impact on the species. Fall HFEs occur long after nesting and fledging dates of the southwestern willow flycatcher (see Appendix O).

In addition to HFEs, lower flows during the May to August nesting period can have a negative effect on southwestern willow flycatchers by drying riparian habitat (Reclamation 2007d). Normal operations under most alternatives would have monthly average flows of 10,000 cfs or more during the nesting period, except for Alternative F, with low steady flows in summer through winter (July through February), and during the experimental implementation of low summer flows under Alternatives C, D, and E. Under these three alternatives, there is the potential for some dewatering of nesting habitat. Only under Alternative F could these impacts be long term, because low summer flows would occur annually under this alternative; low summer flow experiments under Alternatives C and D would occur relatively infrequently and are not expected to have long-term effects on nesting habitat.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect the southwestern willow flycatcher.

As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages, are not expected to be affected differentially by alternatives, and those invertebrates with both aquatic and terrestrial life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in negligible impacts on the southwestern willow flycatcher.

In summary, only Alternative F is expected to produce changes in riparian habitats (through regular low summer flows) that would affect the southwestern willow flycatcher. Direct impacts from HFEs on nesting flycatchers are not anticipated, mostly because the timing of HFEs would be outside of the peak breeding season, but also because nests are typically at elevations above that of a 45,000-cfs flow. Alternatives C, D, F, and G could have high flows that occur during the peak nesting season; proactive spring HFEs under these three alternatives would occur in high volume release years (≥10 maf). Alternative F features an annual 45,000-cfs spike flow that would occur in May.

Western Yellow-Billed Cuckoo (*Coccyzus americanus occidentalis*)

The western yellow-billed cuckoo occurs at a number of sites in the lower Grand Canyon, near the Lake Mead delta where mature cottonwood forests are located. It requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory; the large caterpillars on which it feeds depend on cottonwoods and willows (Section 3.7). It is a rare restricted transient in dense tamarisk thickets, with a few observations in the Lees Ferry reach (Spence et al. 2011). Cottonwood/willow habitats that support the western yellow-billed cuckoo are not expected to be affected by any of the LTEMP alternatives.

Spotted Bat (*Euderma maculatum*)

Most spotted bats occur in dry, rough desert shrublands or in pine forest communities. These habitats are all located well above the river corridor and the area potentially affected by Glen Canyon Dam operations. Their roost sites, including hibernacula, do not occur within the area along the Colorado River affected by daily operations and HFEs. Only negligible adverse effects on insects, the prey base for the spotted bat, would occur under any of the alternatives, and the spotted bat can feed within upland areas that would not be impacted by LTEMP operations. The spotted bat is not expected to be affected by any of the LTEMP alternatives.

4.7.3 Alternative-Specific Impacts on Wildlife

This section describes alternative-specific impacts on wildlife, including special status wildlife species. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.6.2. Tables 4.7-1 and 4.7-2 summarize the potential impacts of all alternatives on wildlife and special status wildlife species, respectively.

4.7.3.1 Alternative A (No Action Alternative)

Changes in riparian habitats under Alternative A would not result in noticeable or measurable changes in invertebrates with only terrestrial life stages (Table 4.7-1). Because aquatic food base productivity under Alternative A would be similar to current conditions

(Table 4.5-1), the contribution of aquatic insects with a terrestrial adult stage to the prey base for wildlife that consume invertebrates will also remain unchanged.

Changes in riparian habitats under Alternative A would not affect amphibian, reptile, bird, or mammal populations, but some amphibians and other wetland-dependent species could be affected by wetland habitat decline expected under Alternative A (Section 4.7.2). The higher flow fluctuations under Alternative A, which provide daily watering of habitats in the varial zone, would limit wetland habitat loss. The effects of HFEs on reptiles and amphibians are expected to be temporary and not result in long-term population effects because the area affected would be small (below the elevation of 45,000-cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and by amphibians and reptiles following HFEs are expected to occur rapidly from nearby unaffected areas.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect bird populations over the long term. HFEs under Alternative A would occur outside the main nesting period of birds and are expected to only temporarily displace birds within the flood zone. Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl. Potential effects of HFEs, although negligible, would not occur after 2020 under Alternative A.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect mammal populations over the long term. HFEs could cause the direct loss of individuals belonging to less mobile species (e.g., small mammals). Recolonization of flooded areas would be expected to occur rapidly. High reproductive rates of most small mammals may compensate losses. HFEs, which would only occur through 2020, may also cause the loss of some individual American beavers and muskrats, but long-term population-level effects are not anticipated (Section 4.7.2.4). Minimal impacts are expected for bats and large mammals.

Impacts of Alternative A on special status wildlife species are summarized in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. HFEs could cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise population of the Kanab ambersnail. Some rebound from the losses would occur between HFEs or after 2020, when HFEs would expire. No impacts are expected on the Elves Chasm population. A 28% decrease in wetland habitat may cause a change in potential habitat of the northern leopard frog (which may already be extirpated downstream of Glen Canyon Dam) and Ridgway's rail (Yuma) (which has not been observed nesting in the area since 1996).

In summary, under Alternative A, there would be little or no change from current conditions for most wildlife species, including special status species, with the exception of a potential impact on amphibians and other species dependent on wetland habitats, including the northern leopard frog and Ridgway's rail (Yuma). HFEs could cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise population of the Kanab

ambersnail. Some rebound from the losses would occur between HFEs or after 2020, when HFEs would expire. There would be no impacts on other special status wildlife species.

4.7.3.2 Alternative B

Impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1), but there would be less impact on wetland habitat (i.e., 20% decrease compared to 28% for Alternative A), except with the implementation of experimental hydropower improvement flows, which could cause an 83% decrease in wetland habitat. There would be slightly more HFEs under Alternative B (mean of 7.2 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by HFEs, but these impacts are not expected to result in long-term population-level effects. Higher daily flow fluctuations would reduce nearshore habitat stability, especially with experimental hydropower improvement flows, and could lower production of insects with aquatic and terrestrial life stages, and impact amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or utilize nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative B on special status wildlife species are presented in Table 4.7-2. As under Alternative A, no impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A, although riparian vegetation treatments could occur on rare occasions near or within habitat at Vasey's Paradise, which could disturb some individuals and habitats. Larger negative wetland and food production losses from hydropower improvement flows under Alternative B may have greater effects on the northern leopard frog (which may be already be extirpated downstream of Glen Canyon Dam) and the Ridgway's rail (Yuma) (which has not been observed nesting in the area since 1996).

In summary, impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A. Higher fluctuations under Alternative B would reduce nearshore habitat stability and result in lower production of aquatic insects, which could impact species that eat insects or use nearshore areas. Experimental implementation of hydropower improvement flows would result in adverse impacts on wetland habitat. There would be some losses of habitat and individuals of Kanab ambersnail associated with HFEs comparable to those under Alternative A, but riparian vegetation treatments could affect individuals and habitat. There would be no impacts on other special status wildlife species.

4.7.3.3 Alternative C

Impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (75% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative C (mean of 21.3 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs; however, these impacts are not expected to result in long-term population-level effects. More uniform monthly flows from December through August under Alternative C compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. In addition, an increase in habitat stability of nearshore habitats compared to Alternative A may result from lower within-day fluctuations. Both increases in insect production and nearshore habitat stability may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative C on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs could adversely affect Kanab ambersnail and Ridgway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard frog and Ridgway's rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although the species generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring HFEs would occur outside the nesting period of the southwestern willow flycatcher. Experimental low summer flows under Alternative C could result in drying of some nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on this habitat.

In summary, impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes and lower fluctuations under Alternative C would provide more stable nearshore habitats and result in higher production of aquatic insects compared to Alternative A, potentially benefitting wildlife that eat insects and use nearshore areas. Compared to Alternative A, Alternative C is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitat). There would be no impacts on other special status wildlife species.

4.7.3.4 Alternative D (Preferred Alternative)[20]

Impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a smaller loss of wetland habitat (16% decrease compared to a 28% decrease), which could benefit wetland-dependent amphibians, reptiles, and birds; Alternative D has the lowest expected wetland loss among all alternatives. There would be more HFEs (mean of 21.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. More uniform monthly flows throughout the year under Alternative D compared to Alternative A would provide more stable aquatic habitats and may increase the production of insects with aquatic and terrestrial life stages. Experimental macroinvertebrate production flows may also increase production and diversity of aquatic insects with terrestrial life stages. More stable nearshore habitat and insect production may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron, and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative D on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs compared to those under Alternative A could affect Kanab ambersnail and Ridgway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. There would be less wetland habitat loss under this alternative, thus reducing impacts on northern leopard frog and Ridgway's rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although the species generally nests above the area that are inundated by 45,000-cfs flows. Sediment-triggered HFEs would occur outside the nesting period for the species. Experimental low summer flows could result in drying of some of nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes under Alternative D would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to Alternative A, potentially benefiting species that eat insects or use nearshore areas. Experimental macroinvertebrate production flows could also increase insect production. Compared to Alternative A, Alternative D is expected to result in a lower impact on northern

[20] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on wildlife.

leopard frog (less wetland loss), and Ridgway's rail (Yuma) (less wetland loss), but greater impact on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), Ridgway's rail (Yuma) (HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.7.3.5 Alternative E

Impacts of Alternative E on most terrestrial wildlife would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a slightly greater loss of wetland habitat under Alternative E (38% compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative E (mean of 17.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects. More uniform monthly flows may increase production of aquatic insects compared to Alternative A, but this may be offset by higher within-day flow fluctuations, which would reduce habitat stability. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative E on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, southwestern willow flycatcher, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. Greater wetland habitat loss under Alternative E could affect the northern leopard frog and Ridway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. Sediment-triggered HFEs would occur outside the nesting period for the southwestern willow flycatcher. Experimental low summer flows could result in drying of some nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative E on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly flows under Alternative E would provide greater nearshore habitat stability and result in higher production of aquatic insects, and potential benefits for species that eat insects, but these benefits may be offset by higher within-day fluctuations. Compared to Alternative A, Alternative E is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma), and southwestern willow flycatcher

(wetland loss and HFE effects on habitat). There would be no impacts on other special status wildlife species.

4.7.3.6 Alternative F

Impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (86% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. Wetland habitat loss would be higher for Alternative F than for all other alternatives. There would be more HFEs under Alternative F (mean of 38.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects; their frequency under this alternative would be comparable to the frequency of annual floods in the pre-dam river. Steady flows and relatively high spring flows under Alternative F compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. This, in addition to an increase in habitat stability of nearshore habitats compared to Alternative A, may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas.

Impacts of Alternative F on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. Impacts on the Kanab ambersnail would be similar to those under Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. The relatively large decrease in wetland habitat compared to other alternatives may affect the northern leopard frog and Ridgway's rail (Yuma). The annual 1-day 45,000-cfs flow in May could affect nesting habitat of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered HFEs would not occur during the nesting period of the southwestern willow flycatcher. Annual low summer flows under Alternative F could result in drying of some nesting habitat, and could have long-term effects on southwestern willow flycatcher nesting habitat.

In summary, impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative F would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to Alternative A, and would benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative F is expected to result in minor impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (high spring flow and low summer flow effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.7.3.7 Alternative G

Impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (58% decrease compared to a 28% decrease), which could affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative G (mean of 24.5 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. Year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages. These conditions may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron and belted kingfisher, because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative G on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, California condor, golden eagle, osprey, spotted bat, and western yellow-billed cuckoo. More frequent HFEs and extended-duration HFEs could affect Kanab ambersnail and Ridgway's rail (Yuma). Riparian vegetation treatments could occur on rare occasions near or within habitat of the Kanab ambersnail at Vasey's Paradise, which could disturb some individuals and habitats. Greater wetland habitat loss compared to Alternative A could affect northern leopard frog and Ridgway's rail (Yuma). Proactive spring HFEs could occur in May and June, affecting nesting habitat of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring and fall HFEs would not occur during the nesting period of the southwestern willow flycatcher.

In summary, impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative G would provide greater nearshore habitat stability, result in higher production of aquatic insects, and benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative G is expected to result in minor adverse impacts on Kanab ambersnail (HFE and riparian vegetation treatment effects on habitat), northern leopard frog (wetland loss), Ridgway's rail (Yuma) (wetland loss and HFE effects on nests), and southwestern willow flycatcher (proactive spring HFE effects on nesting habitats). There would be no impacts on other special status wildlife species.

4.8 CULTURAL RESOURCES

4.8.1 Compliance with Federal Regulations

Issue: How do the alternatives affect the preservation of cultural resources in Glen Canyon and Grand Canyon?

Impact Indicators:

- Erosion of terraces in Glen Canyon that support cultural resources
- Visitor effects on cultural resources
- Wind transport of sediment to protect resource-bearing terraces
- Flow effects on the Spencer Steamboat

The National Historic Preservation Act (NHPA) of 1966 (as amended) requires that federal agencies take into account the effects of their undertakings on historic properties. Historic properties are defined in the NHPA (16 U.S.C. 470w[5]) as any "prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion on, the *National Register of Historic Places*, including artifacts, records, and material remains related to such a property or resource." Cultural resources, in general, include archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties (TCPs), ethnographic resources, and museum collections. They also include locations and objects that are important for American Indian Tribes for maintaining their culture. (Other resources of importance to Tribes are addressed in Section 4.9.)

Based on the analysis of direct, indirect, and cumulative effects for this EIS, up to 220 historic properties have been identified that could be affected by the LTEMP. These historic properties fall within the Grand Canyon River Corridor and the Lees Ferry Lonely Dell Historic Districts discussed in Section 3.8 or the "rim-to-rim" TCP identified in Section 3.9.6. Most of these sites are situated on or within terraces located in the river corridor that are above the modern inundation zone, but that could receive windblown sediment from lower elevation areas that are regularly inundated by river flows or could be exposed by bank retreat or sediment depletion.

4.8.2 Analysis Methods

The alternatives being evaluated in this EIS differ in the way Glen Canyon Dam would be operated under each over the next 20 years. The resource goal for cultural resources is to maintain the integrity of *National Register*-eligible or listed cultural resources in place, where possible, with preservation methods employed on a site-specific basis. There is the potential for the alternatives to affect cultural resources along the river corridor downstream of Glen Canyon Dam via differing flow patterns or non-flow actions. This section focuses on two specific types of historic properties: archeological sites and historic districts; Section 4.9 focuses on other resources that are specifically important to Tribes. Section 4.9 also discusses other resources that are important to Tribes as contributing elements to their TCPs, but which may not qualify for listing on the *National Register* independently. The variables considered include direct flow effects (i.e., erosion of river margin sediments, deposition of sediments along the river margin,

and inundation of sites), indirect effects (i.e., changes in the availability of sediment for redistribution by wind, erosion resulting from reduced sediment availability), and cumulative effects. The analysis relied on both quantitative and qualitative information to determine the potential effects of each of the alternatives. Three indicator metrics (1 in GCNRA and 2 in GCNP) were identified to describe the relative differences among the alternatives in order to evaluate the range of potential impacts on cultural resources.

For this analysis, cultural resources, as described in Section 3.8, that are potentially affected by Glen Canyon Dam operations are archeological resources (including historic and prehistoric structures and districts), TCPs, and ethnographic resources. While museum objects are defined as cultural resources, there are no effects or differences in effects on these classes of resources from the alternatives and will therefore not be discussed in the text. Impacts on cultural landscapes are not discussed separately, but any impacts on other resources (e.g., vegetation, wildlife, and sediment) are considered to have an effect on the landscape.

The physical attributes of cultural resources are nonrenewable and, if lost, irreplaceable. The primary concern is to minimize the loss or degradation of culturally significant material. Cultural resources analyzed within the Grand Canyon River Corridor Historic District and the Lees Ferry and Lonely Dell Ranch Historic District include artifact scatters, dwellings (both prehistoric and historic), resource collection areas, food preparation (roasting and food processing) activity areas, horticultural areas, and petroglyph and pictograph panels, collectively representing more than 12,000 years of human history.

Direct flow effects from releases from Glen Canyon Dam are most noticeable in the river reach immediately below the dam. This is primarily because this reach has little sediment input to help buffer the river terraces, and to a lesser degree because the affected resources are found in closer proximity to the Colorado River in this reach. In GCNP, most affected resources are located on terraces that are primarily affected indirectly by dam operations. Over time, flows and climatic conditions could affect the terraces on which archeological sites are located.

An indicator of flow effects that was considered in the analysis is the erosion of elevated terraces in the Glen Canyon reach, which was evaluated using a flow effects metric for Ninemile Terrace, because this site is a good proxy for similarly situated sites. In general, repeated inundation of the toe of a terrace could produce slumping of the terrace face, which could destroy or destabilize the cultural resources within or on the terrace deposits. The toe of Ninemile Terrace is estimated to be inundated when flows reach 23,200 cfs. The flow effects metric considered the frequency of when flows under the various alternatives reach levels that could create conditions that could result in terrace edge slumping and, ultimately, how they could affect the archeological sites within or on the terraces. The results of the metric were expressed as the number of days per year that the maximum daily flow would be >23,200 cfs under each alternative. See Appendix H for additional information on the flow effects metric.

Another historic property in the Lees Ferry and Lonely Dell Ranch Historic District of GCNRA, which was considered when assessing direct flow effects under the alternatives, is the Spencer Steamboat site, which lies within the Colorado River channel. Although the flow effects metric did not reveal any appreciable difference among alternatives in effect on the Spencer

Steamboat, impacts are still possible under the 20-year duration of the LTEMP from repeated exposure to high flows and repeating cycles of inundation and exposure. The wet-dry cycling resulting from fluctuations in lower flow levels contributes to the deterioration of structural elements. Flow levels that expose the steamboat also increase the potential for impacts from visitation and the accumulation of debris resulting in damage to fragile remains.

Visitor effects are frequently noted at many of the archeological sites along the river; these include the moving or theft of artifacts on archeological sites and the defacing of inscriptions, pictographs, and petroglyphs. A metric, visitor time off river, was developed to characterize how the various alternatives could influence the frequency at which archeological sites could be visited by people on river trips. The metric considered flow rates under the various alternatives during the summer months, when the number of visitors on the river is at its highest. The metric reflects the degree to which, due to the flows under an alternative, visitors would be able to spend more time exploring off of the river, which could result in more cultural resources being visited and possibly affected. See Appendix H for additional information on the time off river metric.

Erosion poses a threat to maintaining the condition of many of the archeological sites in both GCNRA and in GCNP. Any actions that help retain sediment are considered to have a potentially positive effect on maintaining the condition of archeological sites in the Canyons because they aid in maintaining the river corridor landscape and site stability. Most of the archeological sites along the Colorado River are located on terraces that represent the river terraces of the predam river system. Prior to construction of the dam, the terraces would have been directly affected by flooding on a 7–10 year return interval (Topping et al. 2003), and many contain flood deposits indicating they were flooded during or after occupation (see Schwartz et al. 1979; Bright Angel Site). The persistent removal of sediment from the system is a long-term effect on cultural resources resulting from the presence of the dam and will continue under all alternatives. Dam operations that decrease sediment-rich high flows, that increase the elevation and duration of low flows, and that promote the expansion of riparian vegetation all decrease sediment availability in the system for transport by wind (East et al. 2016). Sediment availability in the system for transport by the wind is therefore linked to alternatives that include more HFEs (which deposit sediment in locations that may allow for transport by the wind) and sediment retentive flows (East et al. 2016). Sediment availability in the system for transport by wind is also linked to alternatives that include longer duration low flows that expose bare, dry sand within the active river channel and make it available for windblown transport (East et al. 2016). Similarly, alternatives that reduce or reverse the expansion of riparian vegetation onto bare sand also increase sediment availability in the system for transport by wind (East et al. 2016). As discussed in Section 3.8, research has shown that sediment within the active river channel and/or deposited by HFEs can be transported by the wind to terraces and source-bordering aeolian deposits that contain historic properties (East et al. 2016). That wind-deposited sediment can help stabilize and preserve the archaeological properties in place (East et al. 2016). Sediment can also be removed from archaeological sites by wind and rain, factors that could lead to loss of integrity of a historic property (East et al. 2016; Collins et al. 2016). The actual extent to which current sediment levels can stabilize the archeological sites on the terraces remains unknown and would be determined through the LTEMP experimental period.

A wind transport of sediment index addresses the potential for sediment to be transported by the wind to the terraces along the river which contain hundreds of archeological sites. The metric reflects when conditions exist for movement of sediment by wind, and therefore the potential exists for cultural resources to receive sand and potentially be protected, under each alternative. Optimal conditions for wind transport of sediment occur when (1) fine sediment is deposited by flows above the stage of normal operations, and (2) low flows occur during the windy season (March–June), which exposes dry sand for potential redistribution by the wind. The metric used the sand load index and a flow factor which captures the frequency of low flows in the spring for each alternative. See Appendix H for additional information on the wind transport index. There would be a great deal of variability from site to site throughout the system with regard to the amount of sand deposited upwind by HFEs and the exposure of sediment at varying flows.

Another element incorporated into the alternatives is non-flow vegetation management efforts. All of the alternatives except for Alternative A incorporate non-flow vegetation management efforts (Section 4.6). Vegetation removal could increase erosion near an archeological site, or create more open sand upwind of an archaeological site, which could facilitate wind transport and deposition of sediment onto terraces and archaeological sites (East et al. 2016). The effect of non-flow vegetation management is not considered in the alternative-specific discussions because any vegetation management efforts would be coordinated with the cultural resources managers and would therefore not be anticipated to affect known cultural resources.

Each of the alternatives has the potential to affect cultural resources. These effects can be beneficial, meaning the alternative results in increased stability or preservation of cultural resources, or they can be adverse when an alternative results in destabilization of these resources. It is also possible that the alternatives would have no additional effect beyond those already occurring. The effects of alternatives could differ due to varying frequency, timing, and magnitude of daily flows, HFEs, and of the intervening flows between HFEs.

4.8.3 Summary of Impacts

Although the alternatives vary significantly in how water is released from Glen Canyon Dam within a year, the range of effects alternatives would have on cultural resources is expected to be minimal (Table 4.8-1), in part because annual water release volumes among alternatives would be nearly identical and cultural resources are dependent upon landform stability, a consideration that is primarily controlled by the amount of sediment in the system. The majority of cultural resources would not be inundated under any alternative, but some sites could experience indirect effects. Appendix H provides the results for each of the quantitative metrics considered in this analysis.

It has been noted that the potential for degradation of terrace stability at Ninemile Terrace is currently estimated to begin at 23,200 cfs when flows can begin to erode the toe of the terrace (Baker 2013). Erosion of the toe of a terrace can undermine the stability of the terrace and lead to slumping, as was noted after the 1996 HFE (Baker 2013), a 168-hr 45,000-cfs flow. This single

TABLE 4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions regarding the slumping of terraces in Glen Canyon during HFEs (Glen Canyon flow effects index [GFEI] = 22.7); availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (wind transport of sediment index [WTSI] = 0.16); stability of Spencer Steamboat; and visitor time off river (time off river index [TORI] = 0.82).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); no change in stability of Spencer Steamboat or visitor time off river. Experimental hydropower improvement flows would increase the potential for slumping compared to Alternative A (1.6% increase in GFEI and decrease the availability of windblown sand (-9.5% decrease in WTSI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (137% increase in WTSI); negligible effect on stability of Spencer Steamboat or visitor time off river (<1% change in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (96% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (88% increase in WTSI); negligible effect on stability of Spencer Steamboat; increase in visitor time off river (8.9% decrease in TORI).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI), increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI); negligible effect on stability of Spencer Steamboat; decrease in visitor time off river (2.1% increase in TORI).

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Cultural Resources in Glen Canyon							
Erosion of terraces in Glen Canyon that support cultural resources (GCFEI)[a]	No change from current conditions which may contribute to slumping of terraces in Glen Canyon (GFEI = 22.7).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (1.5% increase in GFEI); experimental hydropower improvement flows would increase the potential for slumping (1.6% increase in GFEI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (4.4% decrease in GFEI)	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (3.1% increase in GFEI).	Compared to Alternative A, decrease in the potential for slumping of terraces in Glen Canyon (6.4% decrease in GFEI; lowest impact alternative).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon due to sustained high flows in the spring (62% increase in GFEI; highest impact alternative).	Compared to Alternative A, increase in the potential for slumping of terraces in Glen Canyon (8.7% increase in GFEI).
Spencer Steamboat	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended high flows on the Spencer Steamboat are not known, but potentially increase the risk of degradation.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known, but potentially increase the risk of degradation.

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Cultural Resources in the Grand Canyon							
Wind transport of sediment to high-elevation cultural resources (WTSI)[b]	Negligible influence on windblown sediment (WTSI = 0.16 out of 1); some benefit from HFEs until 2020 when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020 (highest impact alternative).	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (7.5% increase in WTSI); some benefit from HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (137% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (139% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (96% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (88% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period.	Compared to Alternative A, increase in the availability of sand for wind transport to protect stability of archaeological sites in the Grand Canyon (193% increase in WTSI) resulting from increase in frequency of HFEs over entire LTEMP period (lowest impact alternative).
Visitor effects on cultural resources (TORI)[c]	Negligible effect on visitor time off river (TORI = 0.82 out of 1).	Compared to Alternative A, no change in visitor time off river.	Compared to Alternative A, negligible change in visitor time off river (<1% change in TORI).	Compared to Alternative A, decrease in visitor time off river (1.6% increase in TORI).	Compared to Alternative A, decrease in visitor time off river (1.9% increase in TORI).	Compared to Alternative A, increase in visitor time off river (8.9% decrease in TORI) mostly resulting from high flows in spring (highest impact alternative).	Compared to Alternative A, decrease in visitor time off river (2.1% increase in TORI; lowest impact alternative).

Footnotes on next page.

TABLE 4.8-1 (Cont.)

[a] The Glen Canyon flow effects index (GFEI) represents the average number of days flows would be higher than 23,200 cfs during the 20-year LTEMP period. Higher values indicate a higher likelihood of slumping of terraces in Glen Canyon and greater impact on cultural resources that occur on those terraces. See Appendices B and H for a description of the index.

[b] The wind transport of sediment index (WTSI) is a 0 to 1 index that represents the potential for operations over the 20-year LTEMP period to provide conditions that are favorable for windblown transport of sediment to high-elevation terraces in the Grand Canyon that support archaeological sites. Any sand blown to these sites could reduce the erosion potential of those sites. A value of 0 indicates that there is no potential for windblown sediment transport (greatest impact); a value of 1 indicates that conditions are best for windblown sediment transport (lowest impact). See Appendices B and H for a description of the index.

[c] The time off river index (TORI) is a 0 to 1 index that represents the potential for operations over the 20-year LTEMP period to provide conditions that increase the amount of time whitewater rafters would have to explore nearby archaeological sites during the day. A value of 0 indicates that there is the greatest potential for time of river (greatest impact); a value of 1 indicates that there is the least potential for time off river (lowest impact). See Appendices B and H for a description of the index.

event demonstrated that terrace bank erosion may occur as flow elevations increase, during the period of peak high flow, and following the decrease of high flows to normal operational levels. Under most of the LTEMP alternatives, the greatest flows would be 45,000-cfs flows lasting for 96 hr (Section 4.3); these would be comparable to or less than flows that have occurred historically that resulted in slumping. The only alternatives in which this duration could be exceeded are Alternatives D and G. Alternatives D and G allow for longer duration HFEs (up to 250 and 336 hr, respectively) when there is adequate sediment. However, flows will reach the lower threshold of 23,200 cfs under all alternatives. Under most alternatives, HFEs would be limited in magnitude and duration, but the cumulative effect of more than one HFE in a year and in sequential years is not known, and could result in an even higher risk of slumping compared to the effects of individual HFEs.

The results from the Glen Canyon flow effects metric are shown in Figure 4.8-1. Alternative A most closely represents the current operational conditions. Under the metric, Alternative F would have the highest number of days per year; flows would be >23,200 cfs with an average of 14 days per year more than under Alternative A. Alternative F, therefore, has the highest potential for impacts on terraces that contain cultural resources in Glen Canyon. The higher number of days under Alternative F results from the relatively high spring flows between May and June (Section 2.3.6). The remaining alternatives have an average number of days per year where flows would be >23,200 cfs within 4 days of those under Alternative A.

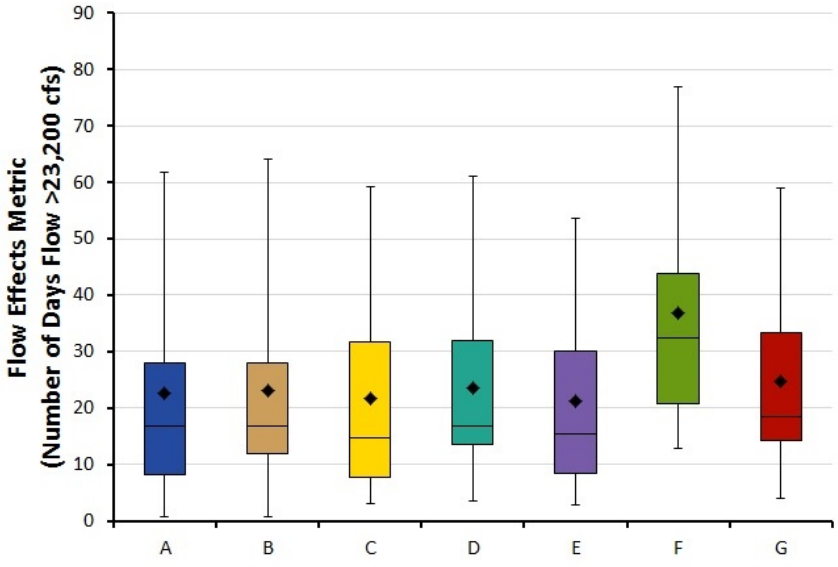

FIGURE 4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives (letters). (Flows of this magnitude have the potential to affect cultural resources in Glen Canyon. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Although there are differences among alternatives in the number of HFEs, these differences have little effect on the number of days per year flows would be >23,200 cfs. This is because HFEs are relatively brief, and the large volume released under the HFE must be compensated for by releasing less water, which results in lower flows, at other times of year. Since all alternatives must release the same annual volume of water, alternatives with HFEs may have lower releases at other times of years than those without. The effect on the metric would be greater in years of high volume (≥10 maf) when equalization flows would be implemented according to the Interim Guidelines (Reclamation 2007a).

A persistent source of impacts on cultural resources is visitors (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013). The effects being identified include the moving of artifacts on archaeological sites and the defacing of inscriptions, pictographs, and petroglyphs. The LTEMP does not incorporate any specific recommendations or policies concerning visitors under any alternatives. The Colorado River Management Plan (CRMP) is the primary document addressing visitor policies related to cultural resources in GCNP (NPS 2005a). Because LTEMP alternatives do not alter any policies concerning visitors, they do not differ with respect to any direct effect caused by visitors on cultural resources. Visitor effects are discussed under cumulative impacts.

An indirect effect related to visitor disturbances to cultural resources concerns the amount of time boaters have off river to explore and potentially interact with archaeological sites. More time would be available when flows are higher during the tourist season (June–September), and this factor could vary among alternatives. Analysis determined that the time off river index for most alternatives did not vary much (<2%) among current conditions (Alternative A). However, Alternative F has higher flows during May and June, so it could provide for more time off river during those months; these higher flows are offset by lower flows in July, August, and September, when time off river would be less than for other alternatives. Overall, the time off river index under Alternative F was lower (8.9% lower than Alternative A), indicating that visitors could spend more time off river than under Alternative A.

The Spencer Steamboat, located in GCNRA, could be directly affected by flows. The steamboat lies in the river, is part of the Lees Ferry/Lonely Dell Ranch National Historic District, and has been subject to all past dam releases, including HFEs (2012, 2013, and 2014), extended-duration HFEs (1996), low flows (2002), fall steady flows (2011–2013), and higher fluctuation flows (pre-1992). Although the site appears to be receiving an ongoing accumulation of sediment, which is beneficial for site preservation, ongoing monitoring has demonstrated that the wet-dry cycling resulting from fluctuations at low flow levels has caused the most obvious and persistent impacts on the site, as predicted by Carrell (1987). The recent installation of submerged monitoring stations (Pershern et al. 2014) will allow the opportunity to systematically evaluate the nature and origin of sediment accumulating at the site, and determine how that mechanism of transport may be influenced or affected by dam operations. Because the proposed flows do not exceed or vary greatly from past flows, similar effects are anticipated under any of the alternatives. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The results from the wind transport of sediment index under the various alternatives are shown in Figure 4.8-2. This index represents the potential for wind to transport sand from channel-margin sandbars to high elevation terraces in the Grand Canyon, which could in turn reduce erosion and stabilize archaeological sites in these terraces. Historic properties contained within the Grand Canyon River Corridor Historic District are most susceptible to both aggregation and erosion of sand, which could create adverse or beneficial effects as explained in Section 4.8.2. Alternative G scores the highest of all the alternatives, with an average index value nearly three times greater than Alternative A. Alternative G has the highest number of HFEs and the lowest maximum daily flows during the windy months. Alternative G has parameters that are ideal for wind transport of fluvial sediment to terraces that contain cultural resources. The second highest scoring alternative is Alternative D. Alternatives A and B scored the lowest on this index.

On the whole, the wind transport of sediment index is highly correlated to the number of HFEs and the corresponding sand load index. The relationship between the sand load index and HFEs is discussed in Appendix E. The wind transport of sediment index is highly correlated to the sand load index because the average maximum discharge between March and June for each of the alternatives is within 5,000 cfs. With minimal difference in flow, the amount of sediment for distribution becomes the determining factor for the index. The exception to this is Alternative F. Although Alternative F was determined to have the second highest potential sand

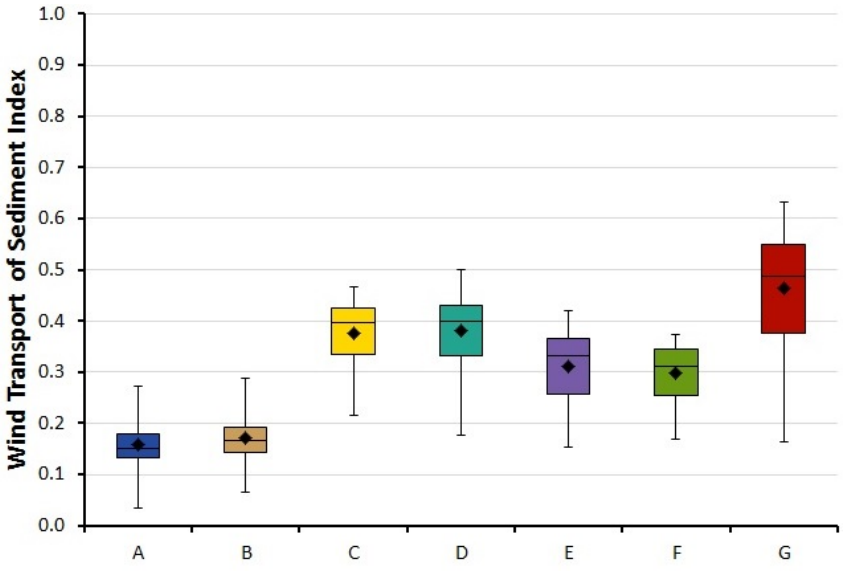

FIGURE 4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives (letters) (Values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

deposition (second highest sand load index, only less than Alternative G), it ultimately has an average index value lower than Alternatives C, D, E, and G because larger discharges of water create less ideal conditions for wind transport.

4.8.4 Alternative-Specific Impacts

4.8.4.1 Alternative A (No Action Alternative)

Dam operations under Alternative A are expected to continue to contribute to conditions that could affect terraces that contain cultural resources in Glen Canyon. Observations in Glen Canyon noted that effects on the toe of the resource-bearing terrace at Ninemile Terrace begin with flows above 23,200 cfs (Baker 2013). Under Alternative A, flows could exceed 23,200 cfs and create conditions that could affect the stability of resource-bearing terraces. However, based on no significant deterioration of the Ninemile site since the 1996 flows, the effects of HFEs and interim operations on terraces in Glen Canyon under Alternative A would not be expected to change from current conditions. However, the cumulative effects of daily flows and the lack of sediment availability remain factors which could affect the stability of the terraces and continue to create the potential for effects as identified under the current MLFF operation. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, sandbar building that would result from HFEs under Alternative A could provide windblown sediment to high terraces; however, based on observations of existing conditions, this effect is expected to be small and would be reduced after HFEs were discontinued under this alternative in 2020. Alternative A is not expected to significantly improve the stability of archaeological sites.

In summary, operations under Alternative A could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under current conditions. Operations under Alternative A are not expected to significantly improve the stability of archaeological sites in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.2 Alternative B

Dam operations under Alternative B are not expected to have additional effects on terraces that contain cultural resources in Glen Canyon. Daily fluctuations under Alternative B would be higher than under Alternative A. In addition, experimental hydropower improvement flows under this alternative could result in daily flows of 25,000 cfs between December and February, as well as between June and August. However, these wider daily fluctuations are not expected to result in increased erosion rates because the alternative results in only a slight

increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows >23,200 cfs) compared to Alternative A, which would result in a minor increase in the potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

It is anticipated that there will be some increase in the amount of sediment available for wind transport under Alternative B; both Alternatives A and B are expected to have approximately the same number of HFEs. Alternative B is expected to have a smaller beneficial effect from windblown sediment in the Grand Canyon relative to other alternatives that have more frequent HFEs. With hydropower improvement flows, there is expected to be a minor decrease with respect to wind transport compared to Alternative A.

In summary, operations under Alternative B could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. Operations under Alternative B are not expected to significantly improve the stability of archaeological sites in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.3 Alternative C

Dam operations under Alternative C are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative C would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the 1996 HFE of 168 hr, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative C would not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs; thus, there is no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The amount of sediment available for wind transport in the Grand Canyon under Alternative C is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from lower daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and after HFEs.

In summary, operations under Alternative C could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There

would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.4 Alternative D (Preferred Alternative)[21]

Dam operations under Alternative D could result in some additional destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 250 hr) that would be implemented as an experimental treatment in years when large inputs of sediment from the Paria River occur. No more than four extended-duration HFEs would be implemented during the LTEMP period under Alternative D. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative D would result is a slight increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in a slightly increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative D is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from more even monthly release volumes, and proactive spring HFEs in wet years.

In summary, operations under Alternative D could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.8.4.5 Alternative E

Dam operations under Alternative E are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative E would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative E do not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs),), which would result in no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects

[21] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on cultural resources.

of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative E is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period (although fewer than under Alternatives C, D, F, and G).

In summary, operations under Alternative E could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be negligible. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.8.4.6 Alternative F

Alternative F is expected to have additional effects on terraces that contain cultural resources in Glen Canyon because there would be an increase in the number of days when the bases of terraces in GCNRA would be inundated. Flows in May and June would be sustained at higher levels under this alternative, resulting in an increased number of days in wetter years when the bases of the terraces would be inundated, compared to Alternative A. Although HFEs would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the bases of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative F would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

Dam operations under Alternative F would allow faster travel times for boaters in May and June; therefore, boaters would have additional time off river to visit cultural resources during those months. This increase would be offset by the effects of lower flows in July–September. Alternative F is the only LTEMP alternative that, based on the analysis, could have any influence on visitor effects.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative F is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period and increased sediment retention from low steady flows throughout much of the year. However, the highest flows under Alternative F are in May, which reduces the potential for wind transport of sediment to terraces during this windy period.

In summary, operations under Alternative F could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat; there could be a small increase in the visitor time off river in May and June, which could result in increased visitation and potential damage to cultural resources.

4.8.4.7 Alternative G

Dam operations under Alternative G could result in some destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 336 hr) that would be implemented in years when large inputs of sediment from the Paria River occur. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative G would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In the Grand Canyon, the amount of sediment available for wind transport under Alternative G would be greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention from steady flows throughout the year, and proactive spring HFEs in wet years. Alternative G has the lowest spring operational flows when windy conditions are most typical. These factors create the best conditions under any of the alternatives for wind transport of sediment to the terraces.

In summary, operations under Alternative G could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in the Grand Canyon. There would be a small decrease in the amout of time off river and subsequent effects on cultural resources, but no change from current conditions with respect to the stability of Spencer Steamboat.

4.9 TRIBAL RESOURCES

Assessing the comparative impacts of the LTEMP alternatives on Tribal resources presents a challenge both because of the Tribes' holistic view of the Canyons, in which all things are interconnected, and because there is no single "Tribal view" held by all members of all Tribes. The holistic view encompasses most of the subject areas considered in this EIS and perspectives of the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes on these resources are found throughout the document.

The values placed by these Tribes on the river and its Canyons are significant and real but may be intangible; thus, they are not easily quantifiable. In addition, many of the values and resources most important to the Tribes are not directly affected by the proposed action as defined by operational patterns of water releases from Glen Canyon Dam.

Issue: How do alternatives affect Tribal resources in Glen, Marble, and Grand Canyons?

Impact Indicators:

- Health of the ecosystem including vegetation, wildlife, fish, and wetlands
- Water rights
- Condition of traditional cultural places

Issue: How do alternatives affect the sacred integrity of and Tribal connections to the Canyons?

Impact Indicators:

- Stewardship and educational opportunities
- Independent access to Canyons
- Number of nonnative fish removed each year
- Economic opportunity
- Incorporating traditional knowledge into the LTEMP EIS

4.9.1 Tribal Resource Goals

As discussed in Section 3.9, the Tribes that have the closest ties to the Canyons and are most actively involved in the LTEMP EIS process are the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes. Eight important themes or values relative to the Colorado River and its Canyons emerged from meetings, workshops, and webinars held with individual Tribal representatives and from reviewing ethnographies and Canyon monitoring reports produced by or for the Tribes. These have been identified as Tribal resource goals for the LTEMP EIS and grouped according to whether they can be represented quantitatively and whether they would be differentially affected by alternative management practices at or related to the operation of Glen Canyon Dam. An initial evaluation was made based on Tribal sources, and the Tribes were afforded the opportunity to review and provide input.

For this discussion, Tribal resources are divided into two categories: (1) traditional cultural places—those elements with fixed and defined locations, and (2) traditional cultural resources—resources that are either widely scattered or mobile, such as riparian vegetation, birds, mammals, and fishes. For many Tribes, resources in these two categories may be considered TCPs or contributing elements to a TCP and may be differently affected by flow and non-flow elements of the seven LTEMP alternatives.

4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons

Tribes such as the Hopi express their perception of the state of the Canyons in terms of the Canyons' health (Yeatts and Huisinga 2003, 2006, 2009, 2010, 2011, 2012, 2013). For the Hopi, natural elements and resources are significant for creating a culturally significant, harmonious landscape. Without them, the landscape would not be whole. These resources, because they are either widely scattered or mobile, rather than existing in a fixed location, may be considered traditional cultural resources.

In general, the affected Tribes are concerned with the state of the Canyons as a whole. The determination of Canyon health from a Tribal point of view can be complex and can vary from Tribe to Tribe. For example, a recent survey of Hopi Canyon monitors showed that most respondents found the Canyons to be in good health, or at least better taken care of than in the past, in part because of Hopi participation in the adaptive management process by monitoring important sites such as the salt mine, and because of the offerings made in the Canyons by Tribal members (Yeatts and Huisinga 2013). Some aspects of Canyon health are quantifiable and parallel or reflect values that have been expressed by the Tribes or their representatives. These include riparian plant diversity, wetland abundance, and characteristics of native fish populations considered here. The interest of the Tribes extends beyond these measures to impacts on other aspects of Canyon health explored elsewhere in this chapter, including natural processes (Section 4.4), aquatic ecology (Section 4.5), vegetation (Section 4.6), wildlife (Section 4.7), hydropower (Section 4.13), and environmental justice (Section 4.14).

The Western concept of ecosystem has much in common with the Tribes' view of their place in an interconnected natural world. Plant communities form a fundamental aspect of any ecosystem, and vegetation health is an indicator of ecosystem health. Metrics for vegetation community diversity and wetland abundance in the riparian zone most directly affected by flow management at the Glen Canyon Dam have been developed based on the results of an existing state and transition model developed by GCMRC for Colorado River riparian vegetation downstream of Glen Canyon Dam; this is described by Ralston et al. (2014) and in Appendix G and discussed in Section 4.6.1. The metrics are on a scale relative to starting conditions where a higher value means greater vegetation community diversity or wetland abundance relative to starting conditions.

A healthy ecosystem from a Tribal perspective is characterized by a high degree of species diversity, represented here by diversity in vegetation community types. The model projects transitions over the 20-year LTEMP period for each alternative analyzed. During discussions with the Tribes, they often expressed their view that all forms of life have value, whether native or nonnative. To take this perspective into account, evaluation of diversity included nonnative (primarily tamarisk) as well as native vegetation, including the invasive arrowweed. The analysis indicated that all alternatives on average would result in a decrease in total vegetation diversity over the 20-year LTEMP period.

The loss in diversity would be greatest under Alternatives C, F, and G. Under these alternatives, the acreage occupied by the invasive tamarisk increases (Table 4.9-1). Alternatives under which tamarisk[22] would increase are characterized by spring high flows (HFEs or ≥30 days with flows >20,000 cfs), which serve to distribute seed, followed by low flows in the growing season (May–September) which would allow seedlings to establish themselves. Alternative B results in the least loss of diversity, followed by Alternatives A, D, and E. Under these alternatives, the area covered by tamarisk decreases.

Another indicator of Canyon health is the abundance of wetlands in the riparian zone. Although they make up only a small part of the riparian area of the river corridor (4.6 acres, or 0.5% of total area of all vegetation types), wetlands include plants of medicinal and cultural significance to some Tribes (Jackson et al. 2001) that continue to be harvested with care (Yeatts and Huisinga 2006). The Hopi generally see the marshes as healthy and well taken care of, but there is some indication in the Tribal monitoring reports that cattail and reed marshes are decreasing in size and number and that cattails are decreasing in number (Yeatts and Huisinga 2013).

TABLE 4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover

Alternative	Mean Diversity Score[a]	Change in Tamarisk Cover (ac)
A	0.95	−58.4
B	0.97	−71.3
C	0.75	104.0
D	0.94	−22.4
E	0.93	−45.7
F	0.70	230.7
G	0.83	46.4

[a] Higher values of diversity indicate better condition relative to other alternatives. A value less than 1 indicates an expected reduction in diversity relative to current conditions over the 20-year LTEMP period. A value greater than 1 indicates an expected increase in diversity.

22 The model takes into account the effects of scouring, drowning, desiccation, and sediment deposition, but does not account for the effects of the tamarisk leaf beetle or tamarisk weevil. These two insect species are expected to result in a reduction in the amount of live tamarisk in the river corridor.

Based on the vegetation models discussed in Section 4.6, the change in abundance was determined for each of the wetland community types (common reed wet marsh and willow/baccharis/horsetail wetland). Wetlands would expand under hydrologic regimes that lack extended periods of high flows (≥30 days with maximum daily flows >20,000 cfs) and extended low flows (≥30 days with maximum daily flows <10,000 cfs), but are maintained with occasional extended high flows (in many cases) or HFEs and an absence of extended low flows during the growing season. Alternatives that include frequent extended low flows, such as the annual flows for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases under Alternative F.

The state of aquatic life in the Canyons is discussed in Section 4.5. Section 4.5.2 presents a summary of projected impacts on native and nonnative fishes and the aquatic food base. These projections correlate well with recent results from the Hopi monitoring program, which found the native fish populations in the Canyons, particularly the humpback chub, to be healthy (Yeatts and Huisinga 2013).

Impacts on riparian and terrestrial wildlife are discussed in Section 4.7.2. Impacts on indicators of wildlife and habitat health are expected to be limited, with no major differences among the alternatives. Alterations in riparian vegetation and the aquatic food base are not expected to be sufficient to adversely affect amphibians and reptiles over the long term; however, alternatives could produce changes in near-shore aquatic and wetland habitats that are important to amphibians and that serve as important food production areas for both amphibians and reptiles (Section 4.7.2.2). The distribution of woody riparian vegetation is not expected to vary enough under any alternative to disrupt the migration of riparian bird species or to have noticeable differences in impacts on species that nest in riparian vegetation; however, alternatives could produce changes in shoreline habitats that could affect waterfowl and wading birds (Section 4.7.2.3). Impacts on mammals such as muskrat and beaver would be negligible under all alternatives (Section 4.7.2.4). Larger mammals such as deer and bighorn sheep are mobile and able to adjust their use of different habitats along the corridor. Impacts on bighorn sheep under all alternatives are expected to be negligible (Section 4.7.2.4). A recent Hopi monitoring report found birds, mammals, insects, and snakes in the Canyons all to be healthy (Yeatts and Huisinga 2013).

4.9.1.2 Protect and Preserve Sites of Cultural Importance

Sites of cultural importance to the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes include archaeological sites, places associated with traditional narratives of Tribal identity, rock writing, sacred places, offering sites, springs, and traditional resource collection areas. Individually or collectively, these may be referred to as traditional cultural places. These places may also be contributing elements to a TCP such as the "rim-to-rim" TCP described in Section 3.9.6.

Expected effects of the alternatives on archaeological sites and historic properties are discussed in Section 4.8. Other cultural resources associated with specific locations are likely to

experience the same types of impacts as those on archaeological sites. Those Tribes that regularly monitor the condition of culturally important sites and resources in the Canyons most often list intentional and unintentional damage to sites from visitors to the Canyons as the prime threat to site integrity. Reported damage includes trailing, trampling, removal of vegetation, disturbance of artifacts, vandalism, and disruption of the sacred context through inappropriate behavior (Section 4.9.1.4). Bank erosion and inundation are mentioned less frequently in the monitoring reports. The majority of visitors to the river corridor arrive by boat. Higher flows have faster currents, so boaters travel more quickly between campsites, leaving more time to explore off-river, which could lead to more visitation of cultural sites and a greater potential for damage. Modeling of visitor time off the river indicates that there is almost no difference in expected amount of time off river among the LTEMP alternatives, with the exception of Alternative F. Under this alternative, boaters could spend slightly more time off the river in May and June when flows are relatively high and steady. Overall, impacts on these sites of importance are not expected to vary significantly as a result of visitation among the alternatives.

For the Fort Mojave Tribe, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Tribes, all water is sacred and the places where it emerges from the ground as seeps and springs are particularly sacred. Tribal members travel to sacred springs in the Canyons to retrieve water for ritual use in their own communities (Dongoske 2011b; Jackson-Kelly et al. 2013). Warm mineral springs, such as Pumpkin Springs, are sacred and their waters are considered therapeutic (Austin et al. 2007). The Tribes are concerned with the purity of these sacred waters and exercise stewardship over them, which can include appropriate prayers and offerings at the springs and along sacred trails that lead to them. The Hopi largely consider the springs to be healthy, as a result of their having access to the springs and being able to perform appropriate stewardship activities (Yeatts and Huisinga 2009). Occasionally, spring sources, such as Pumpkin Springs, may take on a murky, polluted appearance and an HFE is welcome in order to flush out the muck and algae that have accumulated. This may disrupt access for a short amount of time, but water levels return to normal within a few weeks. During consultation, the Tribes that monitor Tribal resources in the Canyons—Hopi, Hualapai, Navajo, Southern Paiute, and Zuni—all have expressed more concern with damage to the springs and disrespect for the sanctity of the waters by non-Tribal visitors to the Canyons than with inundation resulting from flow management. Hopi monitoring reports suggest that the health of the springs is largely unaffected by the operation of Glen Canyon Dam. Overall, adverse impacts on springs and seeps from operation of Glen Canyon Dam are expected to be negligible, while the HFEs have some benefit.

Some adverse impacts can be mitigated through education and communication. All of the Tribes with ties to the Canyons are affiliates of Native Voices on the Colorado River (https://nativevoicesonthecolorado.wordpress.com), and many have their own outreach programs developed to educate visitors to the Canyons regarding Tribal histories and affiliations with the Canyons. This is discussed further in Section 4.9.1.4. Mitigation of potential effects on resources of Tribal concern will be subject to ongoing consultation.

4.9.1.3 Preserve and Enhance Respect for Canyon Life

For those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni TCP. In addition, Pueblo of Zuni have identified significant social and psychological effects to their community during mechanical removal periods. For example, between 2003 and 2006, when the initial mechanical removal efforts occurred at the confluence of the Little Colorado and Colorado Rivers, the Zuni reported an increase in the use of taser guns by Zuni police on Zuni community members. The Zuni view this as a direct adverse effect on the Zuni community from mechanical removal events (Panteah 2016). The Zuni expressed their view on this subject in Section 3.9.6. In the past, the Zuni have expressed a willingness to consult with Reclamation in good faith in "seeking and reaching agreement with the Zuni to avoid, reduce, compensate for, or otherwise mitigate any adverse effects" (Zuni Tribal Council 2010).

Reclamation and the NPS are committed to continue to consult with the Tribes regarding nonnative fish control. Reclamation committed in agreements with Tribes in 2012 to consider live removal when feasible (Reclamation 2012b); however, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. Reclamation and the NPS have worked with the Tribes to determine a beneficial use of the removed fish on other projects and understand that what is considered beneficial use may not be the same for all Tribes. Reclamation and the NPS are committed to consult further with the Tribes to determine acceptable mitigation for nonnative fish control.

The purpose of trout management activities is to enhance the survival of the endangered humpback chub by reducing the numbers of trout in the river. Reducing the trout population would reduce competition with and predation on young-of-the-year chub near the confluence with the Little Colorado River from trout moving downstream from reaches just below Glen Canyon Dam (Section 4.5). Two forms of trout management have been proposed: TMFs and mechanical removal. Each is being considered as a management action that may be triggered when trout and/or chub populations are at specified levels. Trout management is included in all alternatives except Alternative F, and mechanical removal is only possible under Alternative A until 2020 (see Appendix J).

A TMF is a highly variable flow pattern of water releases at Glen Canyon Dam intended to control the number of young-of-the-year trout in the Glen Canyon reach of the Colorado River and, subsequently, the migration of trout to downstream areas such as the confluence of the Little Colorado River (Chapter 2). A typical TMF would consist of several days at a relatively high

sustained flow (e.g., 20,000 cfs) that would prompt young fish to move into the shallows along the channel margins and, depending on the time of year, would prompt spawning fish to construct redds and lay eggs in nearshore shallow areas. The high flows would be followed by a rapid drop to a low flow (e.g., 5,000 cfs), stranding young-of-the-year trout and, depending on the time of year, possibly exposing the eggs, thus preventing them from hatching. With the exception of Alternatives C and D, under which TMFs could be implemented early in the LTEMP period even if not triggered by predicted high trout recruitment, TMFs may be triggered during years in which trout recruitment in the Glen Canyon reach is anticipated to be high. Under each of the alternatives in which TMFs are included, they would initially be conducted as experiments; they would be implemented only if they prove to be successful in reducing the trout population in the Glen Canyon reach. In general, TMFs would most likely be triggered when spring HFEs, which can stimulate the food base and thus trout production, are followed by relatively high steady summer flows. Where the number of HFEs is limited, as in Alternative B, it is expected that TMFs would be triggered in fewer years. Modeling indicates TMFs would be triggered most often under Alternative G. If TMFs prove successful, they would reduce the number of times mechanical removal would be triggered.

Mechanical removal would employ electrofishing to stun and remove nonnative fish. Usually, the removed fish would then be euthanized and put to some beneficial use. For example, in one mechanical removal test, the trout were emulsified and used as fertilizer in the Hualapai Tribal gardens (Reclamation 2011a). In their Comprehensive Fisheries Management Plan, the NPS committed to put all removed nonnative fish (including trout) to beneficial use through human consumption (NPS 2013e). GCMRC has modeled the number of years in which mechanical removal would be triggered under various alternatives. In general, mechanical removal would be triggered in far fewer years than TMFs. In general, when TMFs are projected to be triggered in more years, mechanical removal of trout would be triggered in fewer years. Modeling indicates that under Alternative G (the alternative under which the most TMFs would be triggered), mechanical removal would never be triggered in more than 7 years out of 20.

With regard to fish management, the Tribes have expressed a preference for letting nature take its course rather than intervening to mitigate the consequences of past actions. For example, the Zuni have suggested that it could be that the emergence of whirling disease in trout is nature's way of tempering out-of-balance fish dynamics. The Zuni and Hopi have questioned the trout's level of impact on the humpback chub population and have urged additional studies of this relationship before undertaking the large-scale removal of fish (Zuni Tribal Council 2010; Yeatts and Huisinga 2013). For them, TMFs and mechanical removal are both offensive and would be considered an adverse effect on the Grand Canyon TCP. Likewise, the Hopi Tribe "recommends that efforts to understand what are the limiting factors for the humpback chub (both habitat issues in mainstem and Little Colorado River, and the life stage(s) where mortality rate is limiting) continue to be a focus of aquatic research. In addition, management actions such as the translocation should be continued as long as they are continuing to be successful" (Yeatts and Huisinga 2012).

4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons

The preservation of the sacred integrity of the Canyons is vitally important to the Tribes. Under the provisions of Executive Order 13007, both Reclamation and the NPS have obligations to accommodate access to and ceremonial use of Indian sacred sites by Indian religious practitioners; to avoid adversely affecting the physical integrity of sacred sites; and to maintain the confidentiality of the location of sacred sites as requested by the Tribes. Inappropriate behaviors and activities within the Canyons can negatively affect the sanctity of the Canyons. Visitor impacts noted by Tribes include, but are not limited to, trampling of resources, lack of respect for sacred sites, trailing, illegal collection of artifacts, artifact movement, vandalism, and littering. Disruptive, boisterous behavior in the Canyons disturbs the spiritual ambiance that surrounds sacred trails and sites. Many Tribes have reported experiencing discomfort when performing ceremonies at certain sites within the river corridor because of the number and behavior of visitors present. In some cases, Tribal members have been approached by curious visitors during private ceremonies (Bulletts et al. 2008. 2012; Jackson-Kelly et al. 2013). During consultation meetings, Tribal representatives expressed concerns regarding integrity of the Canyons. For example, the Zuni expressed that from their perspective, any impact on the Canyons is an impact on the Zuni people, because the spirits that are disturbed can bring adverse consequences to the Zuni and their families; and the Navajo indicated that they have observed a reduction in the strength of plants gathered from sites along the river to be used for medicinal and ceremonial purposes, and have sought out other collection sites. In addition, visitor impacts could diminish the feeling, association, settings, and materials of important places, aspects used to evaluate the integrity of a traditional cultural place.

Non-Tribal visitors will continue to be present under all alternatives. As noted in Section 4.8, Alternative F is modeled to result in slightly more visitor time off-river, resulting in slightly more risk to sacred sites than the other alternatives. There is very little variation in the modeled time off river among the other alternatives

Possible adverse effects on sacred sites that result from tourists in the Canyons could be mitigated and in some cases prevented through communication and education. All of the Tribes with historical and cultural ties to the Canyons are affiliates of Native Voices on the Colorado River, an educational program that offers the Tribes a chance to share their historic and contemporary perspectives of the Colorado River and the Canyons with river guides, river outfitters, and the public. River guides and outfitters in turn share this information with their clients on river trips (NVCR undated). In addition, some Tribes have developed their own outreach programs. The Southern Paiute Consortium has developed outreach programs with Colorado River guides, local schools and universities, and civic organizations. When they are conducting monitoring trips or present in the corridor, the consortium also talks with Canyon visitors. The goal of the program is to educate non-Tribal members about the Southern Paiute history and broad cultural landscape of the Canyons (Bulletts et al. 2012). The Hualapai encourage public outreach and education as a means of teaching people about negative impacts on Hualapai resources (Jackson-Kelly et al. 2013). The Zuni have expressed interest in developing an educational program that would allow Zuni cultural advisors to inform river guides, boatmen, NPS, and Reclamation about the importance of Zuni history and traditional

issues as they are related to the Canyons (Dongoske 2011a). Reclamation and NPS are committed to continue working with the Tribes to develop or continue development of education and outreach programs. It is important that visitors to the Canyons understand the magnitude of the consequences their presence has on Tribal resources and Tribal members.

4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons

During the development of the LTEMP DEIS, the Tribes expressed concern with maintaining and improving their connection to the Canyons, including the stewardship responsibilities given to them at creation or emergence. Stewardship is partly expressed through their participation in the Glen Canyon Dam Adaptive Management Work Group (AMWG) and Technical Work Group (TWG), which encourage participation in an open discussion of issues related to the operation of Glen Canyon Dam as well as the design of monitoring and research conducted by the GCMRC.

The Tribes regard maintaining their connection to the Canyon through traditional activities and fulfilling their stewardship responsibilities as vital. Tribal stewardship takes place on many levels, including participation in the management of Canyon resources through monitoring programs, ceremonial activities, and recounting oral histories. These stewardship activities are important for all Tribal members, but they are particularly important for passing down traditions and oral histories to Tribal youth. As discussed above, insensitive behavior by Canyon visitors and researchers may disrupt the Tribes' ritual activities of stewardship and passing cultural values connected to the Canyons to the next generation (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013).

Adverse effects can be avoided or mitigated through continued communication; this includes communicating about the timing and duration of HFEs. Many of the Tribes are members of both the AMWG and TWG. Many Tribes also have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Continued communication and collaboration between the Tribes and federal agencies will enhance stewardship opportunities for the Tribes, as will maintaining the Tribes' continued access to the Canyons to conduct important religious practices necessary for continued stewardship.

4.9.1.6 Economic Opportunity

As discussed in Section 4.14.2.1, economic ventures currently operated by the Tribes and Tribal members rely heavily on tourism both in and around the Canyons. These ventures include commercial rafting on the river, tourist facilities in or near the Canyons, and vendors of Native American crafts, such as jewelry, basketry, and ceramics, that rely heavily on trade with tourists. Within the Canyons, the Grand Canyon Resort Corporation, owned by the Hualapai Tribe, provides recreational facilities including river running below Diamond Creek. The Hualapai River Runners provide day and overnight whitewater rafting trips, and flat-water day trips. The

Tribe (working with GCNP) also issues some permits for private whitewater boating below Diamond Creek. The 1-day whitewater boating trips create the largest river recreation economic impacts within the Canyons (61 jobs and $1.4 million in annual regional income), while day-use flat-water trips also make a significant contribution (19 jobs and $0.4 million in annual regional income). The NPS CRMP (NPS 2006b), developed in consultation with the Hualapai Tribe, places limits on the number and size of trips below Diamond Creek. There are a fixed number of river trip launches allowed under the NPS plan and more demand than capacity. The number of trips would not change as a result of any of the alternatives, so the impacts on the river runners would be the same as Alternative A for all alternatives. The same annual economic impacts would be expected under each of the alternatives.

The Havasupai, Hualapai, and Navajo all operate land-based tourist facilities in or adjacent to the Canyons that are important contributors to their economic development. The Havasupai operate a lodge, café, trading post, and campground on their reservation, and offer Canyon tours. The Hualapai have a number of tourist and recreational facilities and opportunities including a river running operation, skywalk, helicopter rides, and hiking in the Western Grand Canyon. The Navajo have Tribal parks overlooking the Little Colorado River and Grand Canyon, and along Lake Powell. No difference in tourist use of land-based facilities or Native American craft vendors is expected among the LTEMP alternatives. However, Tribes have expressed the desire for communication before and during HFEs to enable them to communicate information to tourists as necessary.

The Navajo also operate the Antelope Point Marina on Lake Powell. Direct and indirect economic impacts of visitation to Lake Powell facilities are discussed in Section 4.14.2.1. There is very little difference among the alternatives regarding impacts on marinas on Lake Powell. Models indicate that all alternatives except Alternative F would result in negligible change in regional income, less than 0.6%. The largest potential decrease would be 1.1% under Alternative F because that alternative has higher releases in the spring and lower releases through the summer every year, and consequently slightly different reservoir levels in the summer months.

4.9.1.7 Maintain Tribal Water Rights and Supply

Reclamation is committed to operating Glen Canyon Dam so that all water obligations are met, including those to Tribes. Lake Powell supplies water to both the Navajo Chapter of LeChee and the City of Page, Arizona, which share a water intake system (NPS 2009b). Currently, two intakes provide water. There is an intake on the face of the dam at 3,480 ft above mean sea level and a second intake off the penstocks to Units 7 and 8 at 3,470 ft above mean sea level. In the current configuration, the minimum pool elevation necessary to supply LeChee and Page is 3,470 ft above mean sea level. The minimum power pool elevation is 3,490 ft above mean sea level, well above the water intakes (Grantz 2014). Plans now under consideration call for a new, lower intake at 3,373 ft above mean sea level. The modeling results for all of the alternatives show Lake Powell levels remaining above the existing and proposed intakes for the entire 20-year period (see Appendix J). The lowest pool level projected is 3,480.3 ft above mean sea level, about the level of the intake on the dam face and 10 ft above the penstock intake.

4.9.1.8 LTEMP Process

Tribes have been involved in the LTEMP development process and will continue to be involved in the implementation of LTEMP. Tribes have routinely expressed concern regarding how LTEMP decisions are made rather than what decision is made, the genuine incorporation of Tribal input, and the importance of learning to improve management over time. They have favored an experimental approach resulting in adaptive management.

Over the course of the development of the LTEMP DEIS, Reclamation and the NPS have sought to incorporate Tribal input into the LTEMP process. Cooperating and consulting Tribes were included in Cooperating Agency and stakeholder meetings. Reclamation and NPS have also held Tribal meetings, workshops, conference calls, and webinars. Various documents related to the development of the LTEMP DEIS have been provided to the Tribes for their review and input. When requested, there have been face-to-face meetings with the Tribes. Tribes were given the opportunity to contribute to the Tribal lands, affected environment, and environmental consequence sections of the EIS, and Tribal views have been incorporated throughout this EIS. A complete summary of Tribal consultation efforts is provided in Section 5 and Appendix N.

4.9.2 Analysis Methods

Two main issues emerged in analyzing how the proposed action would be likely to affect Tribal resources in the Canyons: (1) How would alternatives affect the continued existence of Tribal resources in the Canyons? and (2) How would alternatives affect the sacred integrity of and Tribal connections to the Canyons? Since the Tribes are the best judges of how the alternatives would affect them and because some Tribal resources are sacred and their locations confidential, the answers to these questions require input from the Tribes. The analysis presented here is based mainly on input from the Tribes, augmented with analysis of quantifiable impacts.

Input from the Tribes was sought and continues to be sought in a number of ways. Initially, NPS and Reclamation identified 43 federally recognized Tribes with potential historical and cultural ties to the Colorado River and its Canyons and invited them to participate in the LTEMP EIS process, as either Cooperating Agencies or consulting parties. NPS and Reclamation conducted meetings with groups of cooperating and consulting Tribes; these meetings included workshops, teleconferences, webinars, and face-to-face meetings with Tribal authorities in efforts to fully identify Tribal concerns about impacts of alternatives on resources. The agencies also consulted with Tribes during Cooperating Agency meetings. Tribes that chose to become Cooperating Agencies also were given the opportunity to contribute to the writing of the EIS. Chapter 5 and Appendix N provide descriptions and other information for the consultation process. Goals for resources of Tribal concern were developed from information obtained at these meetings, and Tribes had an opportunity to review, edit, and contribute additional information and concerns. Where possible, potential impacts on these resource goals were determined quantitatively, and modeling was used to quantify impacts. Modeling and analysis incorporated analyses from other resource areas such as aquatic resources, riparian vegetation, and economics. Tribes were invited to meetings where the results of the modeling were presented, and they were given a chance to ask questions and contribute comments.

Qualitative assessments of impacts were based on written information produced by or for the Tribes. Significant insight into Tribal priorities came from the Tribes that regularly monitor the state of resources in the Canyons that they consider significant. Tribal monitoring reports from the Hopi (Yeatts and Brod 1996; Dongoske 2001; Yeatts and Huisinga 2006, 2009, 2010, 2011, 2012, 2013), Hualapai (Jackson et al. 2001; Jackson-Kelly et al. 2009, 2010, 2011, 2013), Navajo (NNHPD 2012), Southern Paiute (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007), and Zuni (Dongoske 2011a) were consulted for information on sites and resources of importance, as were ethnographies produced for the Tribes during previous related National Environmental Policy Act of 1969, as amended (NEPA) analyses (Ferguson and Lotenberg 1998; Lomaomvaya et al. 2001; Roberts et al. 1995; Yeatts and Huisinga 2003; Stoffle et al. 1994, 1995; Hart 1995).

4.9.3 Summary of Impacts

A summary of the impacts of the LTEMP alternatives on Tribal resources is presented in Table 4.9-2. In general, it is anticipated that there will be limited impacts on places and resources from the proposed action and the impacts that are anticipated do not vary greatly among the alternatives. Flow-related impacts on traditional cultural places include inundation by high flows (i.e., flows above the normal maximum operating flow of 25,000 cfs), resulting in erosion and temporary loss of access to such features as springs. Inundation impacts are temporary and can be mitigated through communication between Reclamation and the Tribes regarding scheduled high flows. The potential for the inundation of historic properties and erosion of terraces where historic properties are located is discussed above in Section 4.8. It is anticipated that traditional cultural resources most directly affected by flows would be riparian vegetation and fishes. Flow impacts on culturally important terrestrial wildlife would be minimal and do not vary among alternatives (see Section 4.7).

Some alternatives include non-flow actions that include trout removal and vegetation management. Proposed experimental vegetation management activities include the removal of nonnative species, clearing vegetation to expose sand for camping and distribution by wind, removing encroaching vegetation from campsites, and replacing removed nonnative species with native species, many of which have cultural importance to the Tribes. Vegetation management has the potential for both beneficial and adverse impacts (see Section 4.9.4). Increasing campable area by clearing campsites may not be seen as positive by Tribes that consider the Canyons a sacred space and are concerned with visitors disrespecting and interfering with important ceremonial and other cultural activities. All LTEMP alternatives would have the same overall level of visitation, set by the number of permits, so effects would be negligible in terms of a difference from No Action. In addition, there are potential positive effects that could result from using plants as barriers, closing off trails to culturally sensitive sites, and increasing native plants in treatment areas that are important to Tribes. Removing vegetation to open up sandy beaches has the potential for allowing wind to transport fine sediment to higher elevations and potentially shielding archaeological sites from erosion. These impacts would not vary among the action alternatives. Lethal removal of trout has been identified by the Zuni with the support of other affiliated Tribes as having an adverse effect on the TCP of the Grand Canyon, particularly when

TABLE 4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact to Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact to culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs or mechanical trout removal. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered. Small increase in sediment near Hualapai recreation operations; more frequent HFEs could affect docks.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Places							
Visitation of culturally significant sites	No change in the potential for recreationists to visit culturally significant sites	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, slight increase in the potential for recreationists to visit culturally significant sites in May and June.	Same as Alternative A.
Availability of sand for wind transport to protect culturally important archaeological sites	Negligible change in wind transport of sand; some increase in sand from HFEs until 2020, when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020.	Compared to Alternative A, slight potential increase (+7%) from HFEs continuing over entire LTEMP period; slight decrease (−10%) with implementation of hydropower improvement flows.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+137%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to protect cultural resource sites (+139%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+96%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+88%), resulting from increase in frequency of HFEs.	Compared to Alternative A, increased potential for wind transport of sand to cultural resource sites (+193%), resulting from increase in frequency of HFEs.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Resources							
Riparian plant diversity	Slight loss of riparian plant diversity (0.95 diversity index).	Similar to Alternative A (0.97 diversity index).	Compared to Alternative A, decrease in riparian plant diversity (0.75 diversity index).	Similar to Alternative A (0.96 diversity index).	Similar to Alternative A (0.93 diversity index).	Compared to Alternative A, lowest riparian plant diversity (0.70 diversity index); largest acreage of invasive plants.	Compared to Alternative A, decrease in riparian plant diversity compared to Alternative A (0.83 diversity index).
Retention of wetlands (existing marsh is less than 5 ac total)	Approximately 3.6 ac retained; 28% loss.	Compared to Alternative A, approximately 4 ac retained (8% more). Under hydropower improvement, flows wetlands loss would be greater.	Compared to Alternative A, approximately 1.25 ac retained (47% less). Second-largest area of wetlands loss across alternatives.	Compared to Alternative A, approximately 4.2 ac retained (12% more). Least loss of wetlands across alternatives.	Compared to Alternative A, approximately 3.1 ac retained (10% less).	Compared to Alternative A, approximately 0.7 ac retained (58% less). Largest area of wetlands loss across alternatives.	Compared to Alternative A, approximately 1.5 ac retained (30% less). Third-largest area of wetlands loss.
Frequency of TMFs	No TMFs.	TMFs expected in 3 of 20 years	TMFs expected in about 6 of 20 years.	TMFs expected in 8 of 20 years.	TMFs expected in 3 of 20 years.	No TMFs.	TMFs expected in 11 of 20 years. Most TMFs of any alternative.
Frequency of mechanical removal of trout	Trout removal expected in <1 of 20 years.	Trout removal expected in <1 of 20 years.	Trout removal expected in about 0–3 of 20 years.	Trout removal expected in about 2–3 of 20 years.	Trout removal expected in about 0–2 of 20 years.	No trout removal. Least trout removal of any alternative.	Trout removal expected in 3 of 20 years. Most trout removal of any alternative.
Impacts on culturally important wildlife	Negligible adverse impact effects on culturally important wildlife.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic and Water Resources							
Impact on Tribal recreation operations in Western Grand Canyon	No change from current sediment conditions; facilities may be affected by HFEs until 2020.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; slightly greater impacts on docks due to slightly more frequent HFEs.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.	Compared to Alternative A, potential for small increase (<2%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.[a]	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.	Compared to Alternative A, potential for small increase (6%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to most frequent HFEs.	Compared to Alternative A, potential for small increase (<3%) in sediment deposited near Hualapai recreation operations; greater impacts on docks than Alternative A due to more frequent HFEs.
Impact on Tribal land-based vendors	No impact on land-based vendors.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Impact on Tribal marina operators	No change from current condition.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, slight decrease in marina visitation (1.1%).	Same as Alternative A.
Water supply	Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended duration fall HFE. The number of spring HFEs would be reduced from 6.8 to 5.5 after the prohibition (1.3 fewer), and this reduction in frequency could reduce the impacts on Hualapai docks under Alternative D.

it takes place in proximity to the confluence of the Colorado River and the Little Colorado River, an area of special significance to the Zuni (Dongoske 2011b), the Hopi (Yeatts and Huisinga 2013), and the Navajo (Roberts et al. 1995). The lethal mechanical removal of trout and/or TMFs would be considered a significant adverse impact by some Tribes; however, if done in conjunction with mandated consultation with the Tribes, the impact may be reduced through beneficial uses and other practices that have been used for the Bright Angel fish removal efforts. For a discussion of alternative specific impacts see Section 4.9.4.

As discussed in Section 3.9, many of the Tribes that have been involved with this EIS consider portions of the Colorado River and its tributaries, the Canyons through which they flow, as well as elements within the river and Canyon corridors, as a TCP or part of a TCP. Any impact on any cultural place or cultural resource—be it an archaeological site, sacred place, traditional collection area, important plant or animal, or other element considered a TCP or contributing element to a TCP—is also considered an impact on the TCP, because these resources add to the overall traditional value of the TCP for these Tribes. As previously discussed, many Tribes have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Any effect on the Canyons and their resources will likely be evaluated by each Tribe during the monitoring assessments. The Zuni in particular have stated that any action within the Grand Canyon will have to be assessed by the Zuni people for adverse effects that may be experienced in the Zuni Pueblo itself.

The Hualapai Tribe operates recreational facilities in the Western Grand Canyon, and their facilities and activities could be adversely affected by operation of Glen Cayon Dam. The Hualapai have expressed concern over dam operations they believe are increasing the amount of sediment collecting in the channel in their operational area below Diamond Creek. Their primary operations are centered in and around the Quartermaster area (RM 260). They have reported adverse impacts on their commercial operations from river sediment, including effects on equipment, access to their docks, and navigation in the river.

The Hualapai are concerned over the steep and unstable slopes previously inundated by Lake Mead that are now exposed due to reservoir levels retreating from the previous high-water line. The issues associated with the steep and unstable shorelines in the Lake Mead delta are related to the declining reservoir level, and will not be resolved until the level of Lake Mead either regains its previous high levels or until the banks naturally stabilize under new, lower reservoir levels.

The Hualapai are concerned with the effect of different flows on their boat docks. The number and duration of HFEs under LTEMP alternatives could affect boat docks and other facilities operated by the Hualapai Tribe. The dock structures were evaluated in 2012 by Reclamation engineers (Walkoviak 2012; see Section 4.10.2.6 for a discussion of the findings of this evaluation). LTEMP alternatives differ in the frequency and type of HFEs that would occur over the 20-year LTEMP period (Table 4.3-1; Sections 4.3.2 and 4.3.3). Alternative A would have the fewest (average of 5.5 HFEs over the LTEMP period, with HFEs not being conducted after 2020); Alternative F would have the most (average of 38.1 HFEs over the entire LTEMP period).

It is expected that dam operations, HFEs, equalization flows, and other flow events will continue to deliver sediment to the Western Grand Canyon and Lake Mead. Nearly all sediment that enters the Grand Canyon below Lake Powell will eventually move downstream. Higher flows, in general, do transport more sediment, and sediment transport will continue in the free-flowing portions of the river below Diamond Creek. Based on the analysis presented in Section 4.10.2.6, the increase in suspended sand at RM 225 under LTEMP alternatives relative to Alternative A is approximately 6% for Alternative F, 2% for Alternative D, and less than 3% for all other alternatives. This difference is significantly less than the differences under potential future hydrologic conditions. The location where this suspended sand deposits downstream of RM 225 will be a function of Lake Mead elevation and local hydraulic conditions. However, the amount will not be more that what is in suspension, so the sand deposition at RM 260 will be much less than the 2 to 6% increase in suspended sand expected under the LTEMP action alternatives.

4.9.4 Alternative-Specific Impacts

This section presents the impacts of the LTEMP alternatives on the Tribal resource goals presented in Section 4.9.1. Impacts are based on both quantitative and qualitative indicators of the status of resources that Tribes have indicated are culturally important. Factors considered include the state of riparian plant communities, riparian and terrestrial wildlife, and aquatic resources. Also considered are the time Canyon visitors spend off the river, potentially impacting traditional cultural places and economic opportunities for commercial Tribal river runners.

4.9.4.1 Alternative A (No Action Alternative)

Under Alternative A, the No Action Alternative, the modified fluctuating flows as defined in the 1996 ROD for the operation of Glen Canyon Dam would continue. Existing operations and recent decisions would be maintained. The existing HFE protocol and nonnative fish control actions and experimentation would continue until 2020 as specified in existing EAs. The HFE protocol EA (Reclamation 2011b) projected that access to and use of certain cultural properties could possibly be altered due to inundation in the area directly affected by an HFE. Less sand would be moved from Marble Canyon downstream under this alternative than under any other and it has the lowest sand load index score, which suggests there would be less building of sandbars, resulting in less sand being available for windborne transport to culturally important sites.

Alternative A is likely to result in a relatively even proportional distribution of plant community types, but a slight loss in plant community diversity. Modeling results suggest that 3.6 ac of wetland habitat will remain at the end of the 20-year LTEMP period, a decrease of 28% from the current wetland acreage (Section 4.6). An estimated 4.6 ac of wetlands occurs downstream from the dam.

Testing of TMFs is allowed under Alternative A, but since there has not been a decision to implement these flows, they are not considered a regular action under this alternative. Modeling of trout numbers suggests that mechanical removal trips would only rarely be triggered, resulting in the fewest removal trips of any alternative where mechanical removal is allowed, in part because removal actions would expire in 2020. As indicated by lack of significant changes in the riparian plant communities and the mobility of larger animals, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and would not differ among the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

No change from current conditions is expected with regard to recreational economic or water supply impacts on Tribes. There would be no change in current sediment conditions that could affect Hualapai recreation operations in the Western Grand Canyon, but existing Hualapai docks could be affected by HFEs until 2020. The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be no effect on the Navajo marina under this alternative (Sections 4.2 and 4.14.2.1; Reclamation 2011a). Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative A, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity and wetland acreage. Trout removal trips are expected to be triggered in 1 year out of 20, the lowest expected number of trips among alternatives, which represents no change from current conditions. The availability of sand for wind transport could provide some benefit to some places of traditional cultural importance due to HFEs until 2020 when the HFE protocol expires, at which point these areas could experience an adverse impact due to lack of available sediment for wind transport. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal recreation economics, Tribal land-based vendors, marinas operated by Tribal enterprises, or Navajo Nation water supply. Any impact on a Tribally important cultural place or resource is also considered an impact on a Tribe's TCP.

4.9.4.2 Alternative B

Alternative B would follow the same monthly water release volumes as Alternative A, but there would be greater fluctuations in 10 months of the year and increased down-ramp rates. Under this alternative, HFEs would be implemented over the entire 20-year LTEMP period, but they are limited to no more than one every other year. There is greater daily flow fluctuation than in Alternative A for most months. Hydropower improvement flows—operations with wider fluctuations in high electrical demand months—would be tested in 4 years when the annual release volume is ≥8.23 maf. TMFs would be tested and implemented if successful.

This alternative is likely to result in the maintenance of current levels of evenness and diversity of plant community distribution; slightly higher plant diversity is expected than under Alternative A. Due to a lack of extended high or low flows that scour or desiccate wetlands, approximately 4 ac of wetlands would be retained under Alternative B, 8% more than under Alternative A (Section 4.6), except under the hydropower improvement flows, in which case there would be increased loss of wetlands. An estimated 4.6 ac of wetlands occurs downstream from the dam.

The wider daily fluctuations under Alternative B would reduce the potential for bar-building, making less sand available for windborne transport to culturally important places relative to normal operations under Alternative B. Under typical operations, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be slightly greater (+7%) than under Alternative A, unless hydropower improvement flows are included, in which case the sand load index would be slightly less than under Alternative A (−10%).

Under this alternative, TMFs are expected to occur in about three of the 20 LTEMP years. This alternative and Alternative E likely would have the fewest TMFs among the alternatives that would test and implement TMFs (Alternative A allows testing and Alternative F does not). Low numbers of TMFs result from lower numbers of trout recruits in the Glen Canyon reach. Low trout numbers result from higher daily fluctuations and fewer spring HFEs. When trout numbers are low, mechanical removal is triggered in fewer years.

Based on the lack of significant changes in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as big horn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Few changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the

entire LTEMP period, but the total number of HFEs (7.2) would be comparable to the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be no effect on reservoir elevation and the Navajo marina under this alternative. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative B, current wetland acreage is expected to be retained and plant diversity would be slightly higher than under Alternative A, except under hydropower improvement flows, which would result in greater loss of wetlands. TMFs are expected to be triggered in 3 years out of 20; while trout removal trips are expected to potentially be triggered, if at all, in 1 year out of 20. The availability of sand for wind transport to potentially protect some places of traditional cultural importance would somewhat increase relative to Alternative A because HFEs would occur over the entire LTEMP period. However, the high fluctuations of hydropower improvement flow would potentially decrease the availability of sand. Places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors, marinas operated by Tribal enterprises, or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to a minor increase in the number of HFEs over the LTEMP period. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.3 Alternative C

Under Alternative C, the highest water release volumes would occur in the high electric demand months of December, January, and July, with lower volumes from August through November to conserve sediment inputs during the monsoon period. The HFE protocol would be followed for the entire 20-year period, and some additional HFEs would be allowed. Proactive spring HFEs would be tested in years with a high volume of flow (>10 maf). Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+137%), making more sand available for windborne transport to cultural sites (Section 4.3).

Operations under this alternative are expected to result in relatively low plant community diversity and evenness. High flows followed by growing season lows are likely to result in more loss of diversity than under Alternative A (Section 4.6). This alternative is expected to retain approximately 1.25 ac of wetlands, 47% less than that retained under Alternative A. This alternative results in more wetland loss than any other alternative except Alternative F. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs are expected to be triggered in about 6 out of 20 years under this alternative because of the relatively higher number of trout expected to be produced (Section 4.5). Mechanical trout removal is expected to be triggered in few if any of the 20 years modeled.

As under other alternatives, because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small increase (<3%) in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (21.3) would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative C, the diversity of riparian plant communities is expected to decrease, and this alternative is expected to result in the second-largest area of wetland loss when compared to Alternative A. TMFs are expected to be triggered in 6 out of 20 years, and trout removal trips could potentially to be triggered in 3 out of 20. Under Alternative C, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for an increase in impacts on Hualapai docks related to a minor increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Economic effects on Tribal tourist enterprises would be the same as under Alternative A, except for Tribally operated marinas, which would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.4 Alternative D (Preferred Alternative)

Alternative D adopts characteristics of Alternatives C and E to achieve sediment retention characteristics and other resource benefits while reducing impacts on the value of hydropower generation and capacity, when compared to Alternatives C and E. Like Alternatives C and E, Alternative D includes a number of condition-dependent flow and non-flow actions that may be triggered by resource conditions. Alternative D differs from the other two in the specific trigger conditions and the actions that would be taken. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+139%), making more sand available for windborne transport to cultural sites (Section 4.3).

Under Alternative D, riparian plant community diversity and evenness would be virtually the same as under Alternative A and similar to Alternative E. These alternatives would result in only a slight loss of plant community diversity. There would be on average an overall loss of invasive species; both tamarisk and arrowweed would decrease under Alternative D. There would be somewhat less loss of tamarisk under Alternative D than under Alternatives A or E. Repeated extended high flows can remove tamarisk and arrowweed. The low number of growing season extended low flows would limit tamarisk establishment and the shifting of wetland communities to arrowweed (Section 4.6.3.4).

Approximately 4.2 ac of wetlands would be retained under Alternative D, 12% more than under Alternative A. This alternative would result in the least amount of wetland loss of all alternatives. Greater wetland acreage is associated with greater plant community diversity. Low numbers of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed. An estimated 4.6 ac of wetlands occurs downstream from the dam.

Spring HFEs, which stimulate the food base, and steady summer flows are factors that tend to result in trout population growth. Spring HFEs would be more common under Alternative D than under Alternative A, and summer daily fluctuations would be slightly less under Alternative D than under Alternative A. Under Alternative D, TMFs are expected to be triggered in about 8 out of 20 years. This would be more often than under any alternative except Alternative G, partly because TMFs could be triggered during years in which the production of young-of-the-year rainbow trout in the Glen Canyon reach is anticipated to be high. Overall, because TMFs are expected to reduce the number of fish in the trigger reach, mechanical removal could be triggered in fewer years. Under Alternative D, modeling suggests that trout removal would occur in about 2 to 3 out of 20 years.

As under other alternatives, because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<2%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (21.1)[23] would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative D, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity, similar to Alternative A. The least amount of wetland acreage loss would occur under this alternative. TMFs are expected to be triggered in 8 years out of 20, and trout removal trips could potentially be triggered 3 years out of 20. Under Alternative D, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.5 Alternative E

Like Alternatives C and D, Alternative E includes a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions. Alternative E differs from the other two in the specific trigger conditions and the actions that would be taken. Under Alternative E, the relatively high number of HFEs projected would result in a higher sand load

[23] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs could reduce the impact of Alternative D on Hualapai docks in the Western Grand Canyon.

index (+96%) and significantly more sandbar building potential than under Alternative A, making more sand available for windborne dispersal to culturally important places.

This alternative would result in a slightly less diverse and even distribution of plant community types than under Alternatives A, B, and D, but more diversity and evenness than under Alternatives C, F, or G. This alternative is expected to retain approximately 3.1 ac of wetlands, 10% less relative to Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs would be triggered in about the same number of years as under Alternative B. Fewer TMFs are expected because the number of trout in the Glen Canyon reach is expected to be lower under this alternative as a result of higher summer fluctuation levels and fewer spring HFEs. Mechanical removal would be triggered in up to 2 out of 20 years.

Because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon. Existing Hualapai docks could be affected by HFEs during the entire LTEMP period, and the total number of HFEs (17.1) would be higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative E, diversity and evenness of plant community types would be slightly less than under Alternatives A, B, and D, but slightly more than under Alternatives C, F, or G. This alternative would retain more wetland acreage than Alternatives F, G, and C. TMFs are expected to be triggered in 3 years out of 20, and trout removal trips could potentially to be triggered 2 years out of 20. Under Alternative E, there is a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no

change in the potential for recreationists to visit culturally significant sites. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.6 Alternative F

Alternative F is designed to re-create a more natural (pre-dam) flow pattern while limiting sediment transport and providing lower, stable base flows in summer, fall, and winter, and warmer temperatures in the summer. It allows both spring and fall HFEs, which should significantly increase the deposition and retention of sediment relative to Alternative A. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+88%), making more sand available for windborne transport to cultural sites (Section 4.3).

This alternative would result in the lowest degree of evenness and diversity and the greatest spread of tamarisk-dominated communities. This alternative would have high flows that spread tamarisk seeds followed by growing season low flows, which would allow seedlings to establish themselves. Similarly, this alternative is expected to result in the greatest amount of wetland loss of any alternative, retaining only 0.7 ac of wetlands, 58% less than under Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

This alternative includes neither mechanical removal nor TMFs and would thus allow nature to take its course regarding the interaction of humpback chub and nonnative trout. The steady flows and frequent spring HFEs of this alternative are expected to produce larger numbers of trout relative to most other alternatives.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Under this alternative, visitors to the Canyons would spend slightly more time off the river than under any of the other alternatives (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<6%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP although the total number of HFEs (38.1; highest of alternatives) would be much higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on

reservoir elevation that could result in a decrease (1.1%; highest of alternatives) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative F, plant diversity would be at its lowest, wetland loss would be at its highest, and the largest acreage of invasive species would occur. There would be no TMFs or mechanical trout removal trips under this alternative. Under Alternative F, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be a slight increase in the potential for recreationists to visit and potentially damage culturally significant sites during May and June. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.7 Alternative G

Alternative G targets the conservation of sediment through steady, equal monthly release volumes that would maximize retention of sediment, and the largest number of HFEs of any alternative, some with extended duration, which would distribute and retain sediment at higher elevations. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the sand load index would be greater (+193%), making more sand available for windborne transport to cultural sites (Section 4.3).

With more high flows, it is likely that this alternative would result in somewhat less diversity and evenness of plant communities than under Alternative A, but more diversity and evenness than under Alternatives C and F. The alternative would retain approximately 1.5 ac of wetlands, 30% less than Alternative A. Mean wetland acreage would be lower that of Alternatives A, B, D, and E, but above that of Alternatives C and F (see Appendix J). An estimated 4.6 ac of wetlands occurs downstream from the dam.

The steady summer flows and spring HFEs that characterized this alternative create favorable conditions for the growth of the trout population. As a consequence, TMFs are expected to occur more often under this alternative (11 out of 20 years) than under any other. Mechanical removal would also occur more often under this alternative than any other, on average about 3 out of 20 years.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Some changes relative to current conditions are expected with regard to recreational economic impacts on Tribes; no impacts are expected on water supply. There could be a small (<3%) increase in the amount of sand that could be deposited near Hualapai recreation operations in the Western Grand Canyon; existing Hualapai docks could be affected by HFEs during the entire LTEMP although the total number of HFEs (24.5) would be much higher than the number under Alternative A (5.5). The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be a minor effect on reservoir elevation that could result in a decrease (<0.6%) in income at the Navajo marina. Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation.

In summary, under Alternative G, there would be a decrease in riparian plant diversity, and the third-largest wetland acreage loss across alternatives would occur. TMFs are expected to be triggered in 11 out of 20 years, and trout removal trips could potentially to be triggered 3 out of 20 years. Under Alternative G, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change in the potential for recreationists to visit culturally significant sites when compared to Alternative A. There would be no change from current conditions related to Tribal land-based vendors or Navajo Nation water supply. There is the potential for a minor increase in impacts on Hualapai docks related to an increase in the number of HFEs over the LTEMP period, and a negligible loss of income (<0.6%) at Tribally operated marinas on Lake Powell. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.10 RECREATION, VISITOR USE, AND EXPERIENCE

This section presents the potential impacts of LTEMP alternatives on recreation, visitor use, and experience. Background information on the resources or resource attributes included in this analysis can be found in Section 3.10. There are also references to Sections 4.5 (Aquatic Ecology), Section 4.6 (Plant Communities), Section 4.14 (Socioeconomics and Environmental Justice), and the Recreation Economic Analysis in Appendix L, as they apply to visitor use and experience.

Issue: How do the alternatives affect recreation, visitor use, and experience?

Impact Indicators:

- Fish size and catch rate
- Flow fluctuation, water levels, and HFEs
- Navigability and safety
- Lost visitor opportunities
- Camping and recreation facilities on old sediment terraces
- Campsite area
- Campsite crowding
- Encounters with other groups
- Lake recreation
- Impacts on Tribal recreation operations in the Western Grand Canyon

4.10.1 Analysis Methods

The analysis of impacts on recreation, visitor use, and experience downstream of Glen Canyon Dam was based on assessment of alternative-specific differences in 10 indicators that were based on six quantitative metrics developed using recreational findings in published papers and reports, and quantified based on alternative-specific flow characteristics. The metrics were developed through consultation with subject matter experts and with consideration of comments from Cooperating Agencies.

Four of the metrics address issues important to visitor use and experience in GCNP, while the other two metrics focus on the Glen Canyon reach between the dam and Lees Ferry. Some information used for the assessment is not from measures of specific factors but is qualitative in nature. Most metrics were created as indices with values ranging from 0 to 1, where 1 is the optimal condition for that resource, and 0 represents the lowest possible value. An index with a relative scale was used because it was often impossible to quantify the condition of the resource, but it was possible to generate a relative scale that reflected that condition. For example, there is no current methodology that defines how specific camping areas in GCNP might respond to HFEs, but there is a basis for making conclusions about which conditions are likely to favor a general increase in camping area in the park. The exception to the 0 to 1 scale is the Glen Canyon Rafting Metric, which measures the number of potential lost rafting trips. All of the metrics except the Glen Canyon Rafting Metric are seasonally weighted to reflect seasonal differences in recreational use, with more weight given to conditions in the peak recreation period than in periods with less use. More information including assumptions and limitations of these metrics is in Appendix J. The six recreation-specific metrics are as follows:

- *Camping Area Index*—Accounts for optimal campsite area building and maintenance flows and sediment load (also used as input to the assessment of campsite crowding).

- *Time Off-River Index*—Relates the level of flows to visitors being able to spend time ashore visiting attractions.

- *Fluctuation Index*—Based on combinations of flows and fluctuations identified as preferable by experienced boat operators.

- *Navigation Index*—Based on the percentage of time minimum daily flows are less than 8,000 cfs (also used as input to the assessment of campsite crowding and encounters with other groups).

- *Glen Canyon Rafting Metric*—Estimates the number of visitors unable to participate in day rafting in Glen Canyon due to high flows; the metric is the mean annual number of lost visitor opportunities.

- *Glen Canyon Inundation Index*—Accounts for flows that impact recreational sites and recreational uses within the Glen Canyon reach.

An 8,000-cfs maximum daily fluctuation limit was established in the 1996 ROD (Reclamation 2006) to address safety, recreation, and sediment concerns (Reclamation 1995). The analysis conducted for the LTEMP EIS has not identified new evidence to suggest that these concerns and this fluctuation level do not still apply. The determination of 8,000 cfs as a maximum daily fluctuation level that is suitable for recreation was based on Bishop et al. (1995). Bishop et al. surveyed both the river guides and the general public regarding preferences, and the river guides reported a preference for a maximum of 8,000-cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. The current river guide community and the public have continued to state the preference for retaining the 8,000-cfs maximum daily fluctuation that is currently in place under Alternative A.

In the discussions below, the anticipated impacts of the alternatives are compared to the effects of Alternative A, the No Action Alternative. Impacts on recreation were developed using these metrics as well as published literature to evaluate how recreation would be affected by the alternatives. Information used includes the number and seasonality of HFEs, daily flow information, economic analysis, and fishery and vegetation management information that is documented in other portions of this EIS. Metric values are based on 20-year simulations of Glen Canyon Dam releases under different hydrology and sediment conditions as determined for the various LTEMP alternatives.

The economic analysis conducted by Gaston et al. (2015) quantified the net economic use value (NEV) of recreation at Lakes Powell and Mead, and for three reaches of the Colorado River: Glen Canyon, the Upper Grand Canyon, and the Lower Grand Canyon under the LTEMP alternatives. The results of this analysis are presented in Section 4.14 and Appendix L.

4.10.2 Summary of Impacts

The impacts of LTEMP alternatives on visitor use and experience are summarized in Table 4.10-1. Graphs showing the performance of the alternatives for each of the metrics are shown in Figure 4.10-1. A more detailed analysis for each of the alternatives is presented in Section 4.10.3.

Differences in the alternatives' effects on recreation tend to be mostly related to differences in the frequency and characteristics of experimental flows, particularly HFEs and TMFs, but are also related to differences in operations such as fluctuating flow effects during high-demand seasons for hydropower. Effects are greater for actions that occur during peak recreational use months, for example certain spring HFEs that may occur during the peak rafting season. Some experimental flows and actions occur in only a few years; thus, for the majority of time, the LTEMP alternatives' experimental flows cause little difference for recreation effects. Differences in daily maximum and minimum flows under normal operations can, however, distinguish between alternatives with respect to potential effects on recreation. Daily maximum flows above 8,000 cfs increasingly reduce usable beach area, and would effectively submerge all beach area at flows above 31,500 cfs (Section J.2.1.1). In addition, daily fluctuations resulting in minimum flows below 8,000 cfs can affect river navigability and cause delays at rapids. Flow fluctuations can also affect shoreline angling, and rafters who camp may be forced to move to higher ground and to check boat moorings overnight. Such effects would not occur or would be less prominent under alternatives with reduced fluctuation or steady flows (e.g., Alternatives A, C, D, F, and G), while high steady flows under Alternative F in some spring and summer months would reduce usable camping area. Lastly, not all effects are experienced by all recreational users, and other effects are localized. For example, flow fluctuations may affect overnight boaters who camp more than day-only boaters, while vegetation management and mechanical trout removal are both localized actions that would affect recreation in only portions of the river at any given time.

4.10.2.1 Glen Canyon Fishing

Effects of Flow Fluctuations, Water Levels, and HFEs

Anglers in the Glen Canyon reach identified a preference for steady flows and flows between 8,000 and 15,000 cfs (Bishop et al. 1987). Stewart et al.'s (2000) follow-up of the Bishop et al. (1987) study after the implementation of MLFF flows in 1996 did not identify river level fluctuations as an issue, and in 2011 an AZGFD creel study found that angler satisfaction in the Glen Canyon reach was high (Anderson, M. 2012), indicating that the existing flow regime was favorable for Glen Canyon anglers.

TABLE 4.10-1 Summary of Impacts of LTEMP Alternatives on Recreation, Visitor Use, and Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, few lost day-rafting visitor days (49 over 20-year period), and declining camping area.	Compared to Alternative A, comparable number of HFEs and higher fluctuations result in more lost day-rafting visitor days (45% increase) in Glen Canyon, highest number of large trout (13% increase), lowest trout catch rates, most navigability concerns, and similar camping area (5% increase in index).	Compared to Alternative A, more HFEs and lower fluctuations result in more lost day-rafting visitor days in Glen Canyon (543% increase), similar number of large trout (3% decrease), higher trout catch rates; fewer navigation concerns, and more camping area (170% increase in index).	Compared to Alternative A, more HFEs and comparable fluctuations result in more lost day-rafting visitor days in Glen Canyon (610% increase), similar number of large trout (5% increase), similar trout catch rates, similar navigation concerns, and more camping area (158% increase in index).	Compared to Alternative A, more HFEs, higher fluctuations, and more frequent flows below 8,000 cfs result in more lost day-rafting visitor days in Glen Canyon (261% increase), more large trout (8% increase), lower trout catch rates, more navigation concerns, and more camping area (118% increase in index).	Compared to Alternative A and all other alternatives ,frequent HFEs, steady flows, and lack of trout management actions result in most lost day-rafting visitor days in Glen Canyon (1,776% increase), higher trout catch rates, but fewest large trout (22% decrease); very few navigability concerns, and more camping area (191% increase in index).	Compared to Alternative A, more HFEs and steady flows result in few additional lost day-rafting visitor days in Glen Canyon (4% increase), higher trout catch rates, but fewer large trout (9% decrease); very few navigability concerns, and greatest potential increase in camping area (220% increase in index).

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon—Fishing							
Fluctuations, water levels, and HFEs	No change from current conditions; high angler satisfaction with flow levels and daily fluctuations; average 5.5 HFEs (lowest of alternatives) until 2020 (up to 8 days in a calendar year if both spring and fall HFEs were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 7.2 HFEs over LTEMP period (up to 4 days in a calendar year) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 21.3 HFEs over LTEMP period (up to 10 days in a calendar year if both a spring and an extended-duration fall HFE were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 21.1 HFEs over LTEMP period (up to 10 days in a calendar year if an extended-duration fall HFE were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow levels and fluctuations; average 17.1 HFEs over LTEMP period (up to 8 days in a calendar year if both spring and fall HFEs were triggered) that may disrupt fishing during their implementation.	Compared to Alternative A, lower satisfaction with flow levels; average 38.1 HFEs (highest of alternatives) over LTEMP period (up to 8 days in a calendar year if both spring and fall HFEs were triggered) may disrupt fishing during their implementation.	Compared to Alternative A, similar satisfaction with flow rates; average 24.5 HFEs over LTEMP period (up to 18 days in a calendar year if both spring and extended-duration fall HFEs were triggered) that may disrupt fishing during their implementation.
Fish size and catch rate	No change from current conditions; intermediate catch rates and estimated 770 large trout (≥16 in.).	Compared to Alternative A, lowest angler catch rates, but 13% more large trout (870, most of any alternative).	Compared to Alternative A, slightly higher catch rates; 3% fewer large trout (750).	Compared to Alternative A, similar catch rates; 5% more large trout (810).	Compared to Alternative A, similar catch rate; 8% more large trout (830).	Compared to Alternative A, highest catch rate; 22% fewer large trout (600).	Compared to Alternative A, second highest catch rates; 9% fewer large trout (700)..

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Glen Canyon—Fishing (Cont.)							
Navigability/ safety	No change from current conditions; intermediate number of days when flows below 8,000 cfs could affect navigability; minimal safety concerns from up-ramp rates.	Lowest navigability due to occasional flows below 8,000 cfs; slightly increased wading risk during tests of hydropower improvement flows.	Somewhat higher navigability than Alternative A; minimal safety concerns from up-ramp rates.	Same as Alternative A; minimal safety concerns from up-ramp rates.	Somewhat lower navigability than Alternative A; minimal safety concerns from up-ramp rates.	Somewhat higher navigability than Alternative A; minimal safety concerns, steady flows.	Highest navigability, with few if any flows below 8,000 cfs; minimal safety concerns, steady flows.
Glen Canyon—Day Rafting/Recreation							
Lost rafting visitor opportunities	No change from current conditions; estimated loss of 49 visitors/year out of a total of 50,000 due to HFEs (0.1%).	71 out of 50,000 fewer visitors/year due to HFEs.	315 out of 50,000 fewer visitors/year due to HFEs.	348 out of 50,000 fewer visitors/year due to HFEs.	177 out of 50,000 fewer visitors/year due to HFEs.	919 out of 50,000 fewer visitors/year because of large number of HFEs in peak rafting season.	51 out of 50,000 fewer visitors/year due to HFEs.
Camping and recreation facilities on old sediment terraces	No change from current conditions; lowest potential adverse impact on terraces; estimated 5.5 HFEs and no TMFs over the LTEMP period.	Intermediate potential impact on terraces; estimated 7.2 HFEs, 3 TMFs, and 4 years with hydropower improvement flows.	Intermediate potential impact on terraces; estimated 21.3 HFEs and 6 TMFs.	Intermediate potential impact on terraces; estimated 21.1 HFEs and 8 TMFs.	Intermediate potential impact on terraces; estimated 17.1 HFEs and 3 TMFs.	Highest potential impact on terraces; estimated 38.1 HFEs, but no TMFs.	Intermediate potential impact on terraces; estimated 24.5 HFEs and 11 TMFs.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Grand Canyon—Whitewater Boating							
Campsite area	No change from current conditions; lowest improvement of campsite area; would continue long-term decline since there are no HFEs after 2020; camping area index (CAI) = 0.14 out of 1.	Compared to Alternative A, effects of 2 more HFEs offset by higher fluctuations; overall campsite loss is expected to continue, CAI = 0.15, an increase of 5% over Alternative A.	Comared to Alternative A, more HFEs and moderate fluctuations would result in a potential increase in camping area (CAI = 0.38, an increase of 170%).	Comared to Alternative A, more HFEs and comparable fluctuations would result in a potential increase in camping area (CAI = 0.36, an increase of 158%).	Comared to Alternative A, more HFEs and higher fluctuations would result in a potential increase in camping area (CAI = 0.30, an increase of 118%).	Compared to Alternative A, most HFEs, no daily fluctuations, and high sustained spring flowswould result in a potential increase in camping area (CAI = 0.41, an increase of 191%).	Comared to Alternative A, more HFEs, even monthly volumes, and no daily fluctuations would result in the highest potential increase in camping area (CAI = 0.45, an increase of 224%).
River flow level and fluctuations as indicated by the navigation index (NI) and the fluctuation index (FI)	No change from current conditions; intermediate NI (0.50 out of 1) and intermediate FI (0.79 out of 1) indicate good river conditions for whitewater boating most of the time.	Compared to Alternative A, 22% decrease in NI and 47% decrease in FI (lowest of alternatives) indicate decrease in boating conditions.	Compared to Alternative A, 50% increase in NI and 18% increase in FI indicate improvement in boating conditions.	Compared to Alternative A, 10% decrease in NI and 6% decrease in FI indicate decrease in boating conditions.	Compared to Alternative A, 26% decrease in NI (lowest of alternatives) and 28% decrease in FI indicate decrease in boating conditions.	Compared to Alternative A, 42% increase in NI and 27% increase in FI (highest of alternatives) indicate improvement in boating conditions.	Compared to Alternative A, 92% increase in NI (highest of alternatives) and 24% increase in FI indicate improvement in boating conditions.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Lakes Powell and Mead—Recreation Access Issues Based on Reservoir Elevation							
Lake Powell (percent of seasons in which reservoir elevation drops below 3,580 ft)[b]	No change from current conditions; elevation drops below 3,580 ft in 21.8% of the seasons in the 20-year LTEMP period (percent of seasons with low reservoir elevations occurring in at least 1 month)	Compared to Alternative A, 2.6% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, negligible increase (0.4%) in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 5.1% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 5.1% increase in the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 4.7% increase the percent of seasons elevation drops below 3,580 ft.	Compared to Alternative A, 4.7% increase the percent of seasons elevation drops below 3,580 ft.
Lake Mead (percent of seasons in which reservoir elevation drops below 1,050 ft)[c]	No change from current conditions; elevation drops below 1,050 ft in 25.5% of the seasons in the 20-year LTEMP period (percent of seasons with low reservoir elevations occurring in at least 1 month)	Compared to Alternative A, 10.6% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, negligible (0.3%) decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 2.5% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 1.2% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 2.5% decrease in the percent of seasons during which elevation drops below 1,050 ft.	Compared to Alternative A, 1.9% decrease in the percent of seasons during which elevation drops below 1,050 ft.

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)[a]	Alternative E	Alternative F	Alternative G
Tribal Recreation Program							
Impacts on Tribal recreation operations in the Western Grand Canyon	No change from current sediment conditions; docks may be affected by HFEs until 2020 (average 5.5 over 20-year LTEMP period); lowest impact alternative.	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; slightly greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 7.2 over 20-year LTEMP period).	Compared to Alternative A, approximately 3% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 21.3 over 20-year LTEMP period).	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 21.1 over 20-year LTEMP period).	Compared to Alternative A, approximately 3% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 17.1 over 20-year LTEMP period).	Compared to Alternative A, approximately 6% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 38.1 over 20-year LTEMP period); highest impact alternative.	Compared to Alternative A, approximately 2% increase in suspended sediment at RM 260; greater impacts on Hualapai recreational facilities due to more frequent HFEs (average 24.5 over 20-year LTEMP period).
Park Facilities							
Impacts on park facilities at Pearce Ferry	No change from current conditions; facilities may be affected by HFEs; lowest impact alternative.	Slightly greater impacts than Alternative A due to slightly more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.	Greatest impact alternative due to most frequent HFEs.	Greater impacts than Alternative A due to more frequent HFEs.

[a] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs could reduce Alternative D's impacts on Hualapai docks in the Western Grand Canyon.

[b] Percent of seasons with at least 1 month with Lake Powell elevations equal to or below 3,580 ft AMSL, the level below which boat ramp access is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. Seasons were defined as summer (May, June, July, August), winter (November, December, January, February), and spring/fall (March, April, September, October). See Appendix J.

[c] Percent of seasons with at least 1 month with Lake Mead elevations equal to or below 1,050 ft AMSL, the level below which marinas and boat ramp function is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. Seasons were defined as summer (May, June, July, August), winter (November, December, January, February), and spring/fall (March, April, September, October). See Appendix J.

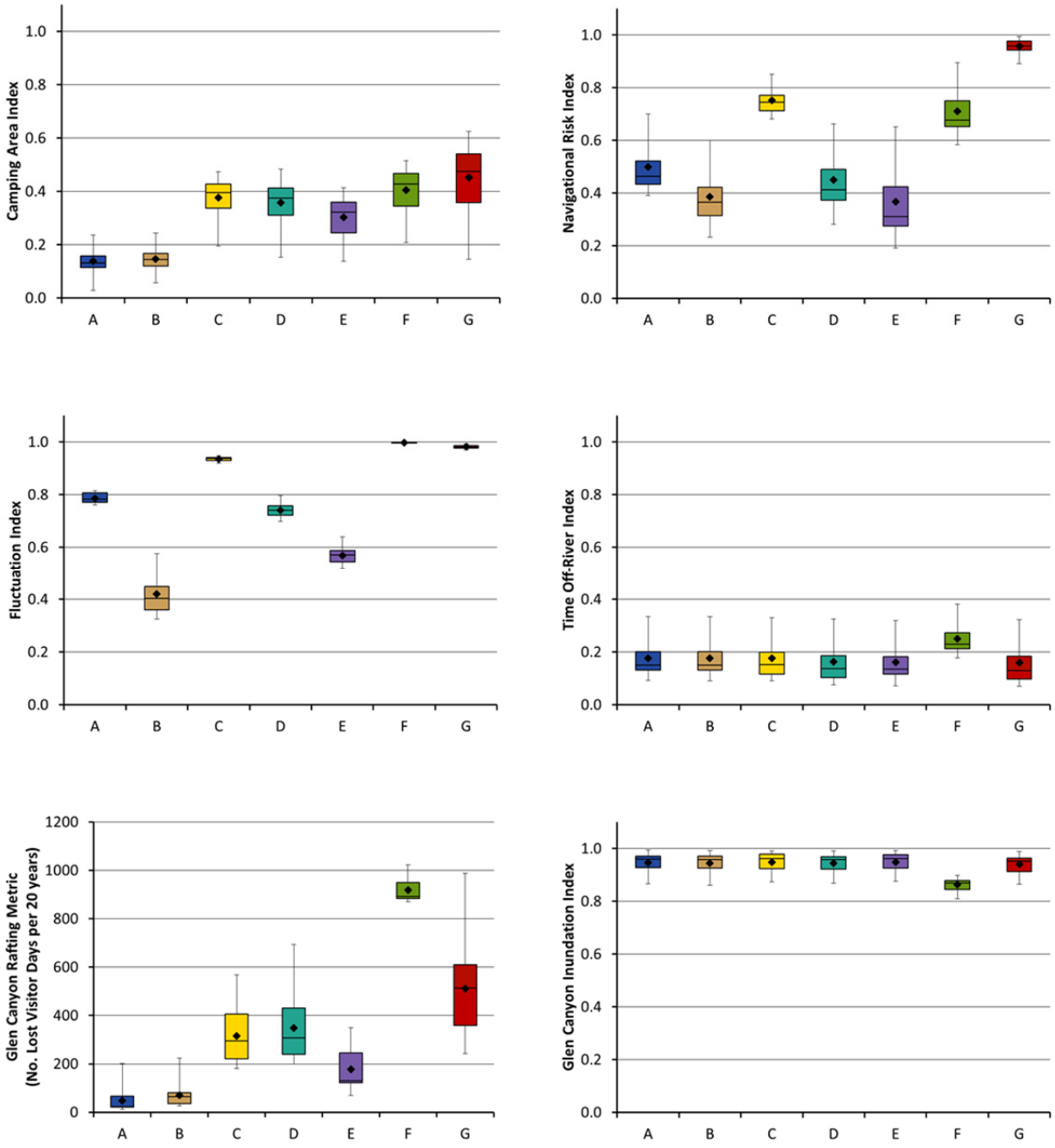

FIGURE 4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Steady flow Alternative F and Alternative G provide daily flows with no fluctuations; Alternative G might be considered better for anglers because flows would be at preferred levels throughout the year, whereas Alternative F has higher-than-preferred flows during some of the most popular fishing months, April through June. The highest fluctuations of fluctuating flow Alternatives C, A, D, E, and B (listed in order from lowest to highest within-day fluctuations) may not occur during peak fishing months. Furthermore, because the daily fluctuations analyzed in Bishop et al. (1987) were greater with respect to angling than those under the proposed alternatives, little difference is expected in effects on angling between alternatives due to fluctuations. Stewart et al. (2000) found that current fluctuations under MLFF were not identified by anglers as an issue. The effects of flow and fluctuation levels on angler satisfaction under the alternatives are quantified in economic terms in Section 4.14.2.1, which indicates that Alternative A would have the highest angler use value by a small margin over all alternatives; Alternative F would have the lowest due to high flows in peak fishing months.

The Glen Canyon Inundation metric was developed to identify the percentage of time river flows were above certain elevations that affect boating, fishing, and shoreline access. The metric is a measure of the suitability of flows between 3,000 and 31,500 cfs. Most alternatives perform similarly with regard to this metric, with Alternative F having a slightly lower metric value as illustrated in Figure 4.10-1. However, because all of the alternatives perform so consistently on this metric, it will not be discussed further.

Fishing would be disrupted during HFEs under all alternatives. The average number of HFEs over the 20-year LTEMP period would vary among alternatives, and would range from 5.5 under Alternative A to 38.1 under Alternative F; Alternative D would have an average of 21.1 HFEs[24] over the 20-year period. The maximum number of days that HFEs would disrupt fishing in any year would range from 4 under Alternative B to 18 under Alternative G; Alternative G is highest because it includes the potential for extended-duration HFEs that are up to 14 days long (Alternative D would have a maximum of 10 HFE days within a calendar year). Extended-duration HFEs are expected to be triggered relatively infrequently and would be limited to no more than four under Alternative D (Section 4.3.3).

Effects of Fish Size and Catch Rates

Anglers in the Glen Canyon reach are almost evenly split in their preference for catching either large fish or for catching more fish (Anderson, M. 2012). Analysis described in more detail in Section 4.5.2.2 concludes there will likely be differences among the alternatives both in the percentages of larger fish (individuals exceeding 16 in. in length) in the population and in the angler catch rate. Among the alternatives, the estimated number of large trout was generally greatest under Alternative B and lowest under Alternatives F and G. Alternatives E, D, A, and C in descending order are expected to produce intermediate numbers of large trout. The modeled

[24] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is not expected to result in a change in Alternative D's impacts on recreation.

angler catch rates are greatest under Alternatives F and G because of their steadier flow regimes, and lowest under Alternative B, with the greatest fluctuations. It is anticipated that recreational angling use in the Glen Canyon Reach would be similar to current conditions under all alternatives and that angler satisfaction would likely remain high, but satisfaction for some alternatives would be based on the size of fish, while that of others would be based on the number of fish.

Navigability and Wading Safety in the Glen Canyon Reach

The ability for boats to navigate freely within the Glen Canyon reach was an issue when low flows of 1,000–3,000 cfs occurred prior to 1996. All alternatives now include a minimum 5,000 cfs flow between 7 PM and 7 AM, and 8,000 cfs from 7 AM to 7 PM (with the exception of Alternative F, which has flows near or somewhat below 8,000 cfs all day during the summer, fall, and winter). The Navigation Index (Figure 4.10-1) is based on the amount of time flows are above 8,000 cfs. Alternatives B and E have lower Navigation Index values than Alternative A due to more frequent low flows. Alternatives C, F, and G are higher than Alternative A, and Alternative D is about the same as Alternative A.

Wading anglers are always at risk from swift water and from rapidly rising water levels, and anglers are urged to exercise caution. Specifically, rapidly increasing flow is a safety concern with respect to the ability of wading anglers to move toward shore. At least three drownings in 12 years preceding the 1995 EIS possibly were related to river stage or stage change (Reclamation 1995). Implementation of the MLFF protocol limiting up-ramp rates to 4,000 cfs/hr for all fluctuating-flow alternatives has reduced the potential safety concerns for wading anglers. An up-ramp rate of 5,000 cfs/hr proposed under Alternative B during tests of hydropower improvement flows could result in an adverse impact on safety of anglers due to rapidly rising water levels. With respect to HFEs, Reclamation and NPS would coordinate to ensure that safety measures are implemented during an HFE, including restricting access immediately below Glen Canyon Dam, and providing public notice about the timing of an HFE. Each of the affected NPS units—GCNRA, GCNP, and Lake Mead National Recreation Area (LMNRA)—has clearly designated responsible parties, staffing needs, and actions that are required to occur prior to and during an HFE.

4.10.2.2 Glen Canyon Day Rafting

The 15-mi Glen Canyon reach hosts a large number of day rafters who use the pontoon-raft concession that departs from near Glen Canyon Dam and travels to Lees Ferry (Section 3.11.1.2). Bishop et al. (1987) established that day rafting participants express no preferences regarding either river flows or fluctuations. As a result, impacts on rafting use are related only to the occurrence of HFEs, which result in lost visitor recreation opportunities and lost revenue for the rafting concessioner. The variables influencing the level of impact are the number of HFEs and the time of year in which they occur. Spring HFEs have a greater impact than fall HFEs because visitor use is higher in the spring months. HFEs are scheduled only in

October, November, March, and April, with the exception of proactive spring HFEs (under Alternatives C, D, and G), which can occur in April, May, or June.

Because of the high number of HFEs, Alternative F would have by far the greatest adverse impact on day-use rafting with an anticipated mean annual loss of about 919 visitor opportunities over the LTEMP period out of a typical annual total of 50,000 such trips expected over the LTEMP period. Alternatives G, D, C, and E would have the next largest adverse impacts with 512, 348, 315, and 177 mean annual lost visitor use opportunities, respectively. Alternatives A and B would be similar in their impact and would result in 49 and 71 mean annual lost visitor use opportunities, respectively (Figure 4.10-1).

4.10.2.3 Glen Canyon Recreational Facilities

Glen Canyon contains both high-elevation sediment terraces, which are remnants of larger terraces that existed prior to construction of Glen Canyon Dam, and lower elevation terraces, which are still affected by dam operations. Glen Canyon has six designated campsites with fire pits and bathrooms along its 15-mi stretch. These recreational facilities are generally located above the high-water level of normal dam operations; however, HFEs are the principal flow actions that could affect these campsites through erosion of terraces combined with an absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of terraces. Alternative F would have the largest adverse impact on these facilities from the projected number of HFEs and annual high releases (Table 4.3-1), followed by Alternatives G, C, D, E, B and A, in decreasing order. In addition, higher fluctuation levels, including during tests of hydropower improvement flows under Alternative B, could lead to increased campsite erosion relative to the other alternatives.

4.10.2.4 Whitewater Boating

The availability, size, and quality of campsites in the Grand Canyon is an important resource for whitewater boaters. As discussed in Section 3.11-2, total campsite area has undergone a long-term downward trend due to sandbar erosion and vegetation growth, having decreased by 56% from 1998 to 2006 (Kaplinski et al. 2010). Generally, alternatives with more sediment-triggered HFEs are expected to result in greater campsite area, although flow and fluctuation levels as well as vegetation control will affect the maintenance of campsite area. Alternatives G and F show the highest potential to create and maintain campsite area based on Camping Area Index values (Figure 4.10-1). These are followed by Alternatives C, D, and E which have index values more than two times greater than those of Alternatives A and B.

River flow levels and fluctuations are important for whitewater boaters (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). The minimum daily flow levels of 5,000 cfs from 7 PM to 7 AM and 8,000 cfs from 7 AM to 7 PM provided by most alternatives are considered only minimally adequate for Grand Canyon boating. Transit times of morning flow increases to 8,000 cfs from 5,000 cfs overnight at the dam to downstream locations may delay the arrival of 8,000 cfs or higher desired at more

challenging rapids. Such concerns would arise only in low-volume months, however, when minimum flow limits would be applied. Flows on most days under the fluctuating flow alternatives would exceed these limits. Steady flow Alternatives F and G could feature daily flows of 5,000 cfs for extended periods of time; however, only four occurrences of 5,000 cfs flows for a period of a month or more appeared in LTEMP 20-year hydrology simulations for Alternative F, and there were none for Alternative G. Extended low flows of 5,000 cfs would adversely affect navigability and trip management in GCNP because of a greater risk of boating incidents. Conversely, the normal steady flows of Alternatives F and G would offer benefits to river trip planning over the alternatives with fluctuating flows because river travel time and off-river time is more predictable. Commercial and private whitewater trip leaders reported (Bishop et. al. 1987) a preference for steady flows in the 20,000–26,000 cfs range. Alternative F approaches these levels in April through June, and thus would have higher perceived value to rafters than would Alternative G, which limits flows to near 12,000 cfs or less year round in 8.23-maf years.

The Navigation Index and the Fluctuation Index both address aspects of the impact of fluctuations on whitewater boating (Figure 4.10-1). Both indices are designed to produce values that increase in the direction of improved boating conditions. Thus, a higher Navigation Index value indicates that an alternative presents relatively lower navigation risks due to low flows (below 8,000 cfs), while higher Fluctuation Index values indicate that an alternative will have fluctuations more often within a preferred range for whitewater boating (Bishop et al. 1987). Alternatives G, F, and C have the highest values for both indices (indicating the best conditions), while Alternatives B and E had the lowest index values (indicating the worst conditions). Alternatives A and D have intermediate values for these two indices.

The Time Off-River Index values indicate there would not be much difference in time available for off-river activities between the alternatives, likely due to similar mean annual flows of between 10,000 and 15,000 cfs. Because the index does not provide a meaningful distinction among the alternatives, it will only be referenced in special circumstances in Section 4.10.3.

4.10.2.5 Reservoir Activities and Facilities

Recreation on Lakes Powell and Mead can be affected by water levels dropping below the level at which ramps and marinas can function. In the case of Lake Powell, the Castle Rock cut is also a critical feature. Although the lowest boat ramp elevations on Lake Powell are not all the same, 3,580 ft AMSL is representative of the level below which major access issues occur. The frequency at which reservoir elevations would be above 3,580 ft AMSL at the end of the month seasonally has been analyzed to determine whether there is any significant difference among the alternatives. The same has been done for Lake Mead using an elevation of 1,050 ft AMSL, the level to which the NPS has committed in order to keep marinas and launch ramps functional.

Simulations were performed of end of the month reservoir elevations by season (summer [May, June, July and August], winter [November, December, January, and February], or spring/fall [March, April, September, and October]) for the 20-year CRSS simulations using

21 hydrology traces for both reservoirs. For Lake Powell, with respect to the 3,580 ft AMSL reference level for boat access, approximately 22% of all simulated seasons showed at least one month with end of the month elevations at or below this level for all alternatives. There was very little difference among the alternatives; all alternative means fall between 21.75% for Alternative A and 22.86% for Alternative E. Such differences by alternative are due to small changes in elevation when reservoir elevation is near the 3,580-ft reference level.

The results for Lake Mead simulations were similar to those for Lake Powell, with a slightly greater range of results. Alternative B, with 22.78%, had the lowest percentage of seasons with at least 1 month at or below the reference elevation, and Alternative A, with 25.48%, had the highest. Differences by alternative are due to small changes in elevation when reservoir elevation is near the 1,050-ft reference level.

As discussed in Section 4.2.2.1, the elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. The dominating effect of hydrology was also observed in the analysis of reservoir elevations with respect to reservoir access, with relatively small effects attributable to differences in alternatives. With respect to ongoing drought conditions affecting operations at LMNRA, as noted in Section 3.10.3.1, an October 2005 NPS General Management Plan Amendment for Low Water Conditions and a Finding of No Significant Impact (NPS 2005b) identified the current strategy for low-water operations. This amendment articulated the intent to maintain boat-launch capacities established in the original General Management Plan of 1986 and a subsequent amendment in 2003, by either extending or relocating existing launch ramps and marinas to be functional down to an elevation of 1,050 ft AMSL. This amendment reflects the current management direction for low-water operations, and it assumes that NPS and concessionaires will continue to modify launching and marina facilities as necessary and possible, given time and budget to continue providing visitor services.

4.10.2.6 Tribal Recreation Operations

The Hualapai Tribe operates recreational facilities in the Western Grand Canyon, and their facilities and activities could be adversely affected by operation of Glen Cayon Dam. The Hualapai have expressed concern over dam operations they believe are increasing the amount of sediment collecting in the channel in their operational area below Diamond Creek. Their primary operations are centered in and around the Quartermaster area (RM 260). They have reported adverse impacts on their commercial operations from river sediment, including effects on equipment, access to their docks, and navigation in the river.

They are also concerned over the steep and unstable slopes previously inundated by Lake Mead that are now exposed due to reservoir levels retreating from the previous high-water line. The issues associated with the steep and unstable shorelines in the Lake Mead delta are related to the declining reservoir level, and will not be resolved until the level of Lake Mead either regains its previous high levels or until the banks naturally stabilize under new, lower reservoir levels.

The Hualapai are also concerned with the effect of different flows on their boat docks. The number and duration of HFEs under LTEMP alternatives could affect boat docks and other facilities operated by the Hualapai Tribe. LTEMP alternatives differ in the frequency and type of HFEs that would occur over the 20-year LTEMP period (Table 4.10-1; Sections 4.3.2 and 4.3.3). Alternative A would have the fewest (average of 5.5 HFEs over the LTEMP period, with HFEs not being conducted after 2020); Alternative F would have the most (average of 38.1 HFEs over the entire LTEMP period).

Reclamation engineers evaluated the Haulapai dock structures in 2012 to consider, among other things, the effect of high flows and related sediment on the dock structures (Walkoviak 2012). The conclusion of this assessment was that "the docks as designed and built are currently at risk of failure under essentially any Glen Canyon Dam operating regime, including normal operations" and the "docks are already at risk of failure regardless of future HFE implementation." Based on this assessment, Reclamation concluded that "there are no appropriate actions necessary regarding these [dock] structures in advance or following a HFE." Reclamation recommended that the operators undertake "a thorough structural, geotechnical, and hydraulic engineering review, and consider rebuilding the structures to standards that would allow certification by a licensed civil engineer."

Since the 2012 assessment, Reclamation has not been notified of any modifications to the dock structures to address the structural issues identified. Accordingly, concerning the potential effects of HFE-related sediment discussed above, Reclamation's position continues to be that there is "no appropriate mitigation for HFEs for the docks as currently built." If modifications are made, Reclamaton will consult with the Haulapai Tribe to discuss next steps.

Regarding the potential for differences among alternatives in their impacts on sediment issues near Hualapai facilities at RM 260, it is expected that dam operations, HFEs, equalization flows, and other flow events will continue to deliver sediment to the Western Grand Canyon and Lake Mead. Nearly all sediment that enters the Grand Canyon below Lake Powell will eventually move downstream to the area of concern. Higher flows, in general, do transport more sediment, and sediment transport will continue in the free-flowing portions of the river below Diamond Creek.

Transport of sand downstream from sources in Marble Canyon (RM 0–RM 61) under various LTEMP alternatives is discussed in Sections 4.3.2 and 4.3.3. The least amount of sand that would be transported would be under Alternative A, primarily because, under this alternative, the HFE protocol would expire in 2020; HFEs are the major source of sand transport under the alternatives. Sand transport would be second lowest under Alternative D and greatest under Alternatives F and G.

One metric that helps explain the potential for differences in sediment that would be relevant to Hualapai recreational operations is the amount of sediment leaving Marble Canyon at RM 61. Table 4.10-2 presents those values for each alternative, as determined from sediment

TABLE 4.10-2 Amount of Sediment Transported Out of Marble Canyon under the LTEMP Alternatives over the 20-Year LTEMP Period

	Alternative						
Indicators	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Sand leaving Marble Canyon (ktons)	17,900	18,800	19,200	18,600	19,100	20,500	19,000
Sand leaving Marble Canyon (% change from Alternative A)	0	5	7	4	7	15	6
% change in suspended sand at RM 225 relative to Alternative A	0	2	3	2	3	6	2

modeling. However, many factors must be considered when trying to assess how these values for RM 61 would relate to sediment settling out at Hualapai facilities near RM 260:

- Based on the results of quantitative modeling performed for the LTEMP, LTEMP alternatives would differ in the amount of suspended sediment transported out of Marble Canyon.

- The sediment model does not estimate transport past the end of Marble Canyon (RM 61). Data at the USGS gage (number 09404200) above Diamond Creek in GCNP (RM 225) was used to estimate values at RM 260.

- Approximately 50% of the sand that is in suspension at RM 225 (and presumably in suspension at the Hualapai facilities at RM 260) is from sources other than Marble Canyon; therefore more than half of the sand in suspension at RM 260 is independent of dam operations and comes from the Little Colorado River and other tributaries downstream of Marble Canyon.

- Some portion of the suspended sediment being transported may settle out in the channel at RM 260; that portion is dependent on a number of factors, including the elevation of Lake Mead and local hydraulic conditions (e.g., velocity and depth). Unless there is a significant geomorphic change near Quartermaster Canyon—such as a change in slope, width, or Lake Mead elevation— suspended sand would likely continue to travel downstream.

- Variability in sand transport out of Marble Canyon based on potential future hydrology is much larger than any variation in sand transport due to LTEMP alternatives considered in this EIS.

The average amount of suspended sand passing RM 225 is approximately 44,000 ktons over 20 years. The increase in suspended sand at RM 225 relative to Alternative A is approximately 6% for Alternative F, approximately 2% for Alternative D, and under 3% for all other alternatives (Table 4.10-2). This difference is significantly less than the differences under potential future hydrologic conditions. The location where this suspended sand deposits downstream of RM 225 will be a function of Lake Mead elevation and local hydraulic conditions. However, the amount will not be more that what is in suspension, so the sand deposition at RM 260 will be much less than the 2 to 6% increase in suspended sand expected under the LTEMP action alternatives.

4.10.2.7 Pearce Ferry

Park facilities at Pearce Ferry, managed by LMNRA, have been damaged in the past by HFEs and may be affected by HFEs in the future. Effects would vary among alternatives, and those with more frequent HFEs, particularly spring HFEs, could have greater impact. In the months following HFEs, there would be temporary impacts on both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–June (following a spring HFE) would have greater impact on visitors than damage in November–January (following a fall HFE).

4.10.2.8 Park Operations and Management

As discussed in Section 3.10.4, potential effects on NPS staffing levels are related to recreation and resource concerns. For this analysis, staff levels were generally calculated as full-time equivalents, based upon known amounts of time currently dedicated to operational functions. To estimate the changes to staff levels that might be different among alternatives, an assumed relationship to a quantitative metric from modeling was used. For instance, if vegetation modeling indicated a 5% increase in nonnative invasive plants, it was assumed that there would be a 5% increase in the need for vegetation treatment work. Staff time for monitoring and maintenance of camping beaches and trails was estimated using the modeled Camping Area Index. Staff time related to special flows, such as HFEs or TMFs, was estimated based on the tracking of GCNRA and GCNP staff time for notification and coordination related to HFEs from 2011 to 2015. Flow patterns were looked at in terms of safety, and boating hazards and staff time for ranger patrols were analyzed, though this was looked at as trend information rather than quantitative contributions to the total as staff time for safety issues can vary greatly from year to year.

Another consideration that was evaluated was impacts on park facilities at Pearce Ferry, managed by LMNRA, as these facilities have been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects would vary between alternatives, as those with more frequent HFEs, particularly spring HFEs, may have more effects than those with fewer HFEs. There would be temporary impacts in the months following HFEs to both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–

June (following a spring HFE) would have more impact on visitors than damage in November–January (following a fall HFE).

Based on the analysis conducted, the maximum difference between action alternatives (B through G) and Alternative A was a 1.8 full-time equivalent decrease (Alternative D), and the maximum was an increase of 0.1 full-time equivalent (Alternative B). However, factors such as safety response and repairs at Pearce Ferry, which were considered but were not possible to quantify, did not vary in the same direction as the quantified effects. Therefore, the differences among alternatives may be less than indicated by the quantified effects. Based on this analysis, it was determined that the variation among alternatives for park staffing for recreation and resource concerns would be negligible.

4.10.3 Alternative-Specific Impacts

The following section provides descriptions of impacts that are expected to occur under each of the LTEMP alternatives.

4.10.3.1 Alternative A (No Action Alternative)

Under Alternative A, trout abundance, size, and catch rates are expected to vary within the ranges that have been observed under MLFF operations over the past 20 years. About 770 large trout (a number intermediate among the alternatives; large trout are defined as individuals exceeding 16 in. in length) would be expected under Alternative A, as well as intermediate levels of angler catch rates (Section 4.5.3.1). Fishing would be disrupted during HFEs, but the number of HFEs under Alternative A is the lowest of all alternatives (5.5) and HFEs would not be conducted after 2020. The maximum number of days that HFEs would disrupt fishing in any year would be 8 if a spring and fall HFE were conducted in the same calendar year. Therefore, under Alternative A overall angler satisfaction is anticipated to remain the same as at present, with a consistent trend in the fishery toward more, but smaller, fish. Alternative A is expected to result in the highest angler satisfaction of all alternatives, by a small margin (Section 4.14.2.1).

The current MLFF maximum up-ramp rate of 4,000 cfs/hour under this alternative has been adopted for all LTEMP alternatives and it is not anticipated that this ramp rate would create angler safety issues. The down-ramp rate of 1,500 cfs is the same as the current rate and also does not create issues for anglers.

Because this alternative only allows for HFEs until 2020 and has the fewest total number of HFEs, Alternative A scores the best among alternatives in the Glen Canyon Rafting Metric, with a projected mean annual loss of only 49 visitor rafting trips (Figure 4.10-1), compared to a total mean annual visitor use of 50,000 visitors. This is a 0.01% reduction. In addition, the lower number of HFEs would result in the lowest anticipated impact on the sediment terraces and the recreational resources they support.

With respect to whitewater boating, about 80% of the time daily fluctuations would remain in a range preferred by whitewater boaters (FI = 0.79) (Figure 4.10-1). Navigational boating risks due to flows below 8,000 cfs under Alternative A, as reflected in the navigation index, would be about in the middle of the range for all alternatives (NI = 0.50) (Figure 4.10-1). Having the lowest mean number of HFEs over the LTEMP period, Alternative A has among the lowest potential for increasing campsite area of all alternatives, with a camping area index value of 0.14 (Figure 4.10-1). Based on observed effects under the current MLFF operating regime, this alternative is expected to lead to a continued loss of campsite area due to erosion and increased campsite crowding.

There would be no change in current sediment conditions that could affect Hualapai recreation operations in the Western Grand Canyon, but these facilities could be affected by HFEs until 2020 (average 5.5 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative A, including mechanical removal of trout in the Little Colorado River reach and testing TMFs. Mechanical trout removal activities are intensive activities that can last many days and over a period of several months (Reclamation 2011a). Mechanical trout removal activities would have a short-term impact to visitor experience from motorized use. Based on modeling of trout numbers, there is a low probability that this activity will occur under Alternative A during the LTEMP period.

In summary, there would be little change from current conditions under Alternative A. Alternative A would have the fewest HFEs (ending in 2020) that could affect fishing and boating, and moderate flow fluctuations. Anglers would expect to see intermediate numbers of large trout and intermediate catch rates. Few navigability concerns from low flows would occur. Concerns for angler safety from high up-ramp rates would be low. Alternative A would have the fewest lost day rafting trips in Glen Canyon resulting from HFEs. Ongoing loss of camping area would continue, leading to increased crowding. There would be very little interference with recreation from testing and implementing experimental elements under the alternative.

4.10.3.2 Alternative B

Of all the alternatives, Alternative B has the lowest estimated number of rainbow trout and trout emigrants in the trout fishery below Glen Canyon Dam, but it has the greatest estimated number of large rainbow trout (>16 in.), about 870 fish. Hydropower improvement flows, which may occur in 4 out of 20 years, would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (Section 4.5.3.2). Angler catch rates would be the lowest of all alternatives because of the relatively low number of trout under this alternative. Fishing would be disrupted during HFEs, but the number of HFEs under Alternative B (7.2) is comparable to the number under Alternative A (5.5). The maximum number of days HFEs would disrupt fishing in any year would be 4, because, under Alternative B, no more than one HFE would be conducted every other year. Alternative B is expected to

have angler satisfaction related to flow levels and fluctuations similar to that under Alternative A. High daily fluctuations (up to 66% higher), down-ramp rates as high as 4,000 cfs/hour (2.7 times higher than under Alternative A), and more frequent flows below 8,000 cfs result in relatively low navigability (Figure 4.10-1).

Alternative B is expected to have slightly more HFEs than Alternative A, and would result in an anticipated mean loss of 71 annual Glen Canyon day-rafting opportunities (Figure 4.10-1). Under Alternative B, there is a slightly increased likelihood of additional impacts on sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, but the total number of HFEs would be comparable to the number under Alternative A (average 7.2 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

Whitewater boating would be affected by high daily fluctuations under Alternative B; daily fluctuations would remain in a range preferred by whitewater boaters only about 42% of the time (FI = 0.42), the lowest of all alternatives. As reflected in a NI value of 0.39, navigational boating risks due to flows below 8,000 cfs under Alternative B would be the second highest. In addition, the down-ramp rate is 2 to 2.6 times higher than under Alternative A, which could lead to boats being stranded in both GCNRA and GCNP. Alternative B is expected to result in slightly more camping area than Alternative A (CAI = 0.15) (Figure 4.10-1) due to a higher number of HFEs, but there would be a continued declining trend in campsite area due to high flow fluctuations. Total number of campsites and campsite area would continue to decrease under Alternative B, potentially increasing competition and crowding at campsites.

In addition to HFEs, Alternative B includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, and hydropower improvement flows in 4 years during the LTEMP period when annual volume is ≤8.23 maf (Section 2.2.2).

The impacts of mechanical trout removal activities would be similar to those described under Alternative A; however, based on modeling of trout numbers there is a low probability that this activity will be triggered under Alternative B during the LTEMP period.

TMFs are expected to be triggered relatively infrequently under this alternative (mean of three TMFs triggered over the 20-year LTEMP period); therefore the overall impact of TMFs on recreation is expected to be minimal. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are intended to decrease trout abundance in the fishery in the Glen Canyon reach, which could result in a reduced angler catch rate but could also increase the number of larger fish.

Tests of hydropower improvement flows in 4 years when annual volume is ≤8.23 maf would more closely resemble the operations at Glen Canyon Dam prior to the early 1990s, and

would produce daily fluctuations up 20,000 cfs (5,000 cfs nighttime to 25,000 cfs daytime). The daily minimum flow would be 5,000 cfs and the up- and down-ramp rates would each be 5,000 cfs/hr. High ramp rates, when combined with the overall level of fluctuations under Alternative B, would create additional difficulties in navigating rapids and managing boats tied to shore. In the 1995 EIS (Reclamation 1995), rapidly increasing flow was identified as a safety concern for wading fishermen with respect to their ability to move toward shore. This pattern of river fluctuations and high daytime flows would also adversely affect fishing and usable campsite area.

In summary, Alternative B would have the second fewest HFEs and the greatest flow fluctuations; the former would result in relatively few days that would disrupt angling and boating from river closings, similar to Alternative A, and the latter would result in reduced whitewater boater satisfaction due to high daily fluctuations compared to Alternative A. The number of large trout would be highest of all alternatives, but catch rates lowest. Navigability and boat stranding concerns would be the greatest of all alternatives due to high fluctuations and high down-ramp rates, but relatively low overall. There would be few lost day rafting trips in Glen Canyon due to HFEs, similar in number to Alternative A. Camping area is expected to continue to decrease due to erosion, similar to Alternative A. Interference with recreation from testing and implementing experimental elements would be low and similar to that under Alternative A, with the exception of hydropower improvement flows, which would produce greater impacts than under Alternative A.

4.10.3.3 Alternative C

Under Alternative C, about 750 large trout are predicted to be present below Glen Canyon Dam, similar to the number under Alternative A (770); angler catch rates would be similar to those under Alternatives A, D, and E, more than under Alternative B and less than under Alternatives F and G (Section 4.5.3.3). Fishing would be disrupted during HFEs, and the number of HFEs under Alternative C (21.3) is much higher than the number under Alternative A (5.5). The maximum number of days HFEs could disrupt fishing in any year would be 10 under Alternative C (if a spring HFE and extended-duration fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under this alternative is expected to be similar to that of Alternative A. The down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an estimated 315 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1) as compared to a loss of 49 such opportunities under Alternative A. In addition, under Alternative C, the larger mean number of HFEs is expected to result in erosion of sediment terraces from wetting and undercutting in the Glen Canyon reach that support recreation facilities and campsites.

Daily fluctuations would remain in a range preferred by whitewater boaters most of the time (FI = 0.93). The low frequency of flows below 8,000 cfs results in good navigation (NI = 0.75), exceeded only by Alternative G. Because of the relatively high number of HFEs and

moderate fluctuations under Alternative C, it has a higher probability of producing an increase in campsite area compared to Alternative A (Figure 4.10-1).

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 21.3 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative C includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, and low summer flows. Mechanical trout removal activities would be triggered infrequently and could temporaily limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate, but could also result in an increased number of larger fish in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered six times during the 20-year LTEMP period under Alternative C, compared to no TMFs under Alternative A (Table 4.9-2).

The impacts of testing low summer flows would vary depending on the level of flows and the number of years they are employed. Flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, and potentially more difficult navigation.

In summary, Alternative C would have almost four times the number of HFEs that could affect fishing and boating, compared to Alternative A, but lower daily fluctuation levels. Angler satisfaction with flow rate and fluctuations would be similar to that under Alternative A, and so would the number of larger trout and trout catch rates. Few navigation concerns would exist, similar to Alternative A. However, the number of lost day rafting trips in Glen Canyon due to HFEs would be about six times the number under Alternative A, but this is still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, while continued reduction is expected under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.4 Alternative D (Preferred Alternative)

Under Alternative D, an estimated 810 large trout are predicted to be present in the trout fishery below Glen Canyon Dam, with angler catch rates similar to those under Alternatives A, C, and E; this would be more than under Alternative B, and less than under Alternatives F and G (Section 4.5.3.4). Fishing would be disrupted during HFEs, and the number of HFEs under

Alternative D (21.1)[25] is much higher than under Alternative A (5.5). The maximum number of days that HFEs could disrupt fishing in any year would be 10 under Alternative D (if an extended-duration fall HFE were conducted). Angler satisfaction related to flow levels and fluctuations under Alternative D is expected to be similar to that under Alternative A. The down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an estimated 348 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1) as compared to a loss of 49 such opportunities under Alternative A. In addition, more frequent HFEs under Alternative D compared to Alternative A are expected to result in relatively greater erosion of sediment terraces due to wetting and undercutting the Glen Canyon reach that supports recreation facilities and campsites.

Daily flow fluctuations (FI = 0.74) and daily minimum flows that may affect navigability (NI = 0.45) under Alternative D are lower those under Alternative A, and intermediate among all alternatives for both metrics. Because of the relatively high number of HFEs and moderate fluctuations, Alternative D is expected to increase campsite area (CAI = 0.36) more than Alternatives A, B, and E, and less than Alternatives C, F, and G (Figure 4.10-1).

There would be a slight increase (2%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 21.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative D includes experimental testing of mechanical removal of trout in the Little Colorado River reach, TMFs, macroinvertebrate production flows, and low summer flows. Although there can be direct effects of these experiments on recreation, long-term indirect benefits for recreation may accrue from the adoption of successful treatments, including potentially improved aquatic food base that supports the trout fishery.

Mechanical trout removal activities, although triggered infrequently, might limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered in 8 years over the 20-year LTEMP period, compared to no TMFs under Alternative A (Table 4.9-2).

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25 Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is could result in a decrease in Alternative D's impacts on Hualapai docks in the Western Grand Canyon.

Low summer flows would be tested only in the second 10 years of the 20-year LTEMP period. Flows of 8,000 cfs or less would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by commercial rafters and fishing guides because of low flows. Testing macroinvertebrate production flows would feature steady flows on every weekend from May through August (34 days total). Under this experiment, the flow on weekends would be held to the minimum flow for that month. Effects on recreation would be similar to those for low summer flows.

In summary, Alternative D would have almost four times the number of HFEs that could disrupt fishing and boating and similar daily fluctuation levels, compared to Alternative A. Angler satisfaction with flow levels and fluctuations would be similar to that underAlternative A, as would the number of larger trout and trout catch rates. Few navigation concerns would exist, similar to Alternative A. However, the number of lost rafting trips due to HFEs would be about seven times that of Alternative A. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.5 Alternative E

Alternative E is expected to result in an estimated number of rainbow trout and trout emigrants near the low end of alternatives and similar to Alternative A, with the second-highest expected number of large rainbow trout (about 830 fish) in the trout fishery below Glen Canyon Dam after Alternative B (Section 4.5.3.5). Angler catch rates similar to those under Alternative A would be expected. Fishing would be disrupted during HFEs, and the number of HFEs under Alternative E (17.1) is much higher than under Alternative A (5.5). The maximum number of days HFEs could disrupt fishing in any year would be 8 under Alternative E (if a spring HFE and fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under Alternative E is expected to be similar to that under Alternative A. The down-ramp rate of this alternative is 1.7 times that of Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative would result in an estimated 177 lost day-rafting visitor opportunities in Glen Canyon (Figure 4.10-1), an increase of 146 over Alternative A. In addition, under Alternative E, the larger mean number of HFEs is expected to result in an increase in adverse impacts on sediment terraces in the Glen Canyon reach that supports recreation facilities and campsites, compared to Alternative A.

Daily fluctuations would be in the range preferred by whitewater boaters only about half of the time (FI = 0.57) and is lower than under all other alternatives except Alternative B, while flows would be below 8,000 cfs more frequently than all other alternatives (NI = 0.37), slightly more frequent that Alternative B. Because of the relatively high number of HFEs under Alternative E, this alternative is expected to increase campsite area (CAI = 0.30) more than Alternatives A and B, but somewhat less than Alternatives C, D, F and G.

There would be a slight increase (3%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 17.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative E, including mechanical removal of trout in the Little Colorado Reach, testing and implementing TMFs, and testing low summer flows in the second 10 years of the LTEMP period.

The impacts of mechanical removal of trout in the Little Colorado reach would be similar to those described under Alternative A. Overall, there is a low probability that this action would be triggered during the LTEMP period based on the expected number of trout in the Little Colorado River reach.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered in 3 years over the 20-year LTEMP period, compared to no TMFs under Alternative A (Table 4.9-2).

The impacts of testing low summer flows would be the same as discussed under Alternative C. When they are tested, summer flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by fishing guides due to angler perception of less-desirable fishing conditions.

In summary, Alternative E would have three times as many HFEs that could affect fishing and boating and similar daily fluctuations, compared to Alternative A. Angler satisfaction with flow levels and fluctuations would be similar to that under Alternative A. The number of large trout would be higher than under Alternative A, while catch rates would be similar to those under Alternative A. Few navigation concerns would exist, but slightly more than under Alternative A. The number of lost rafting trips due to HFEs would be 3 to 4 times that of Alternative A, but still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.6 Alternative F

The steady daily flows of Alternative F are expected to result in higher numbers of trout and increased angler catch rates, but the lowest number of large trout of all alternatives (600 fish) (Section 4.5.3.6). In addition, this alternative does not include any trout management actions

(i.e., mechanical removal and TMFs). Angler satisfaction related to flow levels and fluctuations under Alternative F, however, is anticipated to be lowest of all alternatives due to high flows during peak fishing season (Section 4.14.2.1). In addition, Alternative F has the highest number of HFEs (38.1) of all alternatives, including a 1-day HFE in early May in all years without a sediment-triggered spring HFE. In addition, there would be an annual 7-day 25,000-cfs flow at the end of June that would occur during prime fishing months, which would also adversely impact fishing. The maximum number of days HFEs could disrupt fishing in any year would be 8, under Alternative F (if a spring HFE and fall HFE were conducted in the same calendar year).

An anticipated mean annual loss of 919 day-use rafting opportunities in Glen Canyon due to HFEs (Figure 4.10-1) is the largest such loss of any alternative and about 20 times that of Alternative A (loss of 49 rafting opportunities). In addition, the large number of HFEs in Alternative F would tend to increase erosion of sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

Under the steady flows of Alternative F, whitewater boaters would not be affected by daily flow fluctuations (FI = 1.0). With most daily flows near or above 8,000 cfs (NI = 0.71), navigability is expected to be higher than under Alternatives A, B, D and E and lower than under Alternatives C and G. Thus, conditions are anticipated to be satisfactory for boaters most of the time. With a high number of HFEs and steady monthly flows, Alternative F has a high likelihood of increasing campsite area (CAI = 0.41) (Figure 4.10-1). Steady daily flows would result in predictable availability of campsites. Usable campsite area would be reduced somewhat compared to Alternative G, due to high seasonal flows in March through June under Alternative F. Because Alternative F has lower flows in summer and fall months, that alternative may result in greater useable camping area during those months than under Alternative G.

There would be a small increase (6%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A or any other LTEMP alternative (average 38.1 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

There are no experimental elements in this alternative, other than HFEs, that could affect recreation.

In summary, Alternative F would have the greatest number of HFEs of all alternatives that could affect fishing and boating. In addition, angler satisfaction with flow levels under Alternative F is anticipated to be lowest of all alternatives due to high flows during the peak fishing season. The fewest large trout are expected under this alternative, but highest catch rates. Very few navigability concerns would exist from low flows and no safety or convenience concerns from daily fluctuations. However, the most lost rafting trips due to HFEs would occur, about 20 times the number under Alternative A. Alternative F is expected to be the second most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. It would have no interference with recreation from testing and implementing experimental actions beyond those related to HFEs.

4.10.3.7 Alternative G

Alternative G would have the second-lowest number of large trout (700 fish), but trout abundance and angler catch rates would be high (Section 4.5.3.7). Fishing would be disrupted during HFEs, and the number of HFEs under Alternative G (24.5) is much higher than under Alternative A (5.5). The maximum number of days that HFEs could disrupt fishing in any year would be 18 under Alternative G (if a spring HFE and extended-duration fall HFE were conducted in the same calendar year). Angler satisfaction related to flow levels and fluctuations under this alternative is expected to be slightly less than that under Alternative A.

The relatively high number of HFEs under this alternative (including proactive spring HFEs and extended-duration fall HFEs) would result in an anticipated annual loss of 512 visitor day-rafting opportunities in Glen Canyon over the LTEMP period (Figure 4.10-1); this is more than 10 times larger than under Alternative A (loss of 49 rafting opportunities). The number of HFEs would result in a higher tendency to erode sediment terraces that support recreation facilities and campsites compared to all alternatives but Alternative F.

Under the steady flows of Alternative G, whitewater boaters would not be affected by daily flow fluctuations (FI = 0.98), and the steady monthly flows would be consistently above 8,000 cfs, reflecting high navigability (NI = 0.96). Because of the high number of HFEs under Alternative G, and its steady monthly and daily flows, it has the highest likelihood of any alternative of increasing campsite area (CAI = 0.45) (Figure 4.10-1).

There would be a slight increase (2%) in suspended sediment at Hualapai recreational facilities in the Western Grand Canyon. These facilities could be affected by HFEs during the entire LTEMP period, and the total number of HFEs would be higher than the number under Alternative A (average 24.5 HFEs over the 20-year LTEMP period). Reclamation will address any concerns related to these facilities in the manner stated in the 2012 letter between Reclamation and the Hualapai Tribe (Walkoviak 2012).

In addition to HFEs, Alternative G includes experimental testing of mechanical removal of trout in the Little Colorado Reach; and testing and implementation of TMFs. The impacts of mechanical trout removal activities would be similar to those described under Alternative A. Based on the expected number of trout in the Little Colorado River reach, Alternative G has an estimated three such removals, the greatest number triggered during the LTEMP period of all alternatives (Table 4.9-2).

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects are expected to be fairly short term due to the dynamic nature of the fishery. Based on the anticipated higher trout recruitment levels, Alternative G is expected trigger TMFs in 11 of 20 LTEMP years (Table 4.9-2), the highest number of all alternatives.

In summary, angler satisfaction with flow levels and fluctuations would be similar to that under Alternative A. Alternative G would have fewer large trout than Alternative A, but catch rates would be higher. Very few navigability concerns would exist from low flows and no safety

or convenience concerns from daily fluctuations. There would be about 10 times more lost rafting trips due to HFEs than under Alternative A. Alternative G is expected to be the most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.11 WILDERNESS

This section presents the potential impacts on wilderness and visitor wilderness experience. Although flows from Glen Canyon Dam would not be considered a prohibited use under the Wilderness Act, impacts are disclosed within this section for the purposes of their implications to NPS wilderness management. Background information on the wilderness qualities evaluated in this analysis appears in Section 3.15.

Issue: How do the alternatives affect wilderness and visitor wilderness experience?

Impact Indicators:

- Opportunities for solitude at campsites and on the river
- Preservation of natural conditions as reflected by naturalness of flow
- Rafters' time available for onshore exploration
- Visual and noise disturbances from administrative uses

As stated in Section 3.11, there is proposed wilderness in both Glen Canyon and the Grand Canyon within the Colorado River Ecosystem. The NPS has an obligation to manage the Colorado River corridor through GCNP to protect and preserve the resource in a wild and primitive condition and provide a wilderness river experience (as described in the 2006 Colorado River Management Plan). The proposed wilderness designation does not include areas upstream from Lees Ferry (including Glen Canyon Dam); moreover, the NPS management for wilderness values must remain consistent with the Section 1802 (b) of the GCPA. There are also references to Section 4.10: Recreation, Visitor Use, and Experience.

4.11.1 Analysis Methods

The analysis of impacts on wilderness and visitor wilderness experience downstream of Glen Canyon Dam was based on an assessment of alternative-specific differences in four indicators of the quality of visitor wilderness experience: opportunities for solitude at campsites and on the river; preservation of natural conditions as reflected by naturalness of flow; opportunities for experiencing wilderness as indicated by the amount of time rafters have for exploration; and visual and noise disturbances. These indicators are evaluated qualitatively and comparatively as they relate to the differing properties or features of the seven alternatives.

The effects of the alternatives on campsite crowding and its effect on visitor wilderness experience was evaluated through consideration of the tendency of flow patterns and experimental flows (mainly HFEs) under the various alternatives to build beaches and thus potentially increase campsite area. The likelihood of rafters encountering other groups at rapids

was evaluated based on the expected frequency of daily flows less than 8,000 cfs, a flow level associated with rafting delays at rapids as rafters scout conditions or wait for higher flows. Flows of 8,000–9,000 cfs have been identified by commercial guides as the minimum level necessary to safely run the river with passengers (Bishop et al. 1987; Stewart et al. 2000).

The naturalness of flows was evaluated by determining the magnitude of daily flow fluctuations under alternatives as compared to fluctuation levels perceived to be less natural, generally greater than 10,000 cfs as identified by Bishop et al. (1987). Stewart et al. (2000) found that daily fluctuations of 5,000–8,000 cfs under MLFF were not an issue for most recreational use, but they did not address fluctuations above 10,000 cfs. Opportunities for rafters to explore attraction sites or enjoy personal time at camp were evaluated by determining the effects of flow on river travel duration and the amount of off-river time available each day. Finally, the effects of noise and visual disturbance of wilderness values was evaluated by considering the number of HFEs, TMFs, trout removals, and the relative number of administrative trips expected under the alternatives.

The metrics described in Section 4.10 were used as input to the evaluation of effects on wilderness experience. The potential for beach building used the Camping Area Index to evaluate the effects of campsite availability and size on potential crowding and opportunities for solitude (Figure 4.10-1a); the Navigation Risk Index was used to evaluate potential crowding at rapids (Figure 4.10-1d); the Fluctuation Index was used to evaluate the naturalness of flows(Figure 4.10-1c); and the Time-Off-River Index was used to evaluate the opportunity for onshore exploration (Figure 4.10-1b). The effects of HFEs, TMFs, trout removal, and other experimental actions were evaluated from estimates of the expected frequency of such actions for the alternatives. Using these metrics and supporting information, it was possible to rank the alternatives with respect to their relative effects on associated wilderness values. The details of the methodology used to produce metric values and detailed results are presented in Appendix J.

4.11.2 Summary of Impacts

In Section 3.15, wilderness character is described as having four qualities: untrammeled, natural, undeveloped, and providing for outstanding opportunities for solitude or a primitive and unconfined form of recreation. In describing the wilderness values and visitor experiences within GCNP that are to be preserved and protected, GCNP's General Management Plan states that "Visitors traveling through the canyon on the Colorado River should have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social. Visitors should be able to continue to experience the river corridor with as little influence from the modern world as possible. The river experience should help visitors to intimately relate to the majesty of the canyon" (NPS 1995).

Dam operations and management activities considered under LTEMP alternatives can affect these wilderness values and the quality of the wilderness river experience for river visitors. As dam operations affect beach retention or building, operations under the alternatives can affect campsite crowding and solitude. Similarly, low daytime flows less than 8,000 cfs can increase crowding at rapids. Although these are conceivable effects on wilderness experience and have

been modeled for the alternatives, such effects would detract only slightly from an overall wilderness experience in the study area, and differences in the effects of alternatives would be difficult to discern.

Wilderness experience may also be affected by high daily fluctuations that appear to be greater than what would occur naturally. Fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river (Bishop et al. 1987). TMFs and HFEs would also present less natural conditions to visitors. However, daily fluctuations under MLFF and the proposed alternatives are generally constrained to near or less than 10,000 cfs and thus would have at most a small effect on perceptions of naturalness, differences in which would be difficult to discern among fluctuating flow alternatives; the steady flow Alternatives F and G would have no such effects.

Overall flow level can also affect the wilderness experience through effects on the duration of rafting trips and thus the time available for onshore exploration. However, because there is little difference among the alternatives in time off river (Figure 4.10-1b), this measure is not discussed further in this analysis.

Finally, resource management actions, (i.e., administrative actions) including experimental vegetation treatment under all alternatives but Alternative A; mechanical removal of trout, which is allowed under some alternatives; and other experimental work and administrative trips common to all alternatives can affect visitor experience by increasing encounter rates, placement and use of equipment, and noise from motorized equipment. Such effects would be infrequent and short term and would affect relatively few visitors. Vegetation actions, even though they would conform to minimum tool use requirements, may have short-term negative effects during disturbance but long-term positive effects on wilderness by returning native vegetation and hence wilderness character. Effects on wilderness experience of the LTEMP alternatives are summarized and compared in Table 4.11-1 and analyzed in the discussions that follow.

Campsite crowding has been reduced since the implementation in 2006 of the CRMP (NPS 2005a), but campsite area and campsite size was decreasing (Kaplinski et al. 2010) prior to adoption of the HFE protocol in 2011 (Reclamation 2011b). Alternatives that do not reverse the trend of loss in campsite area eventually would have an adverse effect on wilderness qualities because of increases in crowding at remaining campsites. On the basis of the number of HFEs anticipated under each of the alternatives (Section 4.3), Alternatives F and G are expected to result in the greatest benefit to visitor wilderness experience with respect to opportunity for solitude, because of a greater likelihood of increasing and retaining campsite area (Section 4.10.2). Alternatives C, D, and E rank just below Alternatives F and G, while Alternatives A and B rank lowest with regard to camping area as a consequence of having the fewest HFEs. Under Alternative A (the No Action Alternative), HFEs would not be implemented after the HFE protocol expired in 2020.

On the basis of allowable within-day fluctuation, Alternatives B and E would have more frequent occurrences of very low flows (about 60% of days), including in the periods of peak recreational use, and therefore would tend to result in more crowding at rapids as rafters stop to

TABLE 4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Compared to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Compared to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, greater disturbance from non-flow actions.	Compared to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Compared to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Campsite crowding as indicated by the camping area index (CAI)	No change from current conditions; lack of HFEs after 2020 would lead to continued declining size and number of campsites (CAI = 0.14 out of 1) and could result in further crowding and adverse effects on solitude.	Compared to Alternative A, continued declining trend in campsite area (CAI = 0.15) could result in crowding and adverse effects on solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.38) could reduce crowding and improve solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.36) could reduce crowding and improve solitude.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.30) could reduce crowding and improve solitude, but would be lower than other alternatives except Alternatives A and B.	Compared to Alternative A, the expected increase in campsite area (CAI = 0.41) could reduce crowding and improve solitude. Steady flows also would aid trip planning, helping to avoid crowding.	Compared to Alternative A, greatest increase in campsite area (CAI = 0.45) could reduce crowding and improve solitude. Steady flows also would aid trip planning, helping to avoid crowding.

TABLE 4.11-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Encounters with other groups at rapids due to low flows (8,000 cfs) as indicated by the navigation index (NI)	No change from current conditions; intermediate rank among alternatives; NI = 0.50 out of 1.	More encounters than Alternative A; NI = 0.39.	Fewer encounters than Alternative A; NI = 0.75.	Similar effect as Alternative A; NI = 0.45.	Most encounters due to highest frequency of low flows; NI = 0.37.	Fewer encounters than Alternative A because steady flows mostly above 8,000 cfs; NI = 0.71.	Fewest encounters because of steady flows nearly always above 8,000 cfs; NI = 0.96.
Effect of daily fluctuations as indicated by the fluctuation index (FI)	No change from current conditions; intermediate effect among alternatives, FI = 0.79 out of 1.	Highest daily fluctuations, FI = 0.42.	Almost no effect, FI = 0.93.	Similar to Alternative A, FI = 0.74.	Second-highest daily fluctuations, FI = 0.57.	No effect; steady daily flows, FI = 1.0.	No effect; steady daily flows, FI = 0.98.
Disturbance from non-flow actions: vegetation management, mechanical removal of trout, and administrative trips	No change from current conditions; no vegetation treatments, few mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments; and few mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.	Compared to Alternative A, greater impacts due to vegetation treatments and potentially more mechanical removals of trout.	Compared to Alternative A, less impact due to absence of mechanical removals of trout, but greater effects due to vegetation treatments.	Compared to Alternative A, greater impacts due to vegetation treatments and more mechanical removals of trout.

scout rapids or wait for flows to rise. Alternatives D and A would be similar to each other and comparable to current conditions (about 50% of days with low flows), while Alternatives F, C, and G would have the fewest days with low flows (about 5% to 30% of days), and would result in the lowest chances of encountering other groups. Although these comparisons are easily made on the basis of the flow patterns of the alternatives, the actual effects on crowding at rapids may be small overall, and small differences noted between alternatives may not be significant.

Daily flow fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river. The effect of such flow fluctuations on wilderness experience was evaluated using the fluctuation index (Section J.2.3 in Appendix J) developed from maximum "tolerable" fluctuations preferred by whitewater rafters (Table 3.10-2), which are generally less than 10,000 cfs and depend on overall flow level (Bishop et al. 1987). The fluctuation index is presented in Section 4.10, where it is used to evaluate effects of fluctuations on whitewater rafting. It is used here as a surrogate for effects on perceived natural conditions in the Grand Canyon. Alternatives F and G, which employ steady flows, have fluctuation index values near 1.0, indicating no within-day fluctuations. Fluctuating flow Alternatives A, C, and D would be similar to each other, with most fluctuations within the preferred range; they would have fluctuation index values of 0.79, 0.93, and 0.74, respectively. Alternatives B and E would have the lowest fluctuation index values, indicating the lowest frequency of fluctuations within the preferred range (Figure 4.10-1). Alternative D would include testing of macroinvertebrate production flows during weekend days from March through August, and these steady flows would reduce any impacts of fluctuations on wilderness experience on those days. Because most daily fluctuations under all alternatives are below the 10,000-cfs level (flows ≥10,000 cfs were identified as being perceived as less natural by Bishop et al. 1987), the fluctuation index, which was developed for whitewater rafting for effects of fluctuations on such factors as navigation and camping, is not a perfect surrogate for evaluating perceived naturalness of flows. Visitors would be expected to notice that high daily fluctuations are not natural; however, the overall effects of such perceptions on wilderness experience are likely fairly small.

A metric (time off river) was developed to quantify the relative amount of time rafters would have to explore and enjoy wilderness at the end of each day (Section 4.10.1). Roberts and Bieri (2001) demonstrated that groups spent 50% less time off river at a flow of 8,000 cfs, compared to a flow of 19,000 cfs. Evaluation of the flow patterns of the LTEMP alternatives demonstrated that there would be very little difference among alternatives for this metric, except under Alternative F, which has elevated flows during the peak boating season. This similarity among alternatives is likely due to the fact that each has similar mean annual flows of between 10,000 and 15,000 cfs.

Non-flow experimental actions, including mechanical removal of trout, experimental vegetation treatments, and administrative trips related to monitoring and data collection needed for the GCDAMP would also present less natural conditions to visitors related to noise and visual disturbances. Vegetation treatments, proposed by NPS as an experimental, pilot effort to determine the effectiveness of vegetation control and treatment efforts, would occur under all alternatives except for Alternative A. They would temporarily adversely affect wilderness experience while the activities were ongoing and until treatments were discontinued, either

because they had achieved a level of success that produced natural vegetation communities, or because they were ineffective.

Alternative A would have the lowest impacts from non-flow experimental actions, because vegetation treatment is not included in the alternative. Alternative F would have impacts that were slightly higher than Alternative A, but lower than the remaining alternatives, because this alternative does not employ mechanical trout removal. Alternatives B, C, D, E, and G would have the highest levels of such impacts, which would be comparable under these alternatives.

Considering the effects of flow fluctuation overall, the steady flow Alternatives F and G would rank as having generally lower adverse effects on wilderness experience than the fluctuating flow alternatives, because the latter alternatives have effects on a daily basis. This advantage is reduced somewhat, but not entirely, by the higher frequency of HFEs under Alternative F and of HFEs and TMFs under Alternative G as compared to the fluctuating flow Alternatives A–E. Of the fluctuating flow alternatives, Alternative A would have the lowest effects from fluctuating flows due to moderate daily fluctuations, few HFEs, and no TMFs. Alternatives B, C, D, and E would have comparable effects from fluctuations, with Alternative B having the greatest effect from high daily fluctuations, but the fewest HFEs of these alternatives.

Considering sand retention and potential increase in sandbar area, which is also an effect of flows and flow fluctuations, benefits related to sand retention and increases in sandbar area would be lowest under Alternatives A and B, which would have relatively few HFEs that would build bars and relatively high fluctuating flows that would erode bars. Benefits would be intermediate under Alternatives C, D, and E, which have more HFEs to build sandbar area than Alternatives A and B. Benefits would be greatest under Alternatives F and G, which would have steady flows and the most frequent HFEs. Crowding and loss of solitude would decrease with increasing sandbar area.

While the metrics discussed above provide an analytical tool to evaluate and differentiate the LTEMP alternatives with regard to effects on visitor wilderness experience, actual differences for most visitors would be small and many of the disturbances evaluated—including HFEs, TMFs, mechanical trout removals, and vegetation management—would be infrequent, short-term actions that would not affect most visitors. In addition, few visitors would be expected to experience more than one of these disturbances, as a given action of one type typically excludes the other actions at a given time (e.g., a TMF would not occur at the same time as an HFE or likely within the time period of a single trip).

4.11.3 Alternative-Specific Impacts

The following Section provides descriptions of impacts summarized above as they are expected to occur under each of the LTEMP alternatives. The alternatives are compared in terms of the relative rankings of the various wilderness experience effects and measures considered, rather than in absolute terms.

4.11.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), the HFE protocol would expire in 2020. It is expected that implementation of the protocol up to its expiration would help reverse the ongoing trend of declining campsite area, but the declining trend would resume after the protocol expired. Any increase in crowding would reduce opportunities for solitude and primitive, unconfined recreation under this alternative.

Alternative A, with a navigation index of 0.50 (Figure 4.10-1), ranks in the middle of the LTEMP alternatives, indicating a relatively high tendency for low flows to lead to encountering other groups at rapids under Alternative A. The navigation index is a seasonally weighted measure of the frequency of minimum daily flows greater than 8,000 cfs, identified as the flow below which navigation risks increase (Appendix J.2.2).

Similarly, Alternative A ranks in the middle of alternatives with regard to daily fluctuation levels, with a fluctuation index of 0.79 (Figure 4.10-1); a majority of days would be within the daily range of fluctuations preferred by whitewater rafters (Section J.2.3 in Appendix J), which would also maintain a sense of naturalness as identified by Bishop et al. (1987). This ranking is consistent with allowed daily fluctuations under the respective alternatives. With respect to experimental flows, Alternative A has the lowest projected number of HFEs and no TMFs that would negatively affect wilderness experience.

Alternative A would have the second lowest impacts on wilderness experience from non-flow actions overall among the alternatives. Alternative A has no TMFs, a low expected number of mechanical removal trips, and no experimental vegetation treatments. The number of administrative trips expected under this alternative would be comparable to that of other alternatives.

In summary, Alternative A has the lowest potential to increase campsite area and a corresponding decrease in visitor solitude, and a moderate tendency for crowding at rapids due to periods of lower flows. Alternative A would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and has the lowest adverse effects from non-flow experimental actions on wilderness experience as a result of having the lowest combined number of such actions.

4.11.3.2 Alternative B

Alternative B would have a relatively low potential to retain and build sandbar area, similar to that for Alternative A, and would be expected to continue a long-term trend of increasing campsite crowding due to erosion. The low tendency to retain sand and build beaches is attributable to the low number of projected HFEs over the 20-year LTEMP period (an average of 7.2) and high daily fluctuations. Any increase in crowding would reduce opportunities for solitude under this alternative.

Alternative B, with a navigation index of 0.39 (Figure 4.10-1), has one of the highest tendencies for low flows to lead to encountering other groups at rapids. Any such effect, however, would lead to only small effects on wilderness experience, because frequency of encounters would be slightly increased, short term, and low impact.

Alternative B, with a fluctuation index of 0.42 (Figure 4.10-1), would have the fewest days within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987), resulting in a high relative potential to reduce a sense of naturalness among the alternatives. With respect to experimental flows, Alternative B has the second lowest projected number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative B would be higher than under Alternative A, but comparable to, or in the case of mechanical removals of trout less than, those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short-term and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative B has the second lowest potential to increase campsite area and preserve visitor solitude, while having among the highest tendencies for crowding at rapids due to low flows. Alternative B would have among the highest adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to, or lower than, most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.3 Alternative C

Alternative C is expected to have a relatively high potential to retain sand and build sandbar area (exceeded only slightly by Alternatives F and G) and is expected to reverse the trend in declining campsite area. This high potential results from the high frequency of HFEs (an average of 21.3 over the LTEMP period) and moderate within-day fluctuations in flow. This increase in camping area would improve opportunities for solitude.

Alternative C, with a navigation index of 0.75 (Figure 4.10-1), has a relatively low tendency for encounters at rapids, and thus a relatively low potential to affect solitude.

Alternative C, with a fluctuation index of 0.93 (Figure 4.10-1), ranks third among alternatives; most days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative C has the second-highest projected number of HFEs and a moderate to high number of TMFs that would negatively impact wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative C would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative C has a relatively high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative C would have among the lowest adverse effects on wilderness experience from daily flow fluctuations and experimental flows, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.4 Alternative D (Preferred Alternative)[26]

Alternative D is expected to have a relatively high potential to retain sand and build sandbar area, similar to Alternatives C, F, and G, and is expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average of 21.1), similar to Alternative C, and moderate within-day fluctuations. This increase in camping area would improve opportunities for solitude.

Alternative D, with a navigation index of 0.45 (Figure 4.10-1), would be comparable to Alternative A with regard to encounters at rapids, and would represent little change from current conditions.

Alternative D, with a fluctuation index of 0.74 (Figure 4.10-1), ranks fifth among alternatives, just below Alternative A; a majority of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative D has a high number of HFEs (tied with Alternative C) and the second-highest number of TMFs, which could negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative D would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative D has a relatively high potential to increase campsite area and preserve visitor solitude, while having a moderate tendency for crowding at rapids due to low

[26] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on wilderness.

flows. Alternative D would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.5 Alternative E

Alternative E is expected to have a moderate potential to retain sand and build sandbar area, slightly lower than Alternatives C, D, F, and G, and would be similarly expected to reverse the trend in declining campsite area. This moderate potential results from a medium number of projected HFEs over the next 20 years (an average of 17.1) and daily fluctuations somewhat higher than Alternatives A, C, and D, but lower than Alternative B. This increase in camping area would improve opportunities for solitude under this alternative.

Alternative E, with a navigation index of 0.37 (Figure 4.10-1), would have the highest tendency for low flows to lead to encountering other groups at rapids relative to the other alternatives.

Alternative E, with a fluctuation index of 0.57 (Figure 4.10-1), ranks sixth among alternatives, above only Alternative B; about half of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a high relative potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative E has a moderate number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience

The number of non-flow experimental actions and administrative trips under Alternative E would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative E has a moderate potential to increase campsite area and preserve visitor solitude, while having a relatively high tendency for crowding at rapids due to low flows. Alternative E would have relatively moderate to high adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.6 Alternative F

Alternative F is expected to have the second-highest potential to retain sand and build beach area and would be similarly expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average

of 38.1) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows under this alternative will aid in trip planning, which will also help avoid crowding.

Alternative F, with a navigation index of 0.71 (Figure 4.10-1), would have lower tendency for low flows to lead to encountering other groups at rapids than other alternatives, except Alternatives C and G.

Alternative F, with a fluctuation index of 1.0 (Figure 4.10-1), ranks highest among alternatives; essentially all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative F has the highest number of HFEs but no TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative F would be higher than under Alternative A, but lower than those under other alternatives because this alternative would not feature mechanical trout removal. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative F has a high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative F would have no adverse effects from daily flow fluctuations but some effects from the highest number of HFEs on wilderness experience, and is lower than most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.7 Alternative G

Alternative G is expected to have the highest potential to retain sand and build sandbar area and would be most likely of all alternatives to reverse the trend in declining campsite area. This high potential results mainly from a high number of projected HFEs over the next 20 years (an average of 24.5) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows will aid in trip planning, which will also help avoid crowding.

Alternative G, with a navigation index of 0.96 (Figure 4.10-1), would have the lowest tendency of all alternatives for low flows to lead to encountering other groups at rapids.

Alternative G, with a fluctuation index of 0.98 (Figure 4.10-1), ranks second among alternatives, slightly below Alternative F; nearly all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative G has the second-highest number of HFEs and highest number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative G would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year. Vegetation treatments would also have a slight long-term potential benefit from restoring wilderness character by promoting native vegetation.

In summary, Alternative G has a high potential to increase campsite area and preserve visitor solitude, while having the lowest tendency for crowding at rapids due to low flows. Alternative G would have no adverse effects from daily flow fluctuations, but some effects from the second-highest number of HFEs on wilderness experience; it is comparable to all alternatives except Alternatives A and B with respect to adverse effects of HFEs and comparable to other alternatives with respect to effects of non-flow experimental actions on wilderness experience.

4.12 VISUAL RESOURCES

This section describes the assessment of the potential effects of the alternatives on visual resources, concentrating on changes that could occur to the water, select geological features, and areas of riparian vegetation along the shore lines of the Colorado River, Lake Powell, and Lake Mead.

Issue: How do the alternatives affect visual resources?

Impact Indicators:

- Exposure of lake deltas in Lake Mead and Lake Powell
- Changes in vegetation and sandbar size

Visual resources are important to visitor enjoyment of GCNRA, GCNP, and LMNRA, and the conservation of visual resources is an important component of federal management activities for these areas. For this reason, it is important to understand how dam operations and non-flow management actions may affect visual resources within the project area. Indictors of effects on visual resources include the height of the calcium carbonate ring surrounding Lake Mead and Lake Powell, the exposure of lake deltas in Lake Mead and Lake Powell, the exposure of Cathedral-in-the-Desert in Lake Powell, and potential impacts associated with changes in vegetation and water color, clarity, and surface appearance.

Calcium carbonate deposits form at the water line and are typically visible at reservoir elevations below full pool, where they create a bathtub ring effect. They are generally lighter in color than the walls without calcium carbonate deposits. This creates visual contrast that may

result in visual impacts. The calcium carbonate deposits around both Lake Powell and Lake Mead will be more or less exposed as reservoir levels rise and fall; however, the exposure will be most affected by future hydrology. In order to quantify the extent of visibility of the calcium carbonate rings, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled, and from this the potential range in height of the exposed calcium carbonate ring (the distance from the top of the ring to the water level) was determined. Projected elevations were compared against both reservoirs at full pool. Lake Powell is considered at full pool at 3,700 ft AMSL. Lake Mead is considered at full pool at 1,221 ft AMSL.

Our analysis indicates that the reservoir elevations would vary very little under the different alternatives, resulting in very little difference in the potential maximum height of the calcium carbonate ring. For Lake Powell, the potential difference in the maximum height of the ring varies approximately 1 ft among the alternatives for a short-term period within the year, but would be no different by the end of the water year. For Lake Mead, the potential difference in the maximum height of the ring varies approximately 3 ft for a short-term period within the year, but would be no different by the end of the water year among the alternatives. The calcium carbonate deposits produce a visual contrast regardless of their height and size and make up only a portion of the view in both reservoirs, and the overall difference in visual impacts among the alternatives as a result of exposure of the rings would be negligible.

Lake deltas appear as expansive, eroding sediment deposits that become more visible as the water level in the reservoir decreases. They are considered a visual detraction (Reclamation 2007a). The size of a lake delta is directly affected by the mass of sediment delivered to the delta, and its exposure is directly affected by reservoir elevation. Lake deltas within Lake Powell and Lake Mead will be more or less exposed as reservoir levels fall and rise; however, the exposure of the lake deltas will be most affected by future hydrology. The increased visibility of lake deltas creates increased visual contrast and may result in visual impacts. In order to quantify the extent of the visibility of lake deltas, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled to determine if lake deltas would be more or less exposed in each of the reservoirs.

The analysis indicates that Lake Powell elevations would vary approximately 1 ft among the alternatives, while Lake Mead elevations would vary approximately 3 ft among the alternatives. Lake deltas produce visual contrast regardless of their height and size and make up a very small part of the views in both reservoirs. On the basis of predicted variation in reservoir elevations, there would be little, if any, difference in the exposure of lake deltas in either reservoir among the alternatives, and the overall difference in visual impact among the alternatives as a result of exposure of lake deltas would be negligible.

Cathedral-in-the-Desert is a prominent geological feature in Lake Powell that attracts many visitors when exposed. The feature is exposed when the Lake Powell reservoir elevation is ≤ 3,550 ft AMSL (Reclamation 2007a). Because of the attention Cathedral-in-the-Desert receives when it is exposed, the exposure of this feature could be perceived as a positive impact or benefit. To determine the potential exposure of Cathedral-in-the-Desert, the average number of months per year that Lake Powell's end-of-month elevation was ≤ 3,550 ft AMSL over the

20-year LTEMP period was modeled. Our analysis indicates that Cathedral-in-the-Desert could be exposed an average of 2 months per year over the 20-year LTEMP period under all alternatives, and the overall difference in visual impact between the alternatives would be negligible for Cathedral-in-the-Desert and similar attractions within the reservoir basin.

Vegetation plays an important role in the scenic experience along the Colorado River. Vegetation increases the visual interest of many places where it occurs by adding variety in color and texture in contrast to the river, rocks, and bare canyon walls. Flow variations and non-flow management actions can alter the type and frequency of vegetation along the corridor (see Section 3.6.2 and Section 4.6). Changes in vegetation could result in different levels of color and texture in contrast to the surrounding landscape, but it is difficult to predict how this could affect a visitor's visual experience and is not expected to vary significantly among alternatives. It is not possible to predict what types of vegetation are more appealing than others to recreationists. Individuals are often influenced by their personal experiences and/or expectations, and what is visually pleasing to one individual may not be to another. Potential impacts on vegetation were assessed based on professional judgment and the riparian vegetation assessment presented in Section 4.6.

Although frequent visitors to the Canyons, such as Tribal members, river guides, scientists, and anglers, will likely notice a change in plant states and sandbar size, it is not certain that an individual participating in a once-a-year or once-in-a-lifetime river trip will notice any change unless there are vegetation management activities underway during visitor trips. Visitors standing at scenic overlooks with views of the river may notice vegetation or sandbars in the corridor, but they will be unlikely to notice a change in vegetation state or sandbar size from these locations, given their distance from the river. Therefore, visual impacts on the Canyons from changes in vegetation or sandbar size are expected to be negligible under all alternatives.

NPS management actions that are being proposed in the river corridor of Glen and Grand Canyons as well as on Hualapai lands, such as nonnative plant removal, native plant revegetation, and mitigation at cultural sites, may have effects on the visual environment. These effects are associated primarily with the alteration of the forms, colors, and textures of vegetation, both immediately after implementation of management activities and over longer time periods, because of changes in species composition, but, as discussed above, the visual effects of changes in vegetation type and cover would be negligible.

Based on this analysis, the effects are considered negligible and would not vary among the alternatives.

4.13 HYDROPOWER

This section describes the potential impacts of changes in Glen Canyon Dam operations on the economic value of the powerplant's capacity and energy production. Impacts are measured in terms of changes in regional power system capacity expansion pathways[27] and overall system-level electricity production costs. The amount of generation and associated economics at the Hoover Dam Powerplant is analyzed separately. This section discusses how changes in system resources and operations affect both wholesale electricity rates paid by utilities that purchase firm capacity and energy from WAPA. This section also presents analysis on the retail electricity rates produced by the Glen Canyon Dam Powerplant.

Issue: How do alternatives affect hydropower resources?

Impact Indicators:

- Changes in the amount (MWh) and dollar value of hydropower generation at Glen Canyon Dam
- Changes in SLCA/IP firm capacity
- Changes in capital and operating costs that WAPA's customers incur to serve their loads
- Changes in wholesale rates that WAPA charges its firm electric service customers
- Changes in residential electricity bills of WAPA's customers
- Changes in powerplant generation and economics at Hoover Dam.

4.13.1 Analysis Methods

This section describes the methods used to estimate the impact of alternative Glen Canyon Dam operating criteria on the economic value of its hydropower resources, to compute changes in the rate that WAPA charges its firm electric service (FES) customers, and to estimate the impacts on retail electricity rates charged by entities that purchase power from the Salt Lake City Area Integrated Projects (SLCA/IP or federal preference power). This section also describes the methods used to estimate the possible indirect impact of alternative operating criteria at Glen Canyon Dam on Hoover Dam generation and economics.

The LTEMP hydropower resources impact analysis was largely an economic analysis rather than a financial analysis. A financial analysis focuses on the revenues and costs accrued by a particular entity, including transfer payments, such as power transactions, taxes, and insurance. It also includes payments made by individual entities for previous investments. In contrast, an economic analysis focuses on societal costs and benefits. Transfer payments among entities are excluded because the total net change to society of these transactions is zero; that is, the amount paid by the buying entity equals the amount received by the selling entity. Also excluded from economic costs are past investments, such as those to construct power plants, because these expenditures have already been incurred on society and cannot be recovered. Similar to other power systems EIS analyses performed by Argonne, the economic analysis performed for LTEMP estimates changes to the U.S. economy as the result of altering operating criteria at Glen Canyon Dam. These economic costs include expenditures to build and operate new capacity in the future to replace Glen Canyon Dam Powerplant lost capacity and both fuel and variable

[27] A capacity expansion pathway is a specification of the size, timing, and type of generating units to be constructed over a specified planning horizon.

operation and maintenance (O&M) costs associated with altering the dispatch of Western Interconnection generating units. A financial analysis was performed for the LTEMP EIS to estimate the wholesale (see Section 4.13.1.2) and retail rate impacts (see Section 4.13.1.3) on individual affected entities (e.g., individual FES utilities and their retail customers).

4.13.1.1 Hydropower Resource and Capacity Expansion Impacts

For each of the proposed alternative operating criteria, the hydropower impact analysis estimated the net present value (NPV) of the cost of meeting future energy and capacity demands of utilities (customers) that have long-term firm (LTF) contracts to purchase power from WAPA's SLCA/IP facilities (Section 3.13) and compared these costs to the NPV of costs under the existing operating criteria (Alternative A, the No Action Alternative).

A number of models and spreadsheet tools were used for the analysis, including:

- *Colorado River Simulation System (CRSS)* simulated future monthly operations for the six large SLCA/IP facilities that include the Seedskadee Project (Fontenelle) and the five Colorado River Storage Project (CRSP) facilities; namely, Glen Canyon Dam, Flaming Gorge Dam, and the Aspinall Cascade (Blue Mesa, Morrow Point, and Crystal Dams).

- *Sand Budget Model (SBM)* scheduled the type and timing of HFEs at Glen Canyon Dam and reallocated monthly water release volumes from CRSS, and revised monthly elevations to enable higher water releases during months with HFEs. Another type of experiment at Glen Canyon Dam, TMFs, were also added at this stage.

- *GTMax-Lite* optimized the economic value of hourly energy produced at the five largest CRSP power facilities based on monthly results from CRSS. This model determined an hour-by-hour pattern of both generation (in MWh) and water releases (in cfs) that satisfied the operating constraints imposed by each alternative, such as up/down ramp rates, maximum change in the release over a rolling 24-hour period, maximum hourly release, and others. This model consists of two configurations: one for Glen Canyon Dam and one for the remaining four CRSP facilities and Fontenelle.

- *AURORAxmp (Aurora)* simulated the operation of the modeled power system and projected hourly spot market prices in the Western Interconnection. The model was run in the capacity expansion mode to project system capacity expansion paths that would reliably meet future electricity demands, and in the unit dispatch mode to simulate powerplant unit operations to serve the load while minimizing total electricity production cost. The model was developed by EPIS, Inc., and is commonly used by utilities throughout the United States.

- *Other specialized models and spreadsheet models* developed for the LTEMP analysis included:
  - Representative Trace Tool: selected the most representative trace or hydrological future of all traces simulated by CRSS and the SBM.
  - Hydropower Outage Model: simulated unit outages, both scheduled maintenance and forced outages, at the six large SLCA/IP facilities.
  - Hourly Load Forecast Algorithm: determined hourly loads of WAPA's customers over the study period.
  - Firm Marketable Capacity spreadsheet: estimated the amount of firm capacity from all SLCA/IP facilities that WAPA could offer its customers at an assumed risk preference or exceedance level.

More detail on each model and tool can be found in Appendix K, Sections K.1.4 and K.1.5.

A number of simplifying assumptions were made for the hydropower analysis, as follows:

- The geographic scope of the analysis was limited to the service territories of utilities with which WAPA currently has LTF electricity contracts. Limiting the analysis to WAPA's customers allows the analysis to concentrate on the systems most affected by an LTEMP alternative with an adequate level of fidelity to obtain good estimates of economic impacts. In addition, the hourly economic value of energy which drives much of SLCA/IP operations was estimated by a tangential modeling task that encompasses the entire Western Interconnection.

- Given the amount of power generated at Glen Canyon Dam relative to the amount of electricity in the Western Interconnection power grid, the analysis assumes that the operation of Glen Canyon Dam does not have a significant influence on the marginal value of electricity at locations outside of the large utilities that WAPA serves.

- WAPA's customers are separated into two categories: large and small. Large customers, which comprise about 75% of firm capacity and energy sales, were modeled more rigorously than small customers. The eight largest customers are Deseret Generation and Transmission Cooperative (Deseret), the Navajo Tribal Utility Authority (NTUA), Salt River Project (SRP), Utah Associated Municipal Power Systems (UAMPS), Utah Municipal Power Agency (UMPA), Platte River Power Authority, Tri-State Generation and Transmission Association (Tri-State), and Colorado Springs Utilities (CSU). There are about 130 remaining "small customer" entities accounting for the remaining 25% of LTF sales. Individually, each small customer receives less than 2.5% of WAPA's total SLCA/IP LTF capacity and energy sales.

- The CRSS model was used to project operations under 105 monthly hydrological traces over a 48-year period from 2013 through 2060 for three

sediment traces, namely, high, moderate, and low. Each trace contains a unique historical chronological time sequence of hydrological conditions. Therefore, hydrological conditions are deterministic, and it is extremely unlikely that any one trace will ever be repeated. Of these 105 traces, a common set of 21 was used to estimate the level of firm capacity of the CRSP plants and the Fontenelle powerplant. To estimate the hourly value of Glen Canyon Dam energy production, the AURORA model was run in dispatch mode using a representative hydrological trace. The trace chosen best met a set of criteria for being "representative," and included a significant distribution of hydrological conditions that are very similar to the hydrological distribution of the 21 traces. In addition, the mean of the representative trace is approximately equal to the mean of all 21 traces. Furthermore, the AURORA model run will only use the moderate sediment trace, which was estimated to have a 63.1% chance of occurring. Using a single sediment trace greatly expedites model runs by reducing the number of cases to be examined.

- This analysis uses the GTMax-Lite model to simulate the hourly operation of Glen Canyon Dam and the remaining hydropower facilities that comprise both the CRSP and Fontenelle powerplant. This model was designed specifically for the LTEMP EIS and consists of two configurations. One configuration models only the operation of Glen Canyon Dam, and the other configuration models the remaining aforementioned facilities. This is a simplification for power production because WAPA schedules and Reclamation dispatches all of the CRSP power units concurrently and incorporate some operating goals and guides that are not represented by GTMax-Lite.

- The methodology assumes that the electrical utilities being modeled engage in unfettered exchange with perfect information about the entire system when it comes to exchanging electrical energy and sharing capacity. In reality, each utility makes its own autonomous decisions with imperfect knowledge about both the future and the actions of competing utilities. Transmission constraints are also not explicitly modeled; neither are institutional nor regulatory obstacles to trade.

Figure 4.13-1 shows the modeling sequence and data flows for the power systems analysis. The following section briefly describes the methodology; a more detailed discussion of the methodology can be found in Appendix K, Sections K.1.4 and K.1.5.

Another noteworthy assumption is that "emergency exception criteria" as stipulated under the 1996 Record of Decision will continue under all LTEMP alternatives. Therefore, in accordance with the criteria, Glen Canyon Dam will be allowed to operate outside of minimum and maximum flow limits, daily change constraints, and both maximum hourly up- and down-ramp rates in the event of a power system emergency (e.g., grid energy imbalance events).

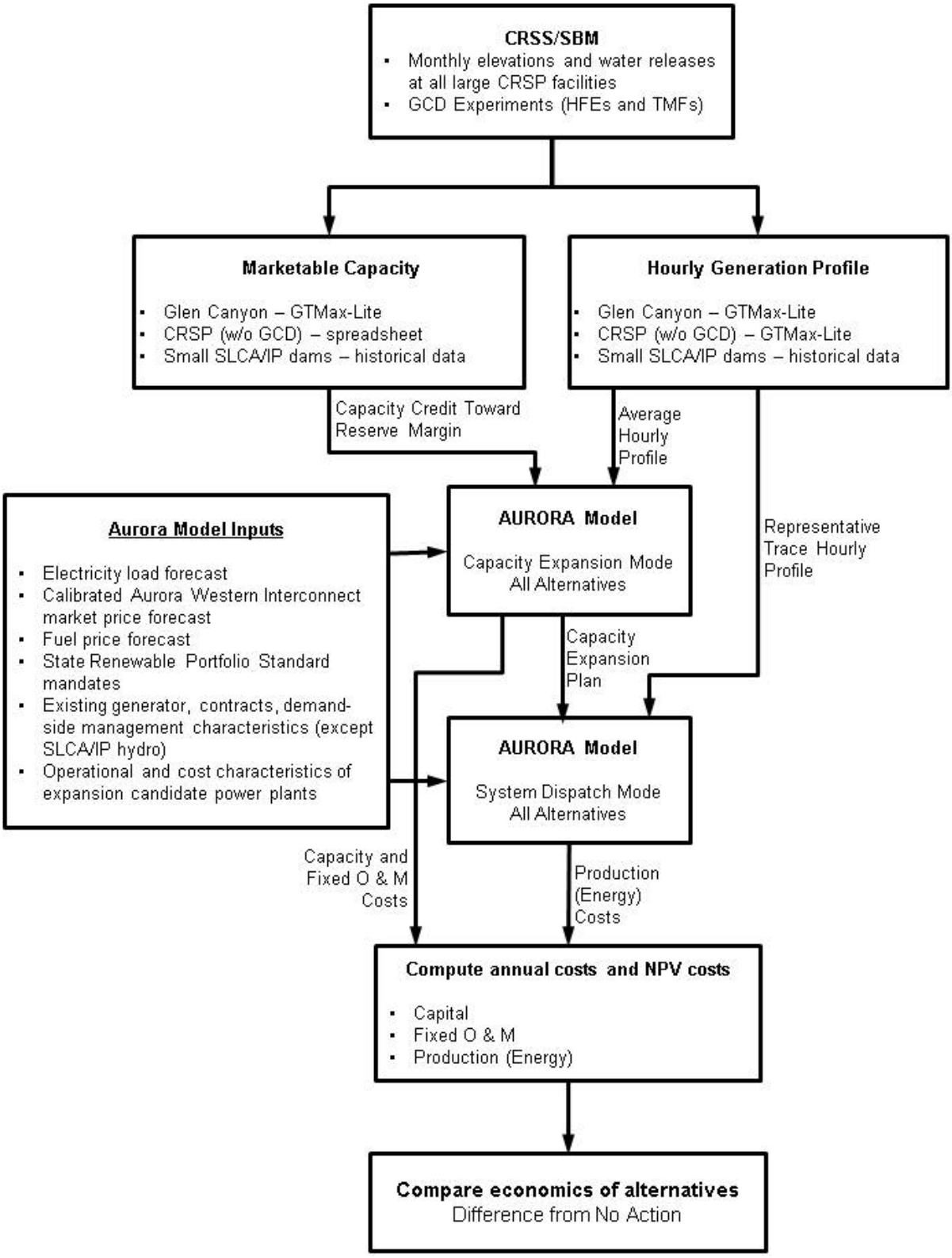

FIGURE 4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS

Alternative-specific Glen Canyon Dam operating criteria would affect the timing and amount of powerplant additions in the SLCA/IP system and system operation. Both would result in economic impacts that are measured by the AURORA model—the core tool used for power systems analysis. If the operating criteria under each alternative result in a reduction in the maximum output from Glen Canyon Dam during the time of peak system load, new generating capacity would be needed elsewhere in the SLCA/IP system to meet SLCA/IP peak loads. Alternative operating criteria could also change the timing of Glen Canyon Dam generation on both a monthly and hourly basis (i.e., less power generated in the high price peak periods and more generated in the low price off-peak hours). Such a change in hydropower operation may cause other powerplants, typically fossil-fuel thermal units, to increase expensive generation in peak hours and decrease relatively inexpensive generation in off-peak hours. The differences in the timing of new resources and in the way the system is dispatched mean that the cost of serving SLCA/IP loads over the 20-year LTEMP period would differ from system operations under the existing operating criteria. Therefore, for each alternative, AURORA was used for two major purposes: (1) to determine the capacity expansion pathway over time during the study period for a joint WAPA/LTF customer system; and (2) to perform a least-cost unit commitment and system dispatch for a given expansion pathway using a single representative hydrology future or trace.

Considerable amounts of data were needed for the AURORA model runs, including:

- Hourly electricity load forecasts for all WAPA's LTF customer utilities
- Western Interconnection electricity market price forecasts (spot market prices were projected using a configuration of AURORA representing the entire Western Interconnection and a spreadsheet model that calibrated those prices to historical 2013 observations at the Palo Verde market hub, which is a key Western Interconnection marketing hub often used as driver for SLCA/IP operations)
- Fuel price projections
- Renewable resource targets; from state renewable portfolio standards and/or from utility-specific goals as stated in their integrated resource plans (IRPs)
- Characteristics of contracts that customer utilities have with other utilities and with other WAPA offices other than SLCA/IP
- Characteristics of demand-side management programs
- Operational and cost characteristics of powerplants owned by customer utilities
- Operational and cost characteristics of candidate generating unit technologies for capacity expansion to reliably meet future SLCA/IP system loads

More details on data sources and how data was generated can be found in Appendix K, Sections K.1.6.1 and K.1.6.3.

Although the AURORA model has its own database of powerplant characteristics, fuel price projections, and hourly load profiles for a number of areas within the entire Western Interconnection, these data were compared to publicly available data sources to verify data accuracy and consistency. Such data sources include those available from the Energy Information Administration (EIA), as well as IRPs that WAPA's customers provide WAPA or post on their company website. Since the methodology modeled WAPA's eight large customers in detail, it was necessary to carefully examine the powerplant characteristics in the AURORA inventory and benchmark them against data compiled by EIA and in IRPs.

Due to the complexities of SLCA/IP hydropower operating criteria and mandates unrelated to power production, AURORA could not model the dispatch of these resources at a level of detail that is required for this study. Therefore, the GTMax-Lite model and other spreadsheet models were used to project powerplant-specific hourly production levels over the study period. The results of these models were input to AURORA as a time series of fixed hourly energy injections into the power grid. Input data for GTMax-lite and the spreadsheet models for each alternative came from the CRSS model and SBM models that include monthly reservoir elevations and water release volumes, as well as the type and timing of experiments at Glen Canyon Dam. Other inputs include both scheduled maintenance outages and forced outages at Glen Canyon Dam and the other large SLCA/IP facilities. Since alternatives only targeted the operation of Glen Canyon Dam, the generation at all other SLCA/IP was typically the same in every alternative. However, in some situations, when Glen Canyon Dam could not provide spinning reserves and/or regulation services, a portion or all of these grid services were provided by powerplants in the Aspinall Cascade, affecting the operations of these facilities.

SLCA/IP firm capacity was an input to the AURORA expansion model. It represents the amount of hydroelectric capacity WAPA is obligated to provide to LTF customers regardless of the state or condition of SLCA/IP resources. It is also the amount of capacity credited toward meeting the SLCA/IP system reserve margin; that is, the spare capacity above the annual coincidental peak of the electric power system. For this study, the reserve margin was assumed to be 15%, which is a typical value in the Western Interconnection. Because WAPA markets the capacity and energy produced by all 11 SLCA/IP facilities as a package, firm capacity was determined for the entire facility group. The GTMax-Lite model results were used to compute the capacity contribution from Glen Canyon Dam, while a spreadsheet using CRSS and SBM results were used to compute the contribution from the other large CRSP facilities. Historical data were used to compute firm capacity from the small SLCA/IP facilities; namely, Deer Creek, Elephant Butte, Towaoc, McPhee, and Molina. Because alternatives only affected Glen Canyon Dam's operation under almost all circumstances, only the contribution of Glen Canyon Dam to firm capacity varied by alternative.

This LTEMP analysis used an exceedance level of 90% to determine firm capacity; that is, 90% of the time that amount of capacity or more is available from SLCA/IP facilities at the time of system peak load. This exceedance level was selected based on a retrospective study performed by Argonne. It shows that the level of SLCA/IP capacity marketed and offered by

WAPA to its FES customers over the last 10 years is approximately at a 90% exceedance level. That is, WAPA has enough SLCA/IP capacity to meet its obligation 90% of the time. Firm capacity at 50% and 99% exceedance levels were also modeled. These results are presented in this section and detailed in Appendix K, Section K.1.10.4.

Hourly generation profiles from all SLCA/IP facilities were an input to both the AURORA expansion and dispatch models. The hourly profile based on the average of all 21 hydrology traces is input to the expansion model, and the hourly profile based on the representative trace is input to the dispatch model. The appropriate configuration of GTMax-Lite is used to compute the hourly generation profiles for Glen Canyon Dam and for the other large CRSP facilities.

The results from the AURORA model run in expansion mode show capacity expansion plans for each alternative over the study period. The plans specify the type of technology built (such as combustion turbines, combined cycle plants, coal plants, nuclear powerplants, etc.), the capacity of the unit, and the year it begins operating. A post-processor spreadsheet written by Argonne computed the annual capacity investment and fixed O&M costs for the new units over the study period. The AURORA model was given a wide selection of technologies from which to choose future capacity additions, including conventional and advanced natural gas combustion turbines, conventional and advanced gas/oil combined cycle units, scrubbed and pulverized coal units, integrated gasification combined cycle units, nuclear units, wind turbines, and solar thermal and photovoltaic facilities. More details on expansion technology candidates and their cost and performance characteristics are provided in Appendix K, Section K.1.6.3.

The capacity expansion plan for each alternative was an input to the AURORA run in dispatch mode to simulate the operation of the system for every hour in the entire study period for a single hydrological future or trace, which is known as the representative trace. Because the dispatch was run for only a single hydrological trace, selection of the trace is very important. Trace 14 was selected as the representative trace. More detail on the method used to select the representative trace can be found in Appendix K, Attachment K.3.

Results of the AURORA dispatch model consisted of costs to produce the electrical energy to meet the system load demand. Production costs are the sum of powerplant fuel costs, variable O&M costs, unit start-up costs, and cost of power purchased from the spot market. Spot sales are subtracted from total system costs. Results from the AURORA expansion and dispatch models (namely, capital, fixed O&M, and production or energy costs) were combined to determine the total annual costs for each alternative over the study period. The net present value stream of annual costs was also calculated to facilitate comparison of each alternative to Alternative A. This single lump-sum value was based on a discount rate of 3.375%, a rate that is used by Reclamation for cost-benefit studies of projects.

Sensitivity analyses were performed to determine the effect of several power systems model assumptions on the estimated cost of LTEMP alternatives. These sensitivity analyses evaluated the effect of differing assumptions for exceedance values (50, 90, and 99%), discount rates (1.4 vs. 3.375%), expansion pathways (various combinations of new combustion turbines and combined cycle plants), hydrology (representative 20-year trace vs. average of 21, 20-year

traces), and ancillary services (increasing [103 to 160 MW] vs. stable [67 MW] ancillary service provision). These analyses indicated that the cost alternatives may be either lower or higher for changes in grid operations and/or capacity replacement than those for the baseline assumption set. The analyses also demonstrated that results are more sensitive to some model assumptions than others. An overview of results is presented in Section 4.13.2.3; details are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

4.13.1.2 Wholesale Rate Impacts

The economic impact of changed operations at the Glen Canyon Dam Powerplant on electrical power production and value is the impact—measured in dollars—on the economy. It includes the system cost of changing the value of electrical power produced at Glen Canyon Dam as a result of changing the timing and routing of water releases (i.e., turbine and bypass). It also includes the expense of constructing (or savings resulting from forgoing construction of) additional electrical generators because of changes in firm SLCA/IP hydropower capacity. Wholesale rates[28] impacts describe how these economic impacts are distributed to utilities that purchase Glen Canyon Dam electrical power from WAPA at the SLCA/IP rate. The change in SLCA/IP rate among alternatives reflects the economic costs of altered Glen Canyon Dam operations.

WAPA sets rates as low as possible consistent with sound business principles to repay the federal government's investment in generation and transmission facilities in addition to specific non-power costs that power users are legislatively required by Congress to repay, such as irrigation costs that are beyond the irrigators' ability to repay. Sales of federal electric power and transmission repay all costs (including interest) associated with generating and delivering the power. WAPA prepares a power repayment study (PRS) for each specific power project to ensure the rates are sufficient to recover expenses.

It was assumed that WAPA will adjust its FES rates as necessary to address costs associated with LTEMP operations, including all net purchased energy, federal capital costs, fixed O&M costs, and interest expense. Interest expense is calculated by multiplying each investment's prior year unpaid balance by the appropriate interest rate. Computations of total purchase energy for each alternative are based on projections of total hourly generation from all SLCA/IP hydropower resources and hourly FES customer loads. The difference between hourly generation and load is resolved by hourly non-firm energy transactions at an energy price projected by the power systems economic analysis described in Section 4.13.1.1. All capital costs and fixed O&M costs associated with a reduction in Glen Canyon Dam Powerplant capacity are also paid by WAPA and passed on to its customers via adjustments to FES wholesale rates. See Appendix K, Section K.2, for more detailed information on the PRS and wholesale rate modeling process.

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28 The term "rate" is used rather than "price." This is the standard convention for wholesale electrical commodities. Rate is the price charged for an energy unit, whether capacity or energy. Rate is often used to describe wholesale prices because it is the price of wholesale units and not necessarily the units used for retail sales.

Several calculations were performed to determine the impact of the LTEMP EIS alternatives on the SLCA/IP rate. Three rates were calculated for each of the seven alternatives: (1) a firm energy rate, (2) a firm capacity rate, and (3) a composite rate. The SLCA/IP FES rate is the price paid per unit of product sold by WAPA's CRSP Management Center to its SLCA/IP FES customers. These calculations and analyses were performed by WAPA CRSP Management Center staff.

WAPA markets SLCA/IP electrical power under firm, long-term contracts. Under these contracts, WAPA is required to deliver this electrical power to federal points of delivery regardless of hydrological conditions, status of generating units, or changes in the operational criteria of the SLCA/IP hydropower plants. The current FES marketing contracts expire on September 30, 2024. For the period following 2024, WAPA is currently engaged in developing a marketing plan. This requires a formal public process in compliance will applicable federal law.

Several assumptions had to be made in order to estimate LTEMP impacts. First, it was assumed that WAPA will continue with its current SLCA/IP obligations until the current marketing period ends and the existing contracts expire.[29] This requires that WAPA deliver the same amount of electrical power and energy to SLCA/IP customers until the end of fiscal year (FY) 2024, regardless of the alternative analyzed. Recognizing uncertainties about WAPA's future marketing of SLCA/IP resources between 2025 and 2034, net firming expenses for the post-2024 time period were analyzed under two sets of assumptions. These are as follows:

1. A continuation of existing SLCA/IP FES contract commitments between FY 2025 and FY 2034 (referred to as No Change or "NC" in Section 4.13.2.4); and

2. A reduction in SLCA/IP FES contract commitments so that net firming expenses are equal to $0 between FY 2025 and FY 2034. This means, for the numbers included in the SLCA/IP power repayment study, zero dollars of firming expense and zero additional dollars of revenue from market sale or from available hydropower sales (referred to as Resource Available or "RA" in Section 4.13.2.4).

These two assumptions constitute "bookends" regarding the outcomes possible in the development of the post-2024 marketing plan.[30] These bookends are for modeling purposes only. They represent a very broad range of possible FES obligations of electrical power in the post-2024 marketing period. The bookends will almost certainly encompass the actual rate impact, once the post-2024 marketing plan is completed. It should be noted that the

[29] There is a provision in the existing SLCA/IP contracts to modify the FES obligations upon a 5-year notice to SLCA/IP customers. However, considering the probable timing of new operating criteria for the Glen Canyon Dam following the completion of the LTEMP EIS and the issuance of a ROD, a 5-year notice would not be significantly different than the end of the current marketing period.

[30] Western could choose a post-2024 SLCA/IP FES obligation of electric power that exceeds its current obligation. However, prior to completion of the required public process it would be difficult to determine what the higher obligation would be that could be considered a reasonable bookend.

establishment of these bookends is not an attempt to predict or to anticipate WAPA's choice prior to the conclusion of the required public process.

4.13.1.3 Retail Rate Impacts

WAPA markets power to utilities serving approximately 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers include small and medium-sized towns that operate publicly owned electrical systems, irrigation cooperatives, and water conservation districts; rural electrical associations or generation and transmission cooperatives who are wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and American Indian Tribes.

The effect of reductions in available generating capacity at Glen Canyon Dam under each of the alternatives on retail electricity rates and bills for customers of municipal, cooperative, and other entities receiving power from WAPA was estimated in four steps. First, a detailed database of retail revenues and sales was developed for 226 utility systems that directly or indirectly receive an allocation of SLCA/IP preference power including American Indian Tribes. This database was combined with aggregate production costs (variable O&M costs, purchased power, and fuel expenses), capital investments for capacity additions, and fixed O&M costs derived from the AURORA analysis. Second, capacity additions were converted to revenue requirements using a carrying charge analysis (see Appendix K, Section K.3.1) along with the capital cost of different investments. Third, the cost of changing Glen Canyon Dam operations under each alternative was distributed to each retail utility system by simulating the WAPA SLCA/IP capacity and energy allocation process. Fourth, overall rate impacts to individual utility systems (including Tribal Systems) were allocated to residential and non-residential consumers to compute retail rate and bill impacts. The process of using a carrying charge analysis along with aggregate production costs does not require SLCA/IP wholesale rates. This methodology, which uses production costs and carrying charges, results in somewhat higher rate impacts than one that uses SLCA/IP wholesale rates.

The objective of the retail rate impact analysis is to measure the change in electric bills that consumers who use electricity in their homes or businesses will ultimately incur because of changes in the way Glen Canyon Dam operates. Retail rate impacts can be measured directly from the change in capacity and energy costs that are computed in the power systems analysis along with the utility carrying charges. This direct method of computing retail rate impacts involves allocating changes in energy and capacity cost to distribution systems and then dividing the cost changes by retail revenues. All of the economic impacts come from the capacity cost (including fixed O&M) and energy cost changes (including ancillary service values). Using this method, additional evaluation of WAPA wholesale rates was unnecessary to derive retail rate impacts, and the wholesale rate analysis presented in Section K.2 of Appendix K was not used as the basis of the retail rate analysis presented here. The power systems simulations combined with the carrying charge rate analysis applied to new capacity resulting from Glen Canyon Dam operation changes measures impacts on wholesale power cost that must ultimately be attributed directly to retail ratepayers. Appendix K demonstrates that the methodology that computes retail

rates using a multi-step process with economic capacity and energy costs results in an appropriate estimate of retail rate impacts.

While the process of computing retail rate impacts from the capacity and energy cost changes implies changes in capacity allocation, under current contract provisions with customer utilities, WAPA may maintain the same capacity allocation to each customer entity. Given this contractual obligation, WAPA rather than the individual utilities may have to replace the lost capacity at Glen Canyon Dam by purchasing the shortfall from other sources. Eventually, these increased costs would be passed on to entities who are allocated preference power and rates would have to be increased because of higher capacity and energy cost. This process of assuming that WAPA would pay for the capacity and energy costs associated with changes in Glen Canyon Dam operations results in the same retail rate impacts as the assumption that the wholesale cost impacts are simply paid by the utilities themselves as long as WAPA would pass on the costs as they are incurred. If WAPA would defer the cost increases, the changes in energy and capacity costs would still be paid, but with a temporary deferral that would presumably include financing costs. Attempting to incorporate potential deferral strategies in WAPA's wholesale rate policy is neither appropriate nor practical in assessing retail rate impacts. For example, if capacity costs and production costs increase, but WAPA incurs the cost for a period of years but then later increases the rate including cost of capital, it would not be appropriate to include the deferral in the rate impacts. Finally, in order to provide a relative benchmark indication of the effects of Glen Canyon Dam capacity cost changes on costs incurred to purchase power, the average aggregate capacity and energy costs are measured relative to amount of money that WAPA currently collects from capacity and energy allocations (see Appendix K for details).

4.13.1.4 Hoover Dam Impacts

Hoover Dam is located about 370 mi downstream of Glen Canyon Dam. Its powerhouse has 17 turbines that have a combined hydropower nameplate capacity of approximately 2,074 MW. Hoover Dam operating criteria are unaffected by LTEMP EIS alternatives. Its energy production and economic value, however, will be impacted primarily by temporary changes in Lake Mead elevation that are projected to occur within a water year. In addition, alternatives will occasionally result in reallocation of Lake Mead monthly water release volumes within a year, when changes in projected December end-of-month Lake Mead elevations result in a different operating condition. Alternatives B, D, and E have the same Glen Canyon Dam October through December total release volumes as Alternative A, and therefore do not affect the Lake Mead operating condition and thus release volumes from Hoover Dam.

Changes in Lake Powell monthly water releases among LTEMP alternatives will affect pool elevations in Lake Mead, and these in turn will affect the Hoover Dam Powerplant derated capacity and energy generation. A modeling tool of Hoover Powerplant monthly operations was developed for the LTEMP EIS to estimate these impacts on Hoover Powerplant economics. The tool, referred to here as the Hoover Powerplant Model, computes and compares two economic metrics; namely, energy and firm capacity that could be used as a capacity credit in utility integrated resource plans. Both are measured in terms of NPV for each alternative.

To perform the analysis, projections of monthly water releases from Hoover Dam were obtained from CRSS, and Lake Mead end-of-month elevation projections were obtained from the SBM for all 21 hydrology traces for each alternative over the study period. Using information from Reclamation, algorithms were developed that relate reservoir elevation and reservoir storage to water-to-power conversion efficiencies and derated powerplant capacity. The Hoover Powerplant Model used this information to determine the difference in monthly generation between Alternative A and each of the other alternatives for all 21 hydrology traces. The Western Interconnection electricity market price forecasts, which are identical to the prices used in the Aurora model simulation of the SLCA/IP system, were used in the Hoover Powerplant Model to compute the value of the generation from the Hoover Powerplant. The value of monthly generation was computed by multiplying the monthly energy generation by the market price of electricity, accounting for the difference in price between energy generated in peak hours versus off-peak hours. Based on information from Reclamation, it was assumed that 95% of generation at the Hoover Powerplant takes place in peak hours and only 5% in off-peak hours. There were no projected changes in firm capacity.

The Hoover Powerplant Model uses methods that are simpler than the ones used to measure the economic impacts of the SLCA/IP system, and it uses a monthly rather than hourly time resolution. In addition, many of the assumptions that drive model results are uncertain. More details on the modeling methodology and the results are presented in Appendix K, Section K.5.

4.13.2 Summary of Hydropower Impacts

This section and Table 4.13-1 summarize the potential impacts of alternative operating criteria on Glen Canyon Dam's hydropower resources. These impacts are measured in terms of changes in both powerplant capacity and generation and associated economic value. Impacts are analyzed from an overall systems perspective in which least-cost electricity production costs are computed and regional power system capacity expansion pathways are determined. This section also discusses how changes in system resources and operations, caused by operational changes at Glen Canyon Dam, impact the wholesale rate that WAPA charges it FES customers and the retail electricity rate that FES customers charge to their end-use customers. Table 4.13-1 does not include the rate impacts on American Indian Tribes; they are discussed separately in Appendix K, Section K.3.

4.13.2.1 Monthly Water Release Impacts

Differences among LTEMP alternatives do not occur from annual water release volumes, but rather from the routing and timing of these water releases during monthly, daily, and hourly timeframes. The total volume of water released from Glen Canyon Dam over the 20-year LTEMP period is essentially identical under all LTEMP alternatives. Also, differences among alternatives in annual water release volumes are less than 1%. However, alternatives significantly impact the timing of water releases within a year. For example, as compared to Alternative A, Alternative F releases much higher water volumes during March, April, May, and June and much

TABLE 4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources[a]

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Overall summary of impacts resulting from changes in operations at Glen Canyon Dam	No change from current condition; second highest firm capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period; no change in average electric retail rate or average monthly residential electricity bill.	Compared to Alternative A, 0.3% decrease in average daily generation (MWh) and 3.8% increase in firm capacity (MW); 0.02% decrease in the cost of generation, 0.45% decrease in the cost of capacity, and 0.04% decrease in total cost to meet electric demand over the 20-year LTEMP period; small decreases in the average electric retail rate (–0.27%) and the average monthly residential electricity bill (–$0.27) in the year of maximum rate impact.	Compared to Alternative A, 0.8% decrease in average daily generation (MWh) and 17.5% decrease in firm capacity (MW); 0.08% increase in the cost of generation, 6.09% increase in the cost of capacity, and 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.43%) and average monthly residential electricity bill ($0.40) in the year of maximum rate impact.	Compared to Alternative A, 1.1% decrease in average daily generation (MWh) and 6.7% decrease in firm capacity (MW); 0.12% increase in the cost of generation, 3.12% increase in the cost of capacity, and 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.39%) and average monthly residential electricity bill ($0.38) in the year of maximum rate impact.	Compared to Alternative A, 0.7% decrease in average daily generation (MWh) and 12.2% decrease in firm capacity (MW); 0.06% increase in the cost of generation, 3.52% increase in the cost of capacity, and 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period; small increase in average retail electric rate (0.50%) and average monthly residential electricity bill ($0.47) in the year of maximum rate impact.	Compared to Alternative A, 1.9% decrease in average daily generation (MWh) and 42.6% decrease in firm capacity (MW) (lowest of alternatives) ; 0.42% increase in the cost of generation, 4.03% increase in the cost of capacity, and 1.17% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period; highest change in average retail electric rate (1.21%) and average monthly residential electricity bill ($1.02) in the year of maximum rate impact.	Compared to Alternative A, 1.7% decrease in average daily generation (MWh) and 24.2% decrease in firm capacity (MW); 0.34% increase in the cost of generation, 7.39% increase in the cost of capacity, and 0.73% increase in total cost to meet electric demand over 20-year LTEMP period; small increase in average retail electric rate (0.64%) and average monthly residential electricity bill ($0.59) in the year of maximum rate impact.

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Overall summary of Hoover Dam economic impacts	No change in the value of generation.	No change in the value of generation.	2.0% increase in the value of generation.	1.0% increase in the value of generation.	1.2% increase in the value of generation.	4.1% increase in the value of generation.	1.4% increase in the value of generation.
Impacts on Generation and Capacity at Glen Canyon Dam							
Annual average daily generation (MWh)[e]	11,599 (no change from current condition)	11,567 (0.3% decrease)	11,506 (0.8% decrease)	11,477 (1.1% decrease)	11,521 0.7% decrease	11,379 (1.9% decrease)	11,403 (1.7% decrease)
SLCA/IP firm capacity (MW)[f]	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP replacement capacity (MW)[g]	Not applicable	–28.1	129.1	49.6[a]	90.2	314.1	179.0
Impacts on Generation and Capacity at Glen Canyon Dam (Cont.)							
System-level generating capacity additions (MW)[h]	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
Impacts on Power System Economics Resulting from Changes in Operations at Glen Canyon Dam							
NPV of SLCA/IP systemwide production cost ($million)[i]	34,228 (no change from current condition)	34,221 (0.02% decrease)	34,255 (0.08% increase)	34,270 (0.12% increase)	34,249 (0.06% increase)	34,373 (0.42% increase)	34,345 (0.34% increase)
NPV of SLCA/IP capital cost ($million) for capacity expansion[i]	1,643 (no change from current condition)	1,635 (0.49% decrease)	1,746 (6.27% increase)	1,696 (3.23% increase)	1,703 (3.65% increase)	1,882 (14.55% increase)	1,769 (7.67% increase)

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Impacts on Power System Economics Resulting from Changes in Operations at Glen Canyon Dam (Cont.)							
NPV of fixed O&M cost ($million) for capacity expansion[i]	345 (no change from current condition)	344 (0.29% decrease)	363 (5.22% increase)	354 (2.61% increase)	355 (2.90% increase)	385 (11.59% increase)	366 (6.09% increase)
NPV of all costs ($million)[i]	36,216 (no change from current condition)	36,200 (0.04% decrease)	36,364 (0.41% increase)	36,320 (0.29% increase)	36,307 (0.25% increase)	36,640 (1.17% increase)	36,480 (0.73% increase)
Difference in Total NPV ($million) Relative to No Action	Not applicable	–16	148	104	91	424	264
Local Hydropower Value ($million)[j]	2,662 (no change from current condition)	2,657 (0.2% decrease)	2,614 (1.8% decrease)	2,613 (1.8% decrease)	2,620 (1.6% decrease)	2,540 (4.6% decrease)	2,556 (4.0% decrease)
Impacts on Wholesale Rates Resulting from Changes in Operations at Glen Canyon Dam							
Energy ($/kWh)							
NC[k]	13.52	13.54	13.99	13.94	13.84	15.67	16.07
Ra[l]	13.40	13.22	14.55	13.78	14.01	16.86	15.22
Average	13.46	13.38	14.27	13.86	13.93	16.27	15.65
Capacity ($/kW)							
NC	5.74	5.75	5.94	5.92	5.88	6.66	6.83
RA	5.69	5.62	6.18	5.85	5.95	7.16	6.50
Average	5.72	5.69	6.06	5.89	5.92	6.91	6.67

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C[b]	Alternative D (Preferred Alternative)[c]	Alternative E[d]	Alternative F	Alternative G
Impacts on Electric Retail Rate Payers Resulting from Changes in Operations at Glen Canyon Dam							
Percent change in retail rates (maximum impact year)[m]	No change from current conditions	–0.27%	0.43%	0.39%	0.50%	1.21%	0.64%
Change in monthly residential bill (maximum impact year)[n]	No change from current conditions	–$0.27	$0.40	$0.38	$0.47	$1.02	$0.59
Impacts on Hoover Dam Power Systems Economics Resulting from Changes in Operations at Glen Canyon Dam							
Total NPV of generation ($million)[o]	2,362.3	2,362.3	2,408.6	2,384.2	2,390.2	2,451.1	2,392.0
Change in NPV of generation ($million)	No change from current conditions	No change from current conditions	46.4 (2.0% increase)	21.9 (1.0% increase)	27.9 (1.2% increase)	88.8 (4.1% increase)	29.7 (1.4% increase)

[a] Assumptions employed in models used to estimate impacts in this table were based on best available information. Sensitivity analyses were performed to determine the possible effect of these assumptions on the estimated cost of LTEMP alternatives. These analyses indicated that costs of alternatives could vary based on particular assumptions made. The analyses also illustrated that results are more sensitive to some model assumptions than others. An overview of results is presented in Section 4.13.2.3; details are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

[b] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative C compared to Alternative A, estimated at $148 million, by about $24.5 million, resulting in a total cost difference of about $173 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.41% increase in cost to a 0.48% increase in cost. The relative ranking of Alternative C compared to other alternatives would not change as a result of adding the cost of experimental low summer flows.

Footnotes continued on next page.

TABLE 4.13-1 (Cont.)

[c] The results presented here are based on the modeling conducted prior to making several adjustments to Alternative D, and they do not include the cost of experimental low summer flows. As presented in Section 4.13.3.4, experimental low summer flows would increase costs by $15 million, while the adjustments would reduce costs by $58.9 million. Combined, the cumulative effect of these adjustments may reduce the relative cost of Alternative D compared to Alternative A, estimated at $104 million, by approximately $44 million over a 20-year period; the resulting difference from Alternative A would be $60 million. These adjustments reduce the percent difference relative to Alternative A from a 0.29% increase in cost to a 0.17% increase in cost. These adjustments would also result in slight reductions to the retail rate costs. The relative ranking of Alternative D compared to other alternatives would change from fourth to third lowest cost.

[d] The results presented here do not include the cost of experimental low summer flows. Adding these costs would increase the relative cost of Alternative E compared to Alternative A, estimated at $91 million, by about $9.95 million, resulting in a total cost difference of about $101 million over a 20-year period. This addition increases the percent difference relative to Alternative A from a 0.25% increase in cost to a 0.28% increase in cost. The relative ranking of Alternative E compared to other alternatives would change from third to fourth lowest cost.

[e] Average daily Glen Canyon Dam generation under representative hydrological conditions.

[f] Firm capacity is calculated based on all 21 hydrology traces with median sediment input (sediment trace 2), which has the highest likelihood of occurrence. It is calculated at the 90% exceedance level, which means that at least that amount of SLCA/IP federal hydropower plant capacity is available in the peak month of August 90% of the time.

[g] Replacement capacity is the difference between the firm capacity in Alternative A and the firm capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.

[h] Additional generation capacity required under the LTEMP alternatives for WAPA's customers over the 20-year LTEMP period to not only meet future load demand but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.

[i] Net present value ($million 2015) of costs to meet total system electric demand over 20-year study period for all SLCA/IP customers under representative trace. Discount rate is 3.375%.

[j] Net present value of electricity generated at Glen Canyon Dam over the 20-year LTEMP period ($million 2015).

[k] NC = no change from current LTF commitment levels.

[l] RA = "resource available" (i.e., commitment level would equal available SLCA/IP federal hydropower resource).

[m] The unweighted average percent changes in retail rates relative to Alternative A across all systems with available data for the year with the highest percentage impact.

[n] The average change in residential electric bills (2015 dollars) relative to average residential bills in Alternative A for the year with the maximum rate impact (residential bills are not weighted by utility size).

[o] Net present value of electricity generated at Hoover Dam over the 20-year LTEMP period ($million 2015).

lower water volumes during July and August. Alternatives also impact the daily profile of water releases. Changes in operating criteria such as maximum and minimum release restrictions and mandates that limit water release changes over time result in very different release patterns during most days. For example, Alternative F requires water releases from Glen Canyon Dam to be at a constant rate an entire day. In contrast, Alternative A allows powerplant operators to change water release levels during a day such that power production more closely matches FES customer energy requests and/or in response to the market price of electricity.

Lastly, alternatives affect the routing of water releases from the dam. Water is typically released through one or more of the powerplant's eight turbines to produce electricity. However, dependent on the pressure exerted by the water elevation in Lake Powell, turbines have a limited amount of water that can flow through them during an hour. In addition, the generating capacity of a unit and the operational status (e.g,, online or out-of-service) limits the flow of water through it. Therefore, whenever a water release is required to exceed the combined flow capabilities of the generating units that are in operation (i.e., emergency, spill avoidance, and approved experiments), some of the water is released through bypass tubes and spillways. Releases such as this that produce no energy are referred to as non-power releases. Each alternative has a unique set of HFE specifications that affect the frequency and duration of Glen Canyon Dam non-power water releases.

Non-power releases can also occur under very low (i.e., dry) hydropower conditions when the Lake Powell elevation is below a minimum turbine water intake level (minimum power pool). All of the water is released through bypass tubes and, therefore, no electricity is produced until the water level rises above the minimum power pool level. All non-power water releases are considered an irretrievable loss of hydropower generation.

4.13.2.2 Hydropower Power Generation and Capacity Impacts

Table 4.13-1 summarizes the impacts of changes in Glen Canyon Dam operations under each alternative on hydropower generation and capacity. Under Alternative A, the average daily generation at Glen Canyon Dam over the 20-year study period is projected to be 11,599 MWh under representative conditions; that is, the monthly water releases and generation levels expected under one of the 21 analyzed hydrology traces, trace 14, which was considered representative of the full range of annual inflow volumes over the 20-year LTEMP period. On average, this represents 72.8% of the generation produced by all SLCA/IP hydropower resources over the 20-year LTEMP study period. With the remaining alternatives, generation would vary between 11,567 MWh under Alternative B (a reduction of 0.3% compared to Alternative A) to 11,379 MWh under Alternative F (a reduction of 1.9%) under representative conditions (Table 4.13-1). These relatively small differences (i.e., less than 2%) in average daily generation among the alternatives are not due to the amount of water released from the dam, but largely attributed to differences in the amount of water routed through bypass tubes to conduct HFEs, which, as described in the previous section, does not generate electricity and requires replacement resources. In addition, differences in monthly reservoir elevations affect both water-to-power conversion efficiency and bypass releases when reservoir elevation is below minimum power level.

Although there is little difference in annual average daily generation at Glen Canyon Dam among the alternatives, there are monthly differences. Under representative hydrological conditions, average daily generation under Alternative A ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,511 MWh in January (Figure 4.13-2). Although generation under Alternative B would be similar to Alternative A between June and August, slightly less electricity would be generated during January through May, and during October through December. In contrast with Alternatives A and B, all other alternatives (except for Alternative F, which is discussed later) have less average daily generation in the summer months of June, July, and August when electricity demand is at its peak. Alternatives C, D, E, and G have a higher average daily generation in the spring months of March, April, and May than Alternatives A and B, with Alternative C generally having the highest values. Alternatives D, E, and G have higher average daily generation in the fall months of October and November compared to Alternatives A and B. However, in September, October, and November, Alternative C has a considerably lower average daily generation than almost any other alternative. In the winter months of December, January, and February, Alternatives A and B typically have a higher average daily generation than most other alternatives.

Generation under Alternative F would result in the most deviation from Alternative A, with a shifting of annual peak generation from the mid-summer months to late spring/early summer, producing a maximum of 19,995 MWh in June, significantly higher than the peak output under Alternative A (Figure 4.13-2). By contrast, generation during the summer would fall considerably, to a low of 9,708 MWh in July, exceeding 9,000 MWh in August, September, and November and falling to just over 6,900 MWh in December and January.

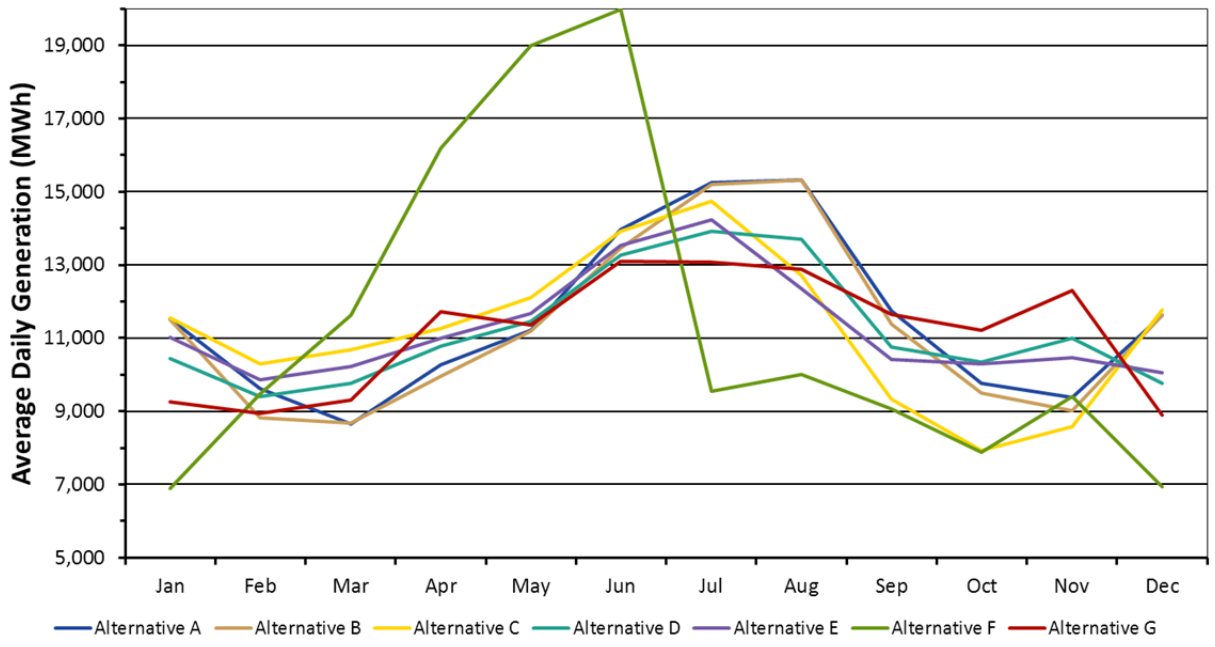

FIGURE 4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives

Although the Glen Canyon powerplant is rated at 1,320 MW, it has been operationally restricted since 1996 and is rarely allowed to produce power at this capacity level (Veselka et al. 2010). This is due to several factors such as the number of units that are operable, the reservoir elevation, grid reliability considerations, and reservoir operating criteria. The latter is most important for the purposes of estimating economics under different LTEMP alternatives. However, it can produce at rated capacity during extremely high hydropower conditions and during high peak release HFEs when the reservoir is relatively high (i.e., about 33,000 cfs and higher).

As shown in Table 4.13-1, under Alternative A, there would be about 737 MW of firm capacity available from the entire SLCA/IP to meet peak system loads. This capacity is based on the assumption that 90% of the time this amount of capacity or more would be available when the system peak loads occur. Under Alternatives C, D, E, F, and G, the firm capacity would decrease to between 687.6 MW under Alternative D to 423.1 MW under Alternative F.

Except for Alternative B, under which the capacity is 28.1 MW higher than Alternative A, all other alternatives would provide approximately 50 MW to 314 MW less capacity—that is, a reduction that ranges from of 6.7% to 42.6% compared to Alternative A. Capacity differences mainly stem from the level of Glen Canyon Dam operational flexibility (daily change, ramp rates, etc.) and monthly water release volumes that are allowed under each alternative in conjunction with both reservoir elevations and monthly water release levels. Operations under Alternative B allow the highest level of flexibility, while Alternatives F and G, which require steady flows each day, restrict capacity. This lost capacity would need to be replaced somewhere in the SLCA/IP system or purchased from an entity outside of the SLCA/IP system footprint.

For LTEMP, it is assumed that the SLCA/IP system will build Glen Canyon Dam replacement capacity. SLCA/IP firm capacity affects the amount and timing of generating units that will be constructed in the future to reliably meet forecasted increases in electricity demand in the service territories of WAPA's FES customer utilities and to replace the retirement of existing powerplant generating capacity. Under Alternative A, an estimated 4,820 MW of new capacity would be built by WAPA's customer utilities. System capacity expansion additions are phased in over time such that a minimum 15% capacity reserve margin is attained in each year of the 20-year LTEMP period. Under alternatives with less SLCA/IP firm capacity, more new generating capacity must be built and system capacity expansion would need to begin sooner. Under Alternative B, 4,820 MW of new capacity would also be added by the end of the LTEMP period; however, because Alternative B has slightly more firm capacity available, one new generating unit would need to be constructed a year later than under Alternative A. All other alternatives have less firm capacity than Alternative A. Under Alternatives C, D, E, and G, 5,050 MW of new capacity would be required (an increase of 230 MW, or 4.8%, compared to Alternative A), and under Alternative F, 5,280 MW of new capacity would be required (an increase of 460 MW, or 9.5%) (Table 4.13-1). Also note that because the capacity is built in sizes/increments that exceed the amount lost, system capacity expansion differences among the alternatives do not typically match the amount of lost capacity. Appendix K, Section K.1.10.2, provides more details and illustrations of alternative impacts on capacity expansion timing and total new construction.

It is assumed that WAPA's eight largest wholesale customers make decisions and function as a single aggregate system, and that they would build enough capacity to reliably meet their total aggregate demands. The modeling of this power system assumes a very high level of cooperation and coordination among WAPA and its LTF power customers. Capacity expansion planning, unit commitment schedules, and least-cost hourly dispatch for the entire system were based on a "single operator/decision maker" model. This is a higher level of cooperation and coordination than what actually occurs and may tend to underestimate capacity replacement costs (or, in the case of Alternative B, benefits). On the other hand, because of siting, permitting, licensing, consruction time, and other factors, it may not be possible to bring units online as soon as indicated by the models. Later capacity replacement dates would lower the NPV of capacity replacements.

4.13.2.3 Economic Impacts

This section presents the anticipated economic impacts of LTEMP alternatives on hydropower resources. Included is a discussion of energy and capacity costs of operational characterisitcs of the LTEMP alternatives, the cost of experiments under Alternative D, and the results of sensitivity analyses performed to determine the effects of modeling assumptions on model results. The impacts of Alternative D on hydropower resources that are presented in this section were based on modeling performed prior to several changes in Alternative D, including an increase in the August volume (from 750 to 800 kaf in an 8.23-maf year, and a corresponding 25-kaf decrease in both May and June [changed from 657 to 632 kaf and 688 to 663 kaf, respectively] with proportional changes in drier and wetter years), reduction in the number of spring HFEs based on the prohibition of spring HFEs in the same water year as extended HFEs, and elimination of experimental load-following curtailment after fall HFEs. For hydropower resources, these adjustments to Alternative D would reduce the percent difference relative to Alternative A from 0.29% to 0.17%..

Energy and Capacity Costs

The power systems economic analysis primarily measures the impacts of LTEMP alternatives on the cost of generating energy to meet system electricity demands and to build sufficient capacity to meet these demands reliably. In doing so, the analysis accounts for system interactions and reactions. For example, when Glen Canyon Dam increases its output, power models estimate the generation response (i.e., decrease) of other online powerplants in the system. The economic impacts are not limited to any one individual system component, but rather to the collective impacts on all components in the system over the entire study period. Impacts measured include production costs that are incurred hourly on a continuous, ongoing basis and capacity expansion costs that occur as needed, and are therefore much less frequent. Focus is also placed on economic differences among alternatives rather than on their absolute values. Comparative analyses such as this one usually reduce modeling errors such as assumptions about high levels of system cooperation because errors occur in all alternatives and tend to cancel (or diminish) in the final calculations.

Capacity expansion cost components include capital investment costs, interest, and other expenses that are accrued during the time period that a generating unit is constructed ,in addition to fixed O&M costs that are incurred after the powerplant has been constructed. Since newly constructed capacity will operate long past the end of the 20-year LTEMP period, these costs along with interest during construction (IDC) are annualized and incurred from the time the unit comes on-line until the end of the study period. Similarly, O&M costs for new units are only incurred during the study years that the units operate. Because the primary focus of the analysis is on cost differences among alternatives, fixed O&M costs for existing powerplants are not included. It is assumed that these costs are identical among all alternatives because the AURORA model retirement schedule is identical across all alternatives.

The cost of serving system loads (system production cost) under each alternative over the 20-year LTEMP period is shown in Table 4.13-1. Costs are expressed in NPV to allow differences in the timing of generation to be normalized, using a 3.375% discount rate. Except for Alternative B, total energy production cost would increase under all alternatives compared to Alternative A, with increases varying from $21 million (a 0.06% increase) under Alternative E to $145 million (a 0.4% increase) under Alternative F. System-level production cost differences are a function of timing and routing of Glen Canyon Dam water releases and reservoir pool elevation effects.

In general, turbine water releases and associated generation occur when they have the highest economic value to decrease overall systemwide production costs. System energy value in this context is the amount of money that is expended to serve all of the system electricity demand. When the demand is low, it is served by generating units that have low production costs; however, as electricity demand increases, units that are more expensive to operate are brought on-line to serve this higher (or incremental) load. Therefore, there is a direct relationship between the cost of serving more demand and the incremental cost to serve it. In this economic analysis, the incremental cost to serve one more MWh of demand, electricity price, and economic value are used synonymously.

When Glen Canyon Dam produces energy during periods of the year when loads and prices are high, the power its produces offsets generation from more expensive units that would have otherwise been utilized. In effect, this lowers overall system production costs. Likewise, system production costs are lower when Glen Canyon generates energy during times of the day when it has the highest economic value. Alternatives with the most operational flexibility also have the highest economic value. This flexibility allows Glen Canyon Dam operators to generate more energy (that is, release more of the limited water resource) during times of the day when prices are highest and reduce generation when prices are low. Appendix K, Section K.1.10, provides more details on market prices and the timing of Glen Canyon Dam power production under each alternative.

Last, it should be noted that because water releases are limited, releases that bypass the generators (such as in the case of most HFEs) not only have zero power system economic value during the time of release, but also reduce future turbine water releases, and hence both energy production and value. In summary, the economic value of Glen Canyon Dam power generation is highest when water is released through powerplant turbines to produce energy which offsets

generation that would have otherwise been produced by generating units that are expensive to operate. The economic impacts of HFEs and other experiments, including low summer flows, TMFs, and sustained low flows for invertebrate production, are included in the impact estimates under each alternative and bundled with all other cost components into a single NPV cost.

The cost of building new capacity (or capital costs) to meet the 15% system reserve margin discussed in the previous section is shown in Table 4.13-1. The table also shows fixed O&M costs associated with the new construction. Both costs are expressed in NPV.

Based on AURORA model runs and a review of both WAPA's customers' IRPs and the IRPs of surrounding utility systems, new capacity additions consist of advanced natural gas-fired combined cycle plants (400 MW) and advanced natural gas-fired combustion turbines (230 MW). Capacity expansion pathways are carefully chosen for each alternative and consist of a mix of new technologies that is consistent with those found in the IRPs of WAPA's large customers and also with Energy Information Administration (EIA) forecasts of future generation capacity in the Western Interconnection (see Appendix K, Section K.1.6.2, for more details).

Total cost, including capital, fixed O&M, and production costs, is shown in Table 4.13-1. The cost is expressed in NPV using a 3.375% discount rate. Based on representative hydrological conditions, the total system cost to reliably supply electric demand during the 20-year LTEMP period under Alternative A would be just over $36.2 billion, with a decrease of about $16 million (or 0.04%) in the cost under Alternative B. Although Alternative B has slightly lower monthly generation than Alternative A, its total system cost is lower because it has a higher firm capacity. The higher firm capacity delays the construction of a natural gas combustion turbine plant by a year compared to Alternative A. With slightly higher spring and slightly lower summer average daily flows under Alternatives C, D, E, and G compared to Alternative A, total costs would be slightly higher, ranging from about $36.3 billion under Alternatives D and E (an increase of about 0.3% compared to Alternative A) to over $36.6 billion under Alternative F (an increase of 1.2%), which would have higher spring and early summer flows, and lower late summer and fall flows, than Alternative A.

The local value of only Glen Canyon Dam energy production under each alternative is presented in Table 4.13-1. It is based on hourly Glen Canyon Dam generation levels and the local value of energy from the dam. The ranking and cost differences among these alternatives for this local value do not match overall system results because they only focus on Glen Canyon Dam. There is no consideration of system-level interactions and reactions. Note that capital and fixed O&M costs are also not included. All alternatives have reductions in the local value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period compared to Alternative A. Smaller reductions in value occur under Alternatives B, C, D, and E; losses in value vary from $5 million (a 0.2% reduction) under Alternative B to $49 million (a 1.9% reduction) under Alternative D. Alternatives F and G have larger reductions in value; namely, $122 million (a 4.6% reduction) and $106 million (a 4.0% reduction), respectively.

Cost of Experiments

A technique to "unbundle" the economic costs of several types of experiments was developed. Estimates of the cost of experiments were computed by comparing the estimated effects of long-term strategies of alternatives that differ only in inclusion of a particular experiment. The one element that differs between the two alternatives is the element for which the economic impacts are measured. For example, to measure the economic cost of low summer flows, two long-term strategies[31] for Alternative D are compared: long-term strategies D1 and D4. Both have identical operating criteria and the same experimental elements, except that under long-term strategy D1 low summer flows are included in the second 10 years of the LTEMP period, while under long-term strategy D4 low summer flow experiments would not be conducted. Subtracting NPV results for long-term strategy D4 from long-term strategy D1 yields the NPV cost of conducting the experiments over the 20-year LTEMP period. Using this methodology, the approximate cost of conducting different types of experimental elements can be "unbundled" from the total aggregate costs. The economic evaluations from the Structured Decision Analysis (Appendix C) provided the basis for this analysis because it modeled all 19 alternatives and long-term strategies.

The estimated NPV cost for each low summer flow experiment ranges from $21.01 million under Alternative D to $13.93 million under Alternative E.The NPV cost for each TMF on average ranges from $0.41 million under Alternative E to $0.45 million under Alternative D. The average NPV cost of each fall HFE ranges from $1.62 million under Alternative C to $1.65 million under Alternative E.

Macroinvertebrate production flows would, on average, increase the combined energy and capacity value by about $1.62 million per 4-month experiment. This experiment results in an increase because in the months of May through August, weekend flows are limited to the minimum flow for that month. Because there is no change in monthly releases for this experiment, lower weekend water releases result in larger water releases, more electric generation, and higher capacity on weekdays when demand and value is higher.

Additional discussion of the cost of experiments is presented in Section K.1.10.3 of Appendix K.

Sensitivity Analyses

Sensitivity analyses were performed on assumptions related to several factors including exceedance values, discount rates, capacity expansion pathways, hydrology, and ancillary services assumptions. These sensitivity analyses estimated how much the results would change if different assumptions were made regarding these factors. Of the factors evaluated, the type of technology used to replace lost capacity, exceedance value, and discount rate had the largest impact on the cost of generation and capacity. In most cases, the relative ranking of alternatives

[31] See Section 4.1 and Appendix C for descriptions of the long-term strategies analyzed for the LTEMP EIS and their relationship to the LTEMP EIS alternatives.

was unaffected by the assumptions used, but the absolute cost levels were either higher or lower than those presented for the baseline in the previous section. Details of these analyses and results are presented in Appendix K (Sections K.1.10.4 through K.1.10.9).

Exceedance Level. The sensitivity analysis for exceedance level was based on the relatively detailed AURORA modeling approach. It compares the baseline 90% exceedance level (i.e., the amount of capacity that is available 90% of the time) to 50% and 99% exceedance levels (i.e., the amount of capacity that is available 50% and 99% of the time, respectively). The higher the exceedance level, the lower the firm capacity credit assigned to SLCA/IP federal hydropower resources. In addition, in the 50–99% exceedance range, the higher the exceedance level, the lower the firm capacity difference among alternatives. Therefore, the higher the exceedance level, the smaller the difference in capital and fixed O&M costs among alternatives. Change in capacity expansion also impacts system production costs, but this tends to have only minor impacts. At 50% exceedance, the NPVdifference compared to Alternative A increased by $0 to $71 million (or 0% to 79%), depending upon the alternative. At 99% exceedance, the cost difference compared to Alternative A decreased by $0 to $59 million (or 0% to 60%), depending upon the alternative. The relative ranking of alternatives changed only slightly across the three exceedance levels. Alternatives D and E switched places at both the 50% and 99% exceedance levels. At 90% exceedance, Alternatives D and E were the fourth and third lowest, respectively, but at both the 50% and 99% exceedance levels they were third and fourth lowest, respectively.

Discount Rate. The discount rate is the rate of return used to make the value of costs or benefits that occur at different points in time commensurate with each other. The sensitivity analysis for discount rates was based on the AURORA modeling approach. To determine the sensitivity of results to discount rate, a model run was made using a discount rate of 1.4% and compared to results for the baseline discount rate of 3.375%. When using a lower discount rate, the NPV costs of alternatives relative to Alternative A are larger because costs at the end of the study period have a larger contribution to the NPV. The costs increase by about $4 to $84 million (or 20% to 25%), depending upon the alternative; the greater an alternative's cost difference relative to Alternative A, the greater the cost increase with the lower discount rate. However, the relative ranking of alternatives and relative percent difference from Alternative A did not change for these two discount rates.

Expansion Pathway. The expansion pathway for an alternative describes the size, timing, and type of generating units that would be constructed over a specified planning horizon. Sensitivity analyses of the expansion pathway were performed using two methodologies; one used the AURORA model and the other the GTMax-Lite model. They each explored different aspects of changes in the power system expansion and their effect on costs and rankings of alternatives.

Base Expansion Mix. A sensitivity analysis was performed on the baseline capacity expansion path using the AURORA model. In the baseline expansion, both advanced combustion

turbines and advanced combined cycle units were chosen by AURORA for new future additions under Alternative A. This is referred to as the base pathway. Adjustments to the timing and number of new advanced combustion turbines were then made to the base pathway to accommodate changes in Glen Canyon Dam capacity under the other alternatives.

The sensitivity study tested two extreme pathways for Alternative A. One base pathway built exclusively advanced combustion turbines and the second one built exclusively advanced combined cycle plants. The base construction pathway (i.e., the type and timing of additions) for Alternative A was used as the starting point for each of the other alternatives. Advanced combustion turbines were added to (or in the case of Alternative B, subtracted from)[32] a base expansion pathway to accommodate capacity changes at Glen Canyon Dam. Costs of the alternatives for each pathway varied slightly, both higher and lower, from the baseline expansion; there was no consistent trend toward higher or lower values in either of the two extreme base pathways as compared to the mixed pathway used for the baseline. Relative to the baseline pathway, the advanced combustion turbines yielded NPV changes that ranged from a decrease of $36 million (less expensive to implement than the alternative) for Alternative F to an increase of $15 million for Alternative C (more expensive). The advanced combined cycle sensitivity analysis produced NPVs that were between $27 million lower (Alternative G) and $51 million higher (Alternative D) than the baseline. These fluctuations in cost are primarily due to the lumpy nature of capacity additions. Alternative rankings for both pathways remain basically the same as the baseline.

Capacity Replacement Technology. A sensitivity analysis was performed on the baseline capacity replacement technology using the GTMax-Lite model. All lost capacity replacements under the baseline and sensitivity analyses described above relied exclusively on the advanced combustion turbine technology. However, models make many simplifying assumptions, and may not consider other factors beyond cost that a utility may use when determining thermal power plant additions. Consequently, a sensitivity analysis was performed to address uncertainties regarding the replacement of future capacity replacement.

The analysis considered a separate case in which capacity expansion changes relative to Alternative A would be made using a mix of 60% advanced natural gas combined-cycle plants and 40% advanced combustion turbines in terms of megawatts of capacity. This mix is approximately equal to the current average thermal capacity expansion mix contained in the IRPs of WAPA's LTF customers and other utilities in the surrounding area. It was derived from a review of IRPs that were available online in May 2016. Attachment K.11 of Appendix K provides a summary of capacity additions through the end of calendar year 2034. The GTMax-Lite model was used for this sensitivity analysis because it can exactly match the desired mix of capacity replacements. In addition, GTMax-Lite runs more rapidly with far fewer resources than AURORA, yet it produces similar results in terms of both differences in total NPV among alternatives and alternative ranking.

[32] This involved building combustion turbines sooner and/or building more combustion turbine capacity for an alternative as compared to Alternative A. Under Alternative B, the construction of a combustion turbine was delayed.

Using a mix of 60% natural gas combined-cycle plants and 40% combustion turbines for capacity replacement increases costs relative to the baseline for all alternatives except for Alternative B. Alternative B has a lower NPV of approximately $11.0 million, while the costs for all other alternatives increase from $17.1 million under Alternative D (the Preferred Alternative) to $93.4 million under Alternative F. The new mix of capacity replacements does not change alternative rankings.

Hydrological Condition. In this case, hydrologic condition refers to the daily, monthly, and yearly pattern of dam releases under different simulated 20-year periods that are based on the historical record. A sensitivity analysis was performed on hydrology assumptions using the AURORA model. As discussed earlier, Trace 14 was selected as the representative trace and used for the AURORA dispatch run for the baseline analysis. Because impacts of alternatives are dependent on hydrology condition, a study was performed on the sensitivity of results to hydrological condition. An additional hydrological condition was run; this condition used the average hourly generation from all 21 traces as projected by GTMax-Lite runs. Capital and fixed O&M costs were identical for both hydrology conditions and there were only slight differences in the production costs. Differences in NPV relative to the baseline ranged from a cost decrease of $15 million under Alternative G to a cost increase of $18 million under Alternative F.

Ancillary Services. Ancillary services are electricity grid services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system (FERC 1995). Services include spinning reserve, non-spinning reserve, replacement reserve, regulation/load following, black start, and voltage support. A sensitivity analysis was performed on ancillary service assumptions for Alternatives A, D, and F using the GTMax-Lite model. Ancillary services included in this analysis consisted of regulation and fast spinning reserves. It was performed on two possible cases: one in which total ancillary services requirements would increase from 103 MW in 2013 to 160 MW by 2030, and another where the current level of 67 MW would remain the same during the entire LTEMP study period. The analysis showed firm capacity and energy at capacity exceedance levels of 50, 90, and 99% would differ by less than 0.8% under low and high ancillary services levels. The difference in total NPV between the two scenarios for Alternatives A and D is $2.8 million (0.08%) and $4.71 million (0.14%), respectively. There is no difference in total NPV between scenarios for Alternative F.

4.13.2.4 Change in FES Wholesale Rates

Through some combination of changed SLCA/IP rates under the No Change (NC) bookend or lower SLCA/IP commitment levels under the Resource Available (RA) bookend, FES utilities that receive SLCA/IP preference power will be impacted as a result of changed operations at Glen Canyon Dam. Under the NC bookend, WAPA would absorb the economic costs (or reap the benefits) of an alternative and adjust FES rates accordingly, passing costs/benefits to its customers. At the other end of the spectrum, SLCA/IP commitment levels

would be adjusted to reflect hydropower resource attributes/capabilities under the RA bookend and FES customers would respond through adjustments to their system dispatch and future resource expansion paths.

For each alternative, WAPA computed the impact of each alternative in terms of single energy and capacity rates that are applied over the entire 2015 through 2034 LTEMP period. This deviates from WAPA's normal 5-year forecast in order to accurately capture each alternative's rate impacts. Table 4.13-1 shows FES customer rates estimated by WAPA RPS studies under both NC and RA bookend marketing structures. The energy and capacity rates reflect WAPA's current method of setting FES rates. SLCA/IP FES customers are billed monthly for the amount of energy used and for their capacity allocation. See Appendix K, Section K.2, for more detailed information on FES wholesale rate results.

This analysis is not a description of policy or an attempt to predict WAPA's post-2024 marketing plan. This set of bookend results is intended to reflect the range of reasonable possibilities.

4.13.2.5 Retail Rate and Bills Impacts

Systemwide production costs, fixed operation and maintenance costs of new capacity and the financing cost associated with building new plants is assumed to be incurred ultimately by entities that receive SLCA/IP preference power.[33] Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam ultimately increases retail rates and bills of residential and non-residential customers. The retail rate impacts experienced by utility systems are not uniform across different utility systems that receive federal preference power. Differential retail rate impacts on particular systems from LTEMP alternatives are largely driven by the amount of power that is allocated from SLCA/IP relative to the quantity of other power that is produced or purchased by a particular system. If utility systems are allocated a large amount of SLCA/IP capacity and energy, but because of their large size, this allocation is a small fraction of the overall amount of power purchased, the retail rate impacts tend to be small. The relative dependence on SLCA/IP capacity and energy varies by a wide margin across entities that receive allocations. SLCA/IP energy allocation as a percent of retail sales range from 0.05% for SRP up to 62% for the City of Meadow (a member of UAMPS). Impacts on the utility systems that are most impacted are presented in Appendix K, Section K.3. This appendix also describes impacts on Tribal systems.

Table 4.13-1 shows impacts on retail electric rates and monthly residential electricity bills for WAPA's preference power customers compared to Alternative A. The change in retail rates and the average change in monthly residential bills are both in the year of maximum rate impact. Both metrics are not weighted by utility size; that is, each utility serving retail customers has the same weight. Note that the estimated retail rate impacts presented here were derived independently by Argonne and did not use the wholesale rates described in Section 4.13.2.4 as input. Wholesale rates were not used because: (1) by using data from the power systems model,

[33] The cost of experimental releases such as HFEs are currently considered to be non-reimbursable expenses.

the direct connection between power system costs and rate impacts could be observed and the process was transparent; and (2) the capital cost of constructing new capacity incurred by utility systems was directly estimated rather than assuming WAPA would carry the burden of replacing the capacity. Retail rate impacts were directly computed from projected wholesale power costs derived from the power systems analysis in Section 4.13.2.3. Rate impact calculations were based on the assumption that the capital, operating, and administrative costs of Glen Canyon Dam operations do not substantively change under different LTEMP alternatives when the energy output from the dam changes. These costs are not expected to be affected by differences in operations under LTEMP alternatives. Because these operating and administrative costs are not affected by the LTEMP alternatives, rate impacts result from changes in the cost associated with replacing capacity and/or energy with changes in dam operations. This approach may have produced somewhat higher estimates of retail rate impacts than if the wholesale rate impacts developed by WAPA in Section 4.13.2.3 had been used. More detailed analyses of retail rates and residential bills are provided in Appendix K, Section K.3.

The average change in the retail rate varies from a decrease of 0.27% in Alternative B to an increase of 1.21% in Alternative F. The average change in the monthly residential electricity bill varies from a decrease of $0.27 in Alternative B to an increase of $1.02 in Alternative F. Both metrics are the average in the year of maximum rate impact and are therefore higher than the average impact over the study period. The electric bill reduction in Alternative B is due to a delay of one year in constructing a new natural gas-fired combustion turbine compared to Alternative A. Similarly the electric bill increase in Alternative F is due to the construction of two new natural gas-fired combustion turbines over the 20-year LTEMP period compared to Alternative A. Retail rate and residential bill impacts are computed from adjusting data in the power systems analysis for municipal and cooperative carrying costs and not from SLCA/IP wholesale prices. If estimated wholesale prices are used instead of adjusting power systems cost, the measured rate impacts would be lower.

4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics

Hoover Dam operating criteria are unaffected by LTEMP EIS alternatives. Its energy production and economic value, however, will be impacted primarily by temporary changes in Lake Mead elevation that are projected to occur within a water year. In addition, alternatives will occasionally result in reallocation of Lake Mead monthly water release volumes within a year, when changes in projected December end-of-month elevations result in a different operating condition, which would also affect Hoover Dam power economics. The Hoover Powerplant Model used projected Lake Mead reservoir elevations over the 20-year LTEMP period to estimate the monthly maximum operational capacity for the Hoover Powerplant for all 21 hydrology traces. Assuming the firm capacity at the Hoover Powerplant is based on the 90% exceedance level in the peak load month of August, the model found that for all alternatives the Lake Mead elevation is below the minimum pool level of 1,050 ft more than 10% of the time. Therefore, because more than 10% of the time in August no generation is possible, no firm capacity (or a firm capacity of zero) was assigned to all of the alternatives (see Section K.5 in Appendix K).

The Hoover Powerplant Model computed the change in economic value of Hoover Powerplant energy production attributed to each LTEMP alternative by multiplying the change in monthly energy production by monthly market prices of energy as projected by the AURORA model. Estimates are made for each month of the 20-year LTEMP period for all 21 hydrology traces. To compare LTEMP alternative economics on a consistent basis, the NPV of Hoover Dam energy was computed using a 3.375% annual discount rate, which is the same rate used for computing the NPV of SLCA/IP costs. The NPV of Hoover Powerplant energy is shown for each alternative in Figure 4.14-4 and presented in Table 4.13-1. The increase in NPV for Hoover Dam energy, relative to Alternative A, ranges from nearly zero for Alternative B to about $89 million for Alternative F.

As discussed in more detail in Section K.5 of Appendix K, the model used to compute Hoover Dam energy value considered fewer factors than the one used to estimate impacts at Glen Canyon Dam. For example, Hoover Dam estimates primarily use a monthly time step, while Glen Canyon Dam estimates are based on a model that optimizes hourly operations. In addition, Hoover Dam model results are highly sensitive to assumptions, particularly the assumed minimum power pool elevation, which affects the economic results for both energy and firm capacity because most of the estimated increases in value are due to lower non-power releases under LTEMP alternatives.

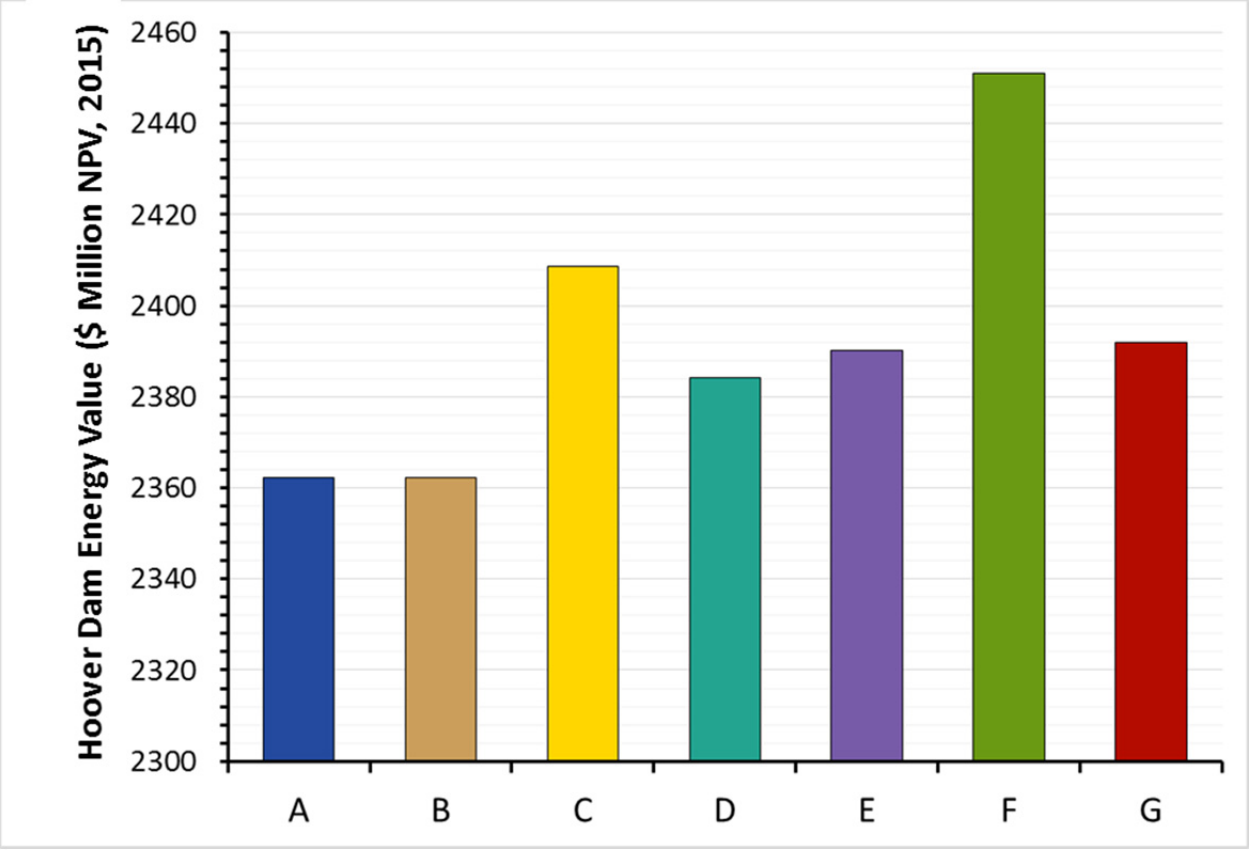

FIGURE 4.13-3 Total NPV of Hoover Powerplant Energy over a 20-Year Period under LTEMP Alternatives

4.13.3 Alternative-Specific Impacts

4.13.3.1 Alternative A (No Action Alternative)

Average annual daily generation at Glen Canyon Dam is currently 11,599 MWh under representative hydrological conditions. Average daily generation ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,606 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,662 million, and would not change under Alternative A. SLCA/IP marketable capacity is currently 737.2 MW at the 90% exceedance level. Average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity would not change under Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative A over the 20-year LTEMP period. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative A would be just over $36.2 billion.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on the wholesale rates WAPA charges its FES utility customers, retail rates charged by WAPA's customer utilities, or the electric bills paid by their residential customers. The average wholesale energy rate of the two bookend cases was estimated to be $13.46/kWh and the average capacity rate was estimated to be $5.72/kW.

In summary, Alternative A would have the second-highest firm capacity from SLCA/IP and tied with Alternative B for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the second-lowest total cost to meet electric demand over that period, and there would be no change in either the average electric retail rate or the average monthly residential electricity bill. There would be no change in the value of generation produced at Hoover Dam.

4.13.3.2 Alternative B

Average annual daily generation at Glen Canyon Dam would be 11,567 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 8,665 MWh in March to 15,405 MWh in August, before falling to 9,046 MWh in November, and then increasing to 11,608 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,657 million, a decrease of $5 million, or 0.2%, compared to Alternative A as explained below. SLCA/IP firm capacity would be 765.3 MW at the 90% exceedance level, which is a 28 MW, or 3.8%, increase compared to Alternative A. There would therefore be slight decreases in average annual daily

generation and hydropower value at Glen Canyon Dam and a slight increase in SLCA/IP firm capacity under Alternative B compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative B over the 20-year LTEMP period. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet electric demand under Alternative B would be $36.2 billion.

Under Alternative B, there would be a small reduction in capital and fixed O&M costs associated with new capacity relative to Alternative A. Although the total amount of capacity added over the 20-year LTEMP period is the same as Alternative A, there would be a 1-year delay in constructing a new natural gas-fired combustion turbine. This delay accounts for the slightly lower total cost of Alternative B compared to Alternative A. Also because of the construction delay, the average electricity retail rate could drop by 0.27% and the average monthly residential electricity bill could be reduced by an average of $0.27. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.38/kWh, which is a decrease of $0.08/kWh (–0.6%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.69/kW, which is a decrease of $0.03/kW (–0.5%) compared to Alternative A.

The economic value of energy produced at Hoover Dam under this alternative would be the same as under Alternative A over the 20-year LTEMP period because there would be no difference in monthly releases between the two alternatives.

In summary, Alternative B would have the highest firm capacity from SLCA/IP federal hydropower resources of any alternative and would be tied with Alternative A for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would decrease compared to Alternative A. There would be a decrease in the average electric retail rate and in the average monthly residential electricity bill compared to Alternative A in the year of maximum rate impact. There would be no change in the value of generation produced at Hoover Dam compared to Alternative A.

4.13.3.3 Alternative C

Average annual daily generation at Glen Canyon Dam would be 11,506 MWh under representative hydrological conditions. Average daily generation under would range from 10,292 MWh in February to 14,855 MWh in July, before falling to 7,971 MWh in October, and then increasing to 11,739 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,614 million, a decrease of $48 million, or 1.8%, compared to Alternative A. SLCA/IP firm capacity would be 608.1 MW at the 90% exceedance level, which is a 129-MW, or 17.5%, decrease compared to Alternative A. There would therefore be slight decreases in

average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative C compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative C over the 20-year LTEMP period. An additional gas turbine would be needed during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative C would be almost $36.4 billion. Including the estimated cost of experimental low summer flows would result in an average increase in cost of about $24.5 million over a 20-year period, assuming the average number of low summer flows anticipated to be triggered (1.8). This would not change the relative rank of Alternative C compared to other alternatives.

Because of the additional gas turbine the average retail electric rate would increase about 0.43% and the average monthly residential electricity bill would increase by an average of $0.40. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $14.27/kWh, which is an increase of $0.81/kWh (6.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.06/kW, which is an increase of $0.35/kW (6.0%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $46 million more than that under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations, which result from changes in monthly water releases upstream at Glen Canyon Dam.

In summary, Alternative C would have the fifth-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the fifth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It would have the fourth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in the value of generation at Hoover Dam compared to Alternative A.

4.13.3.4 Alternative D (Preferred Alternative)

Average annual daily generation at Glen Canyon Dam would be 11,477 MWh under representative hydrological conditions. Average daily generation would range from 9,392 MWh in February to 14,051 MWh in July, before falling to 10,381 MWh in October, and then increasing to 11,052 MWh in November (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,613 million, a decrease of $49 million, or 1.8%, compared to Alternative A. SLCA/IP firm capacity would be 687.6 MW at the 90% exceedance level, which is a 49.6 MW, or 6.7%,

decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative D compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative D over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative D would be just over $36.3 billion.

Because of the additional gas turbine the average retail electric rate would increase about 0.39% and the average monthly residential electricity bill would increase by an average of $0.38. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.86/kWh, which is an increase of $0.4/kWh (3.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.89/kW, which is an increase of $0.17/kW (3.0%) compared to Alternative A.

As noted in Section 4.13.2.3, a technique was used to "unbundle" the economic costs of several types of experiments so the cost of each experiment could be estimated. Alternative D has low summer flows, TMFs, macroinvertebrate production flows, and both spring and fall HFEs.

The estimated average NPV cost for each low summer flow experiment in Alternative D is $21.01 million. This value includes an NPV energy cost of $2.76 million and a capacity cost of $18.25 million (see Table K.1-11 in Appendix K). Each TMF in Alternative D has an average energy cost of $0.45 million; there is no capacity cost because TMFs do not occur in August and monthly reallocations of water are not required to support these experiments.

Each 4-month macroinvertebrate production flow experiment has, on average, a net increase in value of $1.62 million, which consists of an energy value decrease of $871,000 and a capacity value increase of $2.49 million. The capacity increase occurs because water releases are minimized on weekends, which makes more water available for power production during weekdays when the peak load would most likely occur. The estimate provided here differs from that presented in the DEIS. After the DEIS was published, discussions with WAPA indicated that they would implement macroinvertebrate production flows in a different way than under normal operations, and the difference would maximize the benefit of lower weekend flows and capacity production during weekdays. Rather than a net cost of macroinvertebrate flows as presented in the DEIS, a net benefit to hydropower generation and capacity would be realized.

Finally, the average cost for each fall HFE $\leq$96 hr for Alternative D (based on an average of HFEs from the long-term strategies analyzed) is expected to range from approximately $1.62 million to $1.65 million (average of $1.64 million). The cost of fall HFEs consists of an energy component only because they do not occur in August and do not affect monthly water releases during August. Assuming a cost of a fall HFE under Alternative D of $1.64 million, the

per-hour cost would be $17,083 and the total cost for the longest possible extended-duration fall HFE (250 hr) would be $4.27 million. Note that this estimate assumes the costs for each hour would be equal, but in reality there would be some hours of ramp up and ramp down at the beginning and end of the HFE when cost would be less. In addition, a 250-hr HFE would have some additional cost associated with reducing reservoir elevation more than a 96-hr HFE. The cost of a spring HFE is expected to be similar in cost to a fall HFE.

The NPV of energy produced at Hoover Dam under this alternative is $22 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

The results presented in Table 4.13-1 are from modeling conducted prior to making the adjustments to Alternative D described in Section 2.2.4, including prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE; elimination of experimental load-following curtailment after fall HFEs; and an adjustment in the monthly release volumes. Based on these modifications, the actual number of HFEs would be about 19.8 (1.3 fewer), which is estimated to reduce the cost of the alternative on hydropower generation by about $2.1 million over a 20-year period, using the estimated cost of HFEs presented in Section K.1.10.3.

Based on modeling that was performed after the DEIS was published,[34] the change in monthly release volumes would result in decreases in the NPV of the cost of production and capacity of about $5.3 million and $27.6 million, respectively, over the 20-year period. Elimination of load-following curtailment would result in a decrease in NPV of the production cost of about $4.0 million over the 20-year period, but would have no effect on capacity.

In addition to these adjustments to Alternative D, changes in the way macroinvertebrate production flows would be implemented and inclusion of the cost of low summer flows in the total cost of Alternative D would result in changes to the estimated total cost of Alternative D. Implementation of experimental macroinvertebrate production flows were modified based on input from WAPA after the DEIS was published. As described above, this modification would result in a net reduction in cost of individual experiments, producing a total reduction in cost of $19.8 million over a 20-year period rather than the original estimated increase of $94 million. Including the costs of low summer flows results in an average increase in cost of about $15.0 million over a 20-year period assuming the average number of low summer flows anticipated to be triggered (0.714).

[34] This modeling was performed using the screening tool described in Section 2.1, whose hydropower module was based on the GTMax-lite model, but incorporated several simplifying assumptions (e.g., constant flow to power conversion factor, constant within-month daily generation pattern). Unlike the modeling used to estimate costs of alternatives on energy and capacity shown in Table 4.13-1, which used GTMax-lite and Aurora models to estimate systemwide effects of LTEMP alternatives, the modeling used to estimate the effects of Alternative D adjustments focused only on Glen Canyon Dam energy and capacity rather than systemwide effects.

The cumulative effect of all of these adjustments and inclusion of low summer flows may reduce the total cost of Alternative D by approximately $44 million over a 20-year period; the original estimated increase in cost of $104 million relative to Alternative A would be reduced to $60 million. These adjustments to Alternative D reduce the percent difference relative to Alternative A from 0.29% to 0.17%.

These estimates may differ from the results that would be obtained had the integrated modeling been used to assess modifications to Alternative D. The streamlined modeling results are, however, considered representative of the expected effects of the adjustments, and they are provided here as an estimate of the approximate magnitude of the effects these adjustments may have on the actual impacts of Alternative D. Because the streamlined modeling results show that the adjustments to Alternative D are small and positive (i.e., reducing the impact), further analysis under the integrated model would not produce information to assist in making a reasoned choice among alternatives, particularly given the time and cost of further integrated modeling. Alternative D was chosen as the preferred alternative based on the original modeling performed on Alternative D prior to making modifications. It was determined that Alternative D provided an appropriate balance between protection of downstream resources while minimizing impacts on hydropower. The streamlined modeling of the effects of adjustments indicates that those adjustments would continue to provide for the protection of downstream resources while reducing even further the effects of the alternative on hydropower.

In summary, Alternative D would have the third-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also has the fourth-lowest total cost to meet electric demand over that period (third lowest, considering the effects of adjustments discussed above). Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It has the third-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fifth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.5 Alternative E

Average annual daily generation at Glen Canyon Dam would be 11,521 MWh under representative hydrological conditions. Average daily generation would range from 9,858 MWh in February to 14,352 MWh in July, before falling to 10,332 MWh in October, and then increasing to 11,008 MWh in January (Figure 4.13-2). The NPV of local electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,620 million, a decrease of $42 million, or 1.6%, compared to Alternative A. SLCA/IP firm capacity would be 647.0 MW at the 90% exceedance level, which is a 90 MW, or 12.2%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP firm capacity under Alternative E compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity

built under Alternative E over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative E would be just over $36.3 billion. Including the estimated cost of experimental low summer flows would result in an average increase in cost of about $9.95 million over a 20-year period, assuming the average number of low summer flows anticipated to be triggered (0.71). This would not change the relative rank of Alternative D compared to other alternatives (but note that other adjustments to Alternative D would change Alternative E's rank as described in the summary paragraph below).

Because of the additional gas turbine the average retail electric rate would increase about 0.50% and the average monthly residential electricity bill would increase by an average of $0.47. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.93/kWh, which is an increase of $0.47/kWh (3.5%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.92/kW, which is an increase of $0.2/kW (3.5%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $28 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

In summary, Alternative E would have the fourth-highest firm capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the third-lowest total cost to meet electric demand over that period (fourth lowest, considering the effects of Alternative D adjustments discussed above). Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A. It would have the fifth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fourth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.6 Alternative F

Average annual daily generation at Glen Canyon Dam would be 11,379 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 6,918 MWh in January to 19,995 MWh in June, before falling to 7,891 MWh in in October, and then increasing to 9,495 MWh in November and falling to 6,911 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year study period under representative conditions would be $2,540 million, a decrease of $122 million, or 4.6%, compared to Alternative A. SLCA/IP firm capacity would be 423.1 MW at the 90% exceedance level, which is a 314 MW, or 42.6%, decrease compared to Alternative A. There would therefore be large decreases in average annual

daily generation in summer and winter months that have the highest electricity prices and a large decrease in SLCA/IP firm capacity under Alternative F compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,280 MW of new capacity built under Alternative F over the 20-year LTEMP period. Two additional gas turbines are built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative F would be just over $36.6 billion.

Because of the two additional gas turbines the average retail electric rate would increase about 1.21% and the average monthly residential electricity bill would increase by an average of $1.02. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $16.27/kWh, which is an increase of $2.81/kWh (21%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.91/kW, which is an increase of $1.2/kW (21%) compared to Alternative A.

The NPV of energy produced at Hoover Dam under this alternative is $89 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations resulting from the monthly water releases upstream at Glen Canyon Dam.

In summary, the operating constraints of Alternative F would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the lowest firm capacity (or the seventh highest) from SLCA/IP of all alternatives and the most new capacity needed over the 20-year LTEMP period. It also would have the highest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A; in fact, this alternative would have the largest increase in wholesale rates of all alternatives. It would the highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.7 Alternative G

Average annual daily generation at Glen Canyon Dam would be 11,403 MWh under representative hydrological conditions. Average daily generation under would range from 8,932 MWh in February to 13,256 MWh in June, before falling to 8,827 MWh in December (Figure 4.13-2). The local NPV of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,556 million, a decrease of $106 million, or 4.0%, compared to Alternative A. SLCA/IP firm capacity would be 558.2 MW at the 90% exceedance level, which is which is a 179 MW, or 24.3%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and a large decrease in SLCA/IP firm capacity under Alternative G compared to Alternative A.

Forecasted increases in electricity demand in the service territories of WAPA's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative G over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total NPV of all costs (including capital, fixed O&M, and systemwide production costs) to meet system electric demand under Alternative G would be almost $36.5 billion.

While the capital and operating costs borne by WAPA customer utilities to replace generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by customer utilities under Alternative G and, consequently, changes in the electric bills of residential customers, impact on electric bills paid by residential customers of WAPA's customer utilities would be less than 1%.

Because of the additional gas turbine the average retail electric rate would increase about 0.64% and the average monthly residential electricity bill would increase by an average of $0.59. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $15.65/kWh, which is an increase of $2.19/kWh (16%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.67/kW, which is an increase of $0.95/kW (17%) compared to Alternative A.

Finally, the NPV of energy produced at Hoover Dam under this alternative is $30 million more than under Alternative A over the 20-year LTEMP period. This increase in value is due primarily to the changes in Lake Mead reservoir elevations that result from the monthly water releases upstream at Glen Canyon Dam.

In summary, the operating constraints of Alternative G would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the sixth-highest firm capacity from SLCA/IP of all alternatives (the second lowest after Alternative F) and would be tied for the third smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the sixth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by WAPA would increase compared to Alternative A; in fact, this alternative would have the second-largest increase in wholesale rates of all alternatives. It would have the sixth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section describes the potential impacts of changes in dam operations on the recreational use values and nonuse values placed on recreational resources by individuals that visit, or may never visit, Lake Powell, Lake Mead, and the Grand Canyon. It also describes the potential regional economic impacts of changes in recreational visitation in a six-county region, and the potential impacts on low-income and minority populations in an 11-county region in the vicinity of the reservoirs and river corridor, and in eastern Arizona and northwestern New Mexico. The section also describes the regional economic impacts of changes in customer utility electricity bills and of expansion in electricity generation capacity that would occur as a result of changes in dam operations, as well as the potential impacts of changes in utility bills on low-income and minority populations, including Tribal populations, in the seven-state region in which power generated at the Glen Canyon powerplant is marketed.

Issue: How do alternatives affect socioeconomics and environmental justice?

Impact Indicators:

- Recreational use values associated with current and potential levels of visitation
- Nonuse (or passive use) economic value associated with the preferences of nonusers
- Employment and income impacts resulting from changes in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures
- High, adverse, and disproportionate impacts of changes in dam operations on low-income and minority populations

4.14.1 Analysis Methods

This section describes the methods used to estimate changes in recreational use values and non-use (or passive use) economic value that would result from changes in dam operations; the methods used to estimate the economic impacts of change in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures; and methods used to estimate the impacts of changes in dam operations on low-income and minority populations.

4.14.1.1 Recreational Use and Environmental Non-Use Values

The economic significance of recreational resources on the Colorado River can be measured both in terms of economic welfare, or consumer surplus, which is the amount of value a consumer of a good or service receives over and above that which would be paid for the good or service in the marketplace. However, as recreational activities are often not a market good, the characteristics of the demand for recreational resources cannot be based on the demand for recreational resources in the marketplace. Accordingly, consumer surplus is often referred to as *non-market value*, which includes both use value and non-use value (also called passive use value).

Estimation of recreational use values associated with potential changes in recreational resources under each of the alternatives relies on the benefits transfer method. This method involves the application of existing recreational use value estimates for a particular time period, site, level of resource quality, or combination thereof to a situation for which data are not available. The traditional benefits transfer approach to valuing recreation has been to employ existing use values studies conducted at an existing site, adjusting estimates to account for inflation. Transferring use value estimates from older studies rely on finding a study area with the same recreation activity in a similar geographic area as the study site, meaning that the preferred approach is to employ statistical recreation models developed for a study site; such models are used in conjunction with coefficients from an existing site to estimate recreation visitation and/or value at the study site, allowing the model transfer technique to improve the validity of the results compared to the use value transfer approach.

Because statistical models have been developed for estimating recreation value per trip for two of the three river reaches in the LTEMP study area—Glen Canyon and Upper Grand Canyon—and models estimating recreation use have been developed for Lake Powell and Lake Mead, while other studies have estimated values per trip for recreation use of Lake Powell and Lake Mead, the benefits transfer methods provides a useful and reliable approach to estimating river use values and reservoir visitation.

Visitation levels at the reservoirs were estimated using Neher et al. (2013) and then evaluated using the approach described in Gaston et al. (2014). The net economic value of recreation was then estimated for Lake Powell and Lake Mead, using the Lake_Full program; the GCRec_Full program was used to estimate the economic value for recreation on the three reaches of the Colorado River—Glen Canyon (from Glen Canyon Dam to Lees Ferry at RM 0), Upper Grand Canyon (from Lees Ferry to Diamond Creek at RM 225), and Lower Grand Canyon (from Diamond Creek to Lake Mead). These programs and the benefits transfer method are described in Appendix L. A review of use value estimates associated with Lake Powell, Glen Canyon, Upper Grand Canyon, Lower Grand Canyon, and Lake Mead can be found in Gaston et al. (2014).

In addition to use values, there may also be significant non-use values associated with reservoir and river resources in the Grand Canyon. A review of non-use valuation studies is provided in Section L.1.2 of Appendix L. NPS conducted a survey to determine non-use values associated with the impacts of Glen Canyon Dam operations on the endangered humpback chub, sandbars in the Grand Canyon, populations of large trout in Glen Canyon, and hydropower. The survey used a discrete choice model to estimate household and aggregate willingness to pay for various environmental outcomes associated with operations. These outcomes were then mapped to specific LTEMP alternatives to determine willingness to pay for each alternative. Survey data were collected from two samples of households—a national sample including all U.S. households, and a regional sample, including a sample of households purchasing power from Glen Canyon Dam. More information on the survey methods can be found in Neher et al. (2016), which is summarized in Appendix L.

4.14.1.2 Recreational Economic Impacts

The economic impacts of changes in recreational activity under each alternative are estimated using changes in visitor expenditures associated with various types of recreational activities, including angling, rafting, and boating, as well as spending on food and beverages, restaurants, fishing and boating equipment, gasoline for vehicles and boats, camping fees or motel expenses, guide services, and fishing license fees. Impacts occurring under each alternative are estimated for the six-county region in which the majority of recreational expenditures are likely to occur, and includes Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Although a large number of visitors to Lake Mead come from the western side of the Colorado River in Clark County, Nevada, their share of expenditures on reservoir recreation in Clark County is not known. Expenditures are therefore assumed to occur in the six counties included in the analysis. Although the addition of Clark County to the analysis would likely produce slightly larger reservoir recreation employment and income impacts under each of the alternatives, it would not affect relative differences among the alternatives. Economic impacts include both direct and secondary effects of changes in expenditures that may occur on employment and income, and were estimated using the IMPLAN analysis tool (IMPLAN Group, LLC 2014). More information on the data and methods used, and a review of studies of the economic impacts of recreation activities in Glen Canyon, Grand Canyon and the surrounding area can be found in Section L.1.3 of Appendix L.

4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts

Under each LTEMP alternative, the regional economic impacts of the eight largest WAPA customer utilities constructing and operating additional powerplants to replace energy and capacity losses from Glen Canyon Dam, and the resulting changes in customer utility electricity prices, were analyzed for the seven-state region in which WAPA markets power. This region includes Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. Estimates of the required additional powerplant capacity were taken from the AURORAex model results (see Appendix K), and data on gas powerplant construction and operating expenditures, including materials, equipment, services, direct and indirect labor, by technology, size, and location were taken from the JEDI model (NREL 2015). Data on changes in retail electricity rates charged by the eight largest WAPA customer utilities, and the resulting changes in residential customer bills, were also included in the analysis (see Appendix K for a description of the retail rate analysis). IMPLAN input-output models (IMPLAN Group, LLC, 2014) (see Section L.1 of Appendix L), were used to estimate the regional economic impacts of additional generating capacity and changes in electricity prices; a separate IMPLAN model represents each of the seven states in the WAPA power marketing area. Note that the alternatives could affect the seasonal pattern of Lake Mead elevations, and thus power generation and capacity at Hoover Dam. However, such effects at Hoover Dam are anticipated to be relatively small (Section 4.13).

4.14.1.4 Environmental Justice

The analysis of potential environmental justice impacts follows guidelines described in the Council on Environmental Quality's (CEQ's) *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). Environmental justice impacts on Tribes could occur through impacts on Tribal values or through impacts on Tribal economics. Impacts on values could result from temporary changes in access to culturally important Tribal resources, and there may be an adverse impact on Tribal values from trout management actions. Tribal economics may be affected by alternative-specific differences in impacts on recreation in Glen Canyon and the Grand Canyon and in the surrounding area, or from changes in the retail rates of hydropower sold to Tribes.

The analysis of environmental justice issues considered impacts within the 11-county region in which disproportionately high and adverse human health and environmental effects on minority and low-income populations may occur (including Apache County, Coconino County, Mohave County, and Navajo County in Arizona; Cibola County, McKinley County, and San Juan County in New Mexico; and Garfield County, Kane County, San Juan County, and Washington County in Utah). Other potential impacts related to environmental justice include changes in Tribal electricity retail rates, and impacts on Tribal resources and values. Using CEQ guidelines, the impact assessment determined whether each alternative would produce impacts that are high and adverse. If impacts were high and adverse, a determination was made as to whether these impacts would disproportionately affect minority and low-income populations by comparing the proximity of locations where any high and adverse impacts are expected with the location of low-income and minority populations. If impacts are not high and adverse, there can be no disproportionate impacts on minority and low-income populations.

4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice

Table 4.14-1 summarizes the impacts for recreational use values, environmental non-use values, recreational economic impacts, and environmental justice.

4.14.2.1 Recreational Use Values

Recreational resources in Lake Powell, Lake Mead, and the Grand Canyon produce significant mean annual use values, with recreational activities in Lake Mead and Lake Powell constituting almost 97% of overall use value under each alternative (Table 4.14-2). Use values are presented in terms of net present value, to allow for differences in the distribution of use values between activities over time. Total mean annual use value created by all reservoir and river recreational activities amounts to $14,619.8 million under Alternative A (No Action Alternative), values which would decline slightly to between $14,598.7 million under

TABLE 4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice[a]

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts	No change from current conditions in use values, or economic activity with no change in reservoir levels or river conditions. Lowest non-use value of alternatives.	Compared to Alternative A, no change in use values and economic activity associated with Lake Powell recreation, and declines in use values (up to 5.2%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Minimal decrease in use values (less than 0.1%) and no change in economic activity associated with Lake Mead recreation. Minimal increase in economic activity (less than 0.1%) from lower residential electric bills compared to Alternative A.	Compared to Alternative A, declines (0.7%) in use values and economic activity (0.6%) associated with Lake Powell recreation, and in use values (up to 11.5%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 11.7%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less	Compared to Alternative A, declines in use values (0.5%) and economic activity (0.5%) associated with Lake Powell recreation, and in use values (up to 14.0%) associated with most forms of river recreation. No change in economic activity for most forms of river recreation except angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity from higher residential electric bills (less than 0.1%). Annual	Compared to Alternative A, declines in use values (1.1%) and economic activity (1.1%) associated with Lake Powell recreation, and in use values (up to 8.9%) associated with most forms of river recreation. Increase in use values (0.5%) associated with Upper and Lower Grand Canyon private boating. Decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.5%) and economic activity (0.5%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 9.3%), and minimal decrease in economic	Compared to Alternative A, declines in use values (0.4%) and economic activity (0.4%) associated with Lake Powell recreation, and in use values (up to 13.2%) associated with most forms of river recreation. Increase in use values (0.3%) associated with Lower Grand Canyon private boating. Decrease in economic activity for angling, with declines during HFEs. Increases in use values (0.3%) and economic activity (0.3%) associated with Lake Mead recreation. Increased economic activity from capacity expansion (up to 4.5%), and minimal decrease in economic activity

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts (Cont.)		Annual increase in non-use value of $1,511 million at national level.	than 0.1%). Annual increase in non-use value of $3,985 million at national level.	than 0.1%). Highest non-use value of alternatives. Annual increase in non-use value of $4,486 million at national level.	increase in non-use value of $3,963 million at national level.	activity from higher residential electric bills (less than 0.1%). Annual increase in non-use value of $2,353 million at national level.	from higher residential electric bills (less than 0.1%). Annual increase in non-use value of $3,524 million at national level.
Use Values[a]							
Lake Powell	No change from current conditions in use values ($5,016 million) because no change in water levels (lowest impact of alternatives).	Same as Alternative A	Compared to Alternative A, potential declines in use values of 0.7% (to $4,983 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of less than 0.4% (to $4,997 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of less than 0.5% (to $4,990 million) associated with lower water levels.	Compared to Alternative A, potential declines in use values of 1.1% (to $4,961 million) associated with lower water levels (highest impact of alternatives).	Compared to Alternative A, potential declines in use values of 0.4% (to $4,997 million) associated with lower water levels.
Glen Canyon	No change from current conditions in use values ($68.8 million) with no changes in river conditions (lowest impact of alternatives).	Compared to Alternative A, potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 4.7% (to $19.2 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for angling of 13.3% (to $17.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions (highest impact of alternatives).	Compared to Alternative A, potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Upper Grand Canyon	No change from current conditions in use values ($355.8 million) with no changes in river conditions (lowest impact of alternatives).	Compared to Alternative A, potential decline in use values for private whitewater boating of 3.5% (to $66.5 million) and commercial whitewater boating of 5.8% (to $270.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 1.5% (to $67.9 million) and commercial boating of 9.0%, (to $261.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 1.3% (to $68.0 million) and commercial boating of 11.3%, (to $254.4 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 2.3% (to $67.4 million) and commercial boating of 12.9%, (to $249.9 million) associated with changes in river conditions (highest impact of alternatives).	Compared to Alternative A, potential increase in use values for private whitewater boating of 0.4% (to $69.2 million) and decline for commercial boating of 2.3%, (to $280.2 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 0.6% (to $68.5 million) and commercial boating of 13.7%, (to $247.6 million) associated with changes in river conditions.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Use Values*[a] *(Cont.)							
Lower Grand Canyon	No change from current conditions in use values ($64.8 million) with no changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 2.0%, (to $3.6 million) for commercial 1-day boating of 4.6% (to $44.0 million); for overnight trips of 5.2% (to $0.52 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential decline in use values for private whitewater boating of 3.4% (to $3.6 million), for commercial 1-day boating of 9.6% (to $41.7 million), for overnight trips of 11.5% (to $0.49 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 1.9% (to $3.8 million), decrease for commercial 1-day boating of 8.1% ($42.3 million), decrease for overnight trips of 11.7% (to $0.48 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 0.6% (to $3.7 million), decrease for commercial 1-day boating of 10.0% (to $41.5 million), decrease for overnight trips of 14.0% (to $0.47 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 13.3% (to $4.2 million), decrease for commercial 1-day boating of 1.2% (to $45.5 million), decrease for overnight trips 8.9% ($0.46 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions.	Compared to Alternative A, potential increase in use values for private whitewater boating of 6.8% (to $3.9 million), decrease for commercial 1-day boating of 8.0% (to $42.4) million); decrease for overnight trips of 13.2% (to $0.42 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions.
Lake Mead	No changes from current conditions in use values ($9,114.5 million) with no change in water levels (highest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, potential increase in use values of 0.3% (to $9,145.2 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.3% (to $9,139.7 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.3% (to $9143.5 million) associated with higher water levels.	Compared to Alternative A, potential increase in use values of 0.5% (to $9,157.5 million) associated with higher water levels (lowest impact of alternatives).	Compared to Alternative A, potential increase in use values of 0.3% (to 9,143.3 million) associated with higher water levels.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Non-Use Values							
Willingness to pay (national level)	No change in non-use values (highest impact of alternatives).	Compared to Alternative A, $1.5 billion increase.	Compared to Alternative A, $4.0 billion increase.	Compared to Alternative A, $4.5 billion increase (lowest impact of alternatives).	Compared to Alternative A, $4.0 billion increase.	Compared to Alternative A, $2.5 billion increase.	Compared to Alternative A, $3.5 billion increase.
Willingness to pay (regional level)	No change in non-use values (highest impact of alternatives).	Compared to Alternative A, $9 million increase.	Compared to Alternative A, $22 million increase.	Compared to Alternative A, $25 million increase (lowest impact of alternatives).	Compared to Alternative A, $23 million increase.	Compared to Alternative A, $11 million increase.	Compared to Alternative A, $19 million increase.
Economic Impacts[b]							
Lake Powell	No change in direct and indirect employment (2,444 jobs) and income ($99.7 million) (lowest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, declines in direct and indirect employment (to 2,430 jobs) and income (to $99.1 million) of 0.6%.	Compared to Alternative A, declines in direct and indirect employment (to 2,435 jobs) and income (to $99.3 million) of 0.4%.	Compared to Alternative A, declines in direct and indirect employment (to 2,433 jobs) and income (to $99.2 million) of 0.5%.	Compared to Alternative A, declines in direct and indirect employment (to 2,418 jobs) and income (to $98.6 million) of 1.1% (highest impact of alternatives).	Compared to Alternative A, declines in direct and indirect employment (to 2,435 jobs) and income ($99.3 million) of 0.4%.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Glen Canyon, Upper and Lower Grand Canyon	No change in direct and indirect employment (156 jobs) and income ($3.6 million) associated with river-based recreational activities.	Same as Alternative A.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, negligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.	Compared to Alternative A, egligible change in direct and indirect employment (<1 job) and income (<$20,000) associated with HFE effects on angling.
Lake Mead	No change in direct and indirect employment (5,099 jobs) and income ($208.0 million) (highest impact of alternatives).	Same as Alternative A.	Compared to Alternative A, increases in direct and indirect employment (to 5,116 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,114 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%.	Compared to Alternative A, increases in direct and indirect employment (to 5,124 jobs) and income (to $209.0 million) of 0.5% (highest impact of alternatives).	Compared to Alternative A, increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic Impacts*[b] *(Cont.)							
Seven-state region	No additional generation capacity construction and operation beyond existing capacity expansion plans, which would create 9,519 jobs and $841.7 million in income during construction and 1,019 jobs and $69.4 million in income during operation. No change in WAPA customer utility electricity rates (highest impact of alternatives).	Compared to Alternative A, no increases in WAPA customer utility generation capacity construction and operation direct and indirect employment and income impacts. Negligible decreases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 10,286 jobs) and income (to $909.6 million) of 8.1%, and increases in operations employment (to 1,114 jobs) and income (to $75.7 million) of 9.3%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income (lowest impact of alternatives).	Compared to Alternative A, increase in WAPA customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9%, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5%; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice							
Overall summary of environmental justice impacts	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and <1 year, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 6 years and 0–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 8 years and 2–3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in 3 years and 0–2 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in 11 years and 3 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.
Tribal commercial and flat-water boating river boat rentals	No impacts expected with no changes in river visitation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Tribal retailing in vicinity of GCNRA and GCNP	No impacts expected with no changes in river visitation.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.
Tribal marina operators	No impacts expected.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, some impacts expected; decrease of 1.1% in visitation (highest impact of alternatives).	Same as Alternative A.
Access or damage to culturally important plants and resources	Negligible impacts.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, some damage and reduced access to resources; increase in visitor time off river (highest impact of alternatives).	Same as Alternative A.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Effects on Tribal values associated with TMFs and mechanical extraction of trout in proximity to sacred places of emergence	Negligible impacts, with no TMFs and infrequent trout removal actions (in <1 year of LTEMP period).	TMFs and mechanical removal triggered in an average of 3 years and <1 year, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 6 years and 1 to 3 years, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 11.0 years and 2 years, respectively, of LTEMP period.	TMFs and mechanical removal triggered in an average of 3 years and 2 years, respectively, of LTEMP period.	No impact; TMFs and mechanical removal not allowed under this alternative (lowest impact of alternatives).	Highest impact of all alternatives; TMFs and mechanical removal triggered in an average of 11 years and 3 years, respectively, of LTEMP period (highest impact of alternatives).
Financial impacts on Tribes related to electricity sales	No impacts expected.	Impacts would be similar to those on non-Tribal customers and those under Alternative A (lowest impact of alternatives).	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A (highest impact of alternatives)	Impacts would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A

[a] Use values for alternatives are presented in Table 4.14-2.

[b] Employment and income values associated with recreational expenditures are presented in Tables 4.14-4 and 4.14-5, respectively. Employment and income associated with generation capacity are presented in Table 4.14-6, and residential electricity bills are presented in Table 4.14-7.

TABLE 4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP Alternatives[a]

Location and Activity	Mean Annual Net Economic Value ($ Million Net Present Value, 2015) for each Alternative						
	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Lake Powell							
General recreation	5,016.0	5,016.0	4,983.3	4,996.6	4,990.1	4,961.0	4,997.1
Glen Canyon							
Angling	20.1	19.4	18.9	19.2	19.4	17.4	18.9
Day-use rafting	48.7	48.7	48.7	48.7	48.7	48.7	48.7
Upper Grand Canyon							
Private whitewater boating	68.9	66.5	67.9	68.0	67.4	69.2	68.5
Commercial whitewater boating	286.9	270.2	261.2	254.4	249.9	280.2	247.6
Lower Grand Canyon							
Private whitewater boating	3.7	3.6	3.6	3.8	3.7	4.2	3.9
Commercial whitewater boating, 1-day trips	46.1	44.0	41.7	42.3	41.5	45.5	42.4
Commercial whitewater boating, overnight trips	0.55	0.52	0.49	0.48	0.47	0.46	0.42
Commercial flat-water boating	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Lake Mead							
General recreation	9,114.5	9,114.3	9,145.2	9,139.7	9,143.5	9,157.5	9,143.3
All activities	14,619.8	14,598.0	14,585.3	14,587.6	14,579.1	14,598.7	14,585.3

[a] Use values are based on historical direct natural flow hydrology, weighted by sediment flow condition.

Source: Gaston et al. (2014).

Alternative F and $14,579.1 million under Alternative E, the latter of which is a decline of 0.3% compared to Alternative A.

Mean annual use values for general recreation in Lake Powell would fall slightly from $5,016 million under Alternative A to between $4,997.1 million under Alternative G and $4,961.0 million under Alternative F the latter of which represents a decline of 1.1%. Potential declines in use values under each alternative would come primarily as a result of lower reservoir water levels, which would mean exposed beaches and mudflats, reducing the quality of the recreational experience. There would be no change in use values associated with Alternative B compared to Alternative A. For Lake Mead, general recreation use values would increase slightly, from $9,114.5 million under Alternative A to between $9,139.7 million under Alternative D to $9,157.5 million under Alternative F, the latter of which is an increase of 0.5%. Higher use values would primarily result from higher reservoir water levels covering previously exposed mudflats and beaches, improving the quality of the recreational experience. There would be a slight decrease in use values associated with Alternative B compared to Alternative A.

Although river-based recreation activities produce less mean annual use value than reservoir-based activities, there would be more variation among alternatives. Differences between each alternative and Alternative A, where high flow experiments are restricted, are primarily due to the extent to which larger fluctuations in flow associated with each alternative are shifted to seasons of the year that are more popular with visitors.

Angling use values in Glen Canyon would decline from $20.1 million under Alternative A to between $19.4 under Alternative E to $17.4 million under Alternative F, the latter representing a decline of 13.3%. Use values associated with commercial whitewater boating in the Upper Grand Canyon would fall from $286.9 million under Alternative A to between $280.2 million under Alternative F and $247.6 million under Alternative G, the latter representing a 13.7% decline. Mean annual use value generated by 1-day commercial whitewater boating trips in the Lower Grand Canyon would fall from $46.1 million under Alternative A to between $45.5 million under Alternative F and $41.5 million under Alternative E, the latter of which represents a decline of 10.0%.

Private whitewater boating in the Upper Grand Canyon produces $68.9 million in use values under Alternative A, values that would increase to $69.2 million under Alternatives F, an increase of 0.4%, and fall to between $68.5 million under Alternative G and $66.5 million under Alternative B, a decrease of 3.5%. Private whitewater boating in the Lower Grand Canyon would decrease from $3.7 million under Alternative A to $3.6 million for Alternative B and C, and increase to between $3.7 million under Alternative E, and $4.2 million under Alternative F, an increase of 13.3%,

Day-use rafting in Glen Canyon would generate $48.7 million in use value under each of the alternatives, commercial boating overnight trips would produce $0.5 million under each alternative, while commercial flat-water boating in the Lower Grand Canyon would produce $14.5 million under each alternative. Use values for either activity would not change under any of the alternatives, because demand for these activities would not be affected by river levels or fluctuations in river flow.

With the exception of changes in use value associated with commercial whitewater overnight boating trips and commercial flat-water boating in the Lower Grand Canyon, changes in use value for all other forms of river recreation were statistically significant at the 90% confidence level under each alternative, while changes in use value associated with reservoir recreation were not statistically significant under any of the alternatives.

4.14.2.2 Environmental Non-Use Values

NPS conducted a survey to determine non-use values associated with the impacts of Glen Canyon Dam operations on the endangered humpback chub, sandbars in the Grand Canyon, populations of large trout in Glen Canyon, and hydropower (Neher et al. 2016). The survey used a discrete choice model to estimate household and aggregate willingness to pay for various environmental outcomes associated with operations. These outcomes were then mapped to specific LTEMP alternatives to determine willingness to pay for each alternative. These outcome results were based on the primary modeling metrics used in the LTEMP EIS for these resource areas. For sediment, the metric used was the sand load index. For humpback chub, the metric used was from the coupled rainbow trout–humpback chub model. For the purposes of this quantative study, the simplication of using these main modeling metrics was necessary; however, additional quantitative and qualitative analyses are fully discussed in the LTEMP EIS Sections 4.3 and 4.5. It should also be noted that the survey respondents seemed to value the status quo for trout populations most highly and provided no solid trend regarding increasing trout populations; therefore the trout results were deemed inconclusive and not used for the final outcomes listed below.

Survey data were collected from two samples of households, a national sample including all U.S. households, and a regional sample including a sample of households purchasing power from Glen Canyon Dam, and including all utilities receiving power from the Glen Canyon Dam.

The results from the national and regional samples indicated that, based on the estimated willingness to pay for environmental outcomes, Alternative D (the preferred alternative) would be the most highly valued of the alternatives with an aggregate annual willingness to pay value of $4,486 million, and a regional aggregate annual value of $25 million (Table 4.14-1) (Neher et al. 2016). The next highest rated alternatives were Alternatives C and E. Alternative B was associated with the lowest willingness to pay value based on expected outcomes.

A recently published study (Jones et al. 2016) offers an alternative total economic value analysis to that presented by Neher et al. (2016). The Jones et al. analysis relied on the contingent valuation methodology, which is similar to the methodology used by Welsh et al. (1995), but different from the methodology used by Neher et al. The Neher et al. analysis relied on the choice experiment methodology, which incorporates recent methodological advances in non-market valuation. However, the Jones et al. analysis is also different from the Neher et al. analysis because it included two additional attributes: (1) impacts on Tribes and rural western communities that depend on hydroelectric production, and (2) increases in air pollution by switching to nonrenewable fossil fuels in the power generation system. The Jones et al. study concluded that including these additional attributes would “significantly decrease willingness to

pay for changing Glen Canyon Dam operations, and demonstrate a significant fraction of the population with a positive willingness to pay for maintaining dam operations at current levels."

The Jones et al. (2016) study was a pilot study that relied on an internet panel rather than a randomized mail survey; the Tribe and rural western community attributes did not identify specific causal relationships or quantified values to ensure consistent respondent interpretation, and potential air quality impacts associated with increased fossil fuel use may be overstated for the range of alternatives analyzed for LTEMP (see Sections 4.15 and 4.16). While this study created a new framework that provided a different way of evaluating some of the attributes that would not have been analyzed otherwise, the issues discussed above limit the application of this study to the LTEMP EIS.

4.14.2.3 Recreational Economic Impacts

The regional economic impacts of recreation in Lake Powell, Lake Mead, and the Grand Canyon are closely tied to visitation levels for each recreational activity. By far the most significant recreational resource is Lake Mead, which drew almost 6 million individual trips in 2012, 72.0% of the total number of trips to these areas (Table 4.14-3). Lake Powell drew 1.9 million trips, or 23.0% of the total, while there were 0.2 million individual Grand Canyon river trips in 2012 (2.5% of the total). Of the river-based recreational activities, commercial flat-water boating in the Lower Grand Canyon, below Diamond Creek, drew the largest number of individual trips (95,520 individual trips, or 46.0% of the total number of individual river trips), followed by day-use rafting in Glen Canyon (53,578 individual trips, 25.8% of the total) and 1-day white water boating below Diamond Creek (28,748 individual trips, 13.8% of the total). Commercial whitewater boating in the Upper Grand Canyon drew 17,384 individual trips, or 8.4% of total river trips.

Recreational expenditures by visitors to Lake Powell and Lake Mead, and to the Upper and Lower Grand Canyon, create substantial employment and income in the six-county area in Arizona and Utah (Tables 4.14-4 and 4.14-5). Boating in Lake Mead currently produces 5,099 total (direct and indirect) jobs and $208 million in total income (direct and indirect) annually; boating on Lake Powell produces 2,444 total jobs and $99.7 million in income. Over the 20-year LTEMP period, annual direct and indirect economic activity would fall to between 2,435 jobs and $99.3 million in income for Alternative G and 2,418 jobs and $98.6 million in income for Alternative F, for Lake Powell, with increases of between 5,115 jobs and $208.6 million in income for Alternative G, and 5,124 jobs and $209.0 million in income for Alternative F for Lake Mead. Changes in employment under Alternative F resulting from changes in recreation at Lake Powell would represent a decrease of 1.1% in compared to Alternative A, and an increase of 0.5% under Alternative F at Lake Mead. There would be no change in recreational economic impacts associated with Alternative B compared to Alternative A.

Because current NPS regulations restrict the number of river boating trips that can be taken, and demand consistently exceeds the number of available permits (Gaston et al. 2014), the analysis assumes that the number of whitewater boating trips would not change as a result of any

TABLE 4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012

Location	Activity	Number of Annual Individual Trips
Lake Powell	General recreation	1,914,768
Glen Canyon	Angling	4,925
	Day-use rafting	53,578
Upper Grand Canyon	Private white water boating	5,978
	Commercial white water boating	17,384
Lower Grand Canyon	Private white water boating	1,445
	Commercial white water boating, one-day trips	28,748
	Commercial white water boating, overnight trips	100
	Commercial flat-water boating	95,520
Lake Mead	General recreation	5,991,767
Total	All activities	8,114,213

Source: Gaston et al. (2014).

TABLE 4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives

	Annual Employment (Number of Full-Time Equivalent Jobs[a]) under LTEMP Alternatives						
Location and Activity	A	B	C	D	E	F	G
Lake Powell							
General Recreation	2,444	2,444	2,430	2,435	2,433	2,418	2,435
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	156	156	156	156	156	156	156
Lake Mead							
General Recreation	5,099	5,099	5,116	5,114	5,115	5,124	5,115
Total							
All Activities	7,699	7,699	7,700	7,704	7,702	7,697	7,706

[a] To accurately estimate employment, which may include part-time or overtime working, full-time equivalent (FTE) jobs are used. These are the total number of hours worked in a particular activity divided by the number of regular working hours in a year.

Source: IMPLAN Group, LLC (2014).

TABLE 4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives

Location and Activity	Annual Income ($million, 2013) under LTEMP Alternatives						
	A	B	C	D	E	F	G
Lake Powell							
General Recreation	99.7	99.7	99.1	99.3	99.2	98.6	99.3
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Lake Mead							
General Recreation	208.0	208.0	208.6	208.6	208.6	209.0	208.6
Total							
All Activities	311.3	311.3	311.3	311.5	311.4	311.2	311.6

Source: IMPLAN Group, LLC (2014).

of the alternatives, meaning that the regional economic impacts for river recreation under each of the alternatives would be the same as for Alternative A.

Angling trips could be affected under each of the alternatives, especially if HFEs occur during prime fishing months. High flows would mean poor fishing conditions, limited or no beach or shoreline access, and no wading; these restrictions and limitations could affect annual visitor spending (including spending on lodging, boat fuel, groceries, guide fees, and fishing licenses) and consequently could affect the regional economy. The number of HFEs would vary among alternatives, and would range from 5.5 under Alternative A to 38.1 under Alternative F (Alternative D would have an average of 21.1 HFEs).[35] The maximum number of days HFEs would disrupt angling in any year would range from 4 under Alternative B to 18 under Alternative G; Alternative G is highest because it includes the potential for extended-duration HFEs up to 14 days long (the maximum number of HFE days within a calendar under Alternative D would be 14 days). Note that extended-duration HFEs are expected to be triggered relatively infrequently and would be limited to no more than four under Alternative D (see Section 4.3.3). Although the variation in HFE frequency and duration would mean larger impacts under Alternatives D and G, because of the relatively small number of HFE days, and the timing of the proposed HFEs compared to that of the majority of angler trips, the overall economic impact of HFEs on angling and on the regional economy would be negligible, with less than one job and less than $20,000 in income lost annually in the six-county area.

[35] Adjustments made to Alternative D after modeling was completed included a prohibition of sediment-triggered and proactive spring HFEs in the same water year as an extended-duration fall HFE. The estimated number of HFEs after this adjustment would be about 19.8 (1.3 fewer than were modeled). This reduced number of HFEs is not expected to result in a change in Alternative D's impacts on socioeconomics.

Similarly, although the impacts of HFEs on license revenues would be slightly larger under Alternatives D and G, as would the economic impact of the spending of these revenues, the economic impacts are expected to be negligible for all alternatives, less than one job and $2,500 annually in income in the six-county area.

The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs annually and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and $0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts. A total of 156 jobs and $3.6 million in income are currently produced annually across all river recreational activities under Alternative A, with the same annual impacts expected under each alternative.

4.14.2.4 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts

Although there would be no change in Glen Canyon Dam capacity under Alternative A, forecasted increases in the demand for electricity and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built by the eight largest WAPA customer utilities under Alternative A over the 20-year study period. Under Alternative B, 4,820 MW of additional capacity would also be added, while a reduction in available generating capacity at Glen Canyon Dam under Alternatives C, D, E, and G would mean that alternative generating capacity would be required by WAPA customer utilities to replace lost hydropower capacity. An additional 5,050 MW would be required under Alternatives C, D, E, and G (an increase of 4.8% compared to Alternative A), with 5,280 MW needed under Alternative F (an increase of 9.5%) (see Section 4.13.2.3).

Using estimated capital and operating costs associated with providing additional capacity under each alternative for the eight largest WAPA customer utilities, the economic impacts of construction and operation of additional capacity are shown in Table 4.14-6. Under Alternative A, powerplant construction would produce an estimated 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative A would create 1,019 total jobs and $69.4 million in annual earnings. Alternative B would also require the same capacity as Alternative A, with 9,519 jobs and $841.7 million in earnings created directly and indirectly in the seven states. Operations would produce 1,019 total jobs and $69.4 in earnings per year. Alternatives C, D, E, and G would require slightly more additional capacity than Alternative A, producing 9,895 total construction and 1,065 total operations jobs, an increase of 3.9%, $875.3 million in construction earnings, and $72.5 annually during operations. The largest impacts of capacity additions would be under Alternative F, where 10,286 total jobs, an increase of 8.1%, and $909.6 million in earnings would be produced during construction, and 1,114 jobs and $75.7 million would be produced annually in earnings during operations. It should be noted that the alternatives could affect the seasonal pattern of Lake Mead elevations and, thus, power generation and capacity at

TABLE 4.14-6 Seven-State Economic Impacts[a] under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033

	Alternative						
Parameter	A	B	C	D	E	F	G
Construction							
Employment (FTEs)	9,519	9,519	9,895	9,895	9,895	10,286	9,895
Earnings ($Million 2015)	841.7	841.7	875.3	875.3	875.3	909.6	875.3
Operations							
Employment (FTEs)	1,019	1,019	1,065	1,065	1,065	1,114	1,065
Earnings ($Million 2015)	69.4	69.4	72.5	72.5	72.5	75.7	72.5

[a] Impacts assume average hydrological conditions, and that powerplants would use advanced oil/gas combined cycle or advanced combustion turbine technology. Construction impacts are total impacts over a 3-year construction period; operations impacts are average annual impacts.

Source: IMPLAN Group, LLC (2014).

Hoover Dam, and the associated impacts described here for Glen Canyon Dam. However, such effects related to Hoover Dam generation are anticipated to be relatively small (Section 4.13).

Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently, changes in the electric bills of residential customers. Although there is considerable variation in the amount of power sold by WAPA to customer utilities, ranging from 0.8% of customer utility power sales with Salt River Project to 23.7% with Navajo Tribal Utility Authority among the eight largest customer utilities, only 7.3% of power sales for all eight of the largest customer utilities comes from WAPA, meaning that the cost of additional capacity required under each alternative to replace capacity lost at Glen Canyon Dam has only negligible impacts (average less than 2% in maximum impacts year) on electric bills paid by residential customers of the eight largest WAPA customer utilities. Two groups of utilities that are allocated a large fraction of their generation resources from SLCA/IP projects are Tribal utilities and other small utilities. These groups would be affected more by capacity expansion differences among alternatives than others; Tribal utilities (Navajo and Cocopah) would experience up to a 2.8% increase in retail rates, while small utilities with the largest impact would experience up to a 3.1% increase in retail rates (see Appendix K for additional detail).

Although the economic impacts of changes in retail electricity rates and the corresponding impacts on residential customer bills would be dependent on the timing and magnitude of capacity expansion required under each alternative, changes in customer rates under each alternative are small. Table 4.14-7 shows the average annual losses in economic activity in the seven-state region for the eight largest customer utilities. Impact data are based on the aggregation of bill increases across the eight largest customer utilities, weighting by

TABLE 4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A

	Alternative					
Parameter	B	C	D	E	F	G
Changes to employment (FTE jobs) compared to Alternative A	An increase in up to 10 new jobs	A reduction of 23 jobs	A reduction of 10 jobs	A reduction of 10 jobs	A reduction of 41 jobs	A reduction of 25 jobs
Changes to earnings (in millions of 2015 dollars) compared to Alternative A	An increase of $0.1 in earnings	A loss of $1.0 in earnings	A loss of $0.4 in earnings	A loss of $0.3 in earnings	A loss of $1.9 in earnings	A loss of $1.2 in earnings

Source: IMPLAN Group, LLC (2014).

individual utility power sales compared to total power sales for all eight utilities. Changes in retail rates range from a decrease of 0.27%% under Alternative B to an increase of 1.21% under Alternative F (Table 4.13-1).

The impact of these increases on employment and income in the seven-state region would range from less than 10 total (direct and indirect) jobs lost and $0.3 million in earnings lost under Alternative E to 41 jobs and $1.9 million in earnings lost under Alternative F. A slight decrease in electric bills under Alternative B would mean small increases in employment (less than 10 jobs) and earnings (an increase of $0.1 million).

4.14.2.5 Environmental Justice Impacts

Changes in river and reservoir recreational visitation might disproportionately impact low-income and minority populations including Tribal communities, both in the counties in the vicinity of the GCNRA and GCNP, and in the seven-state area in which power from Glen Canyon Dam is marketed.

Eleven-County Region

There were a large number of low-income and minority individuals in the 11-county region as a whole in the 2010 Census, with 38.0% of the population classified as minority, and 12.7% classified as low-income using data from the 2008–2012 American Community Survey. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in a state, for example), rather than only on the number of minority and low-income *individuals* present in a geographic area. The number of

minority or low-income individuals does not exceed state averages by 20 percentage points or more, and does not exceed 50% of the total population in the area. This means that for the 11-county region as a whole, there are no minority or low-income populations based on the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. The number of minority individuals exceeds the state average by 20 percentage points or more in Apache County, Arizona; McKinley County, New Mexico; and San Juan County, Utah. Minority individuals exceed 50% of the total population in Apache County and Navajo County, Arizona; Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah, indicating that there are minority populations in each of these counties based on county level data in the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. Because the number of low-income individuals does not exceed the state average by more than 20 percentage points, or does not exceed 50% of the total population in any of the 11 counties, there are no low-income populations based on county-level data in the 11-county region.

A large number of census block groups in the vicinity of the GCNRA and GCNP with low-income and minority populations could be affected if changes in visitation levels produced impacts that were high and adverse. In Coconino County, Arizona, a number of block groups have populations where the percentage of minorities is more than 20 percentage points higher than the state average. These are located in the eastern part of the county on the Navajo Nation Indian Reservation and Hopi Indian Reservation, in the western part of the county, including the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County, Arizona. One census block group in Page, Arizona, also has a minority population which is more than 50% of the total. There are a number of census block groups in San Juan County, Utah, where more than 50% of the total population is minority. These are located in the southern portion of the county and include the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation.

There are a large number of census block groups in the vicinity of GCNRA and GCNP where the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located in (1) Coconino County, Arizona, on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; (2) Navajo County, Arizona, on the Navajo Nation Indian Reservation, which also contains the Fort Apache Indian Reservation; (3) eastern Mohave County, Arizona, on the Hualapai Indian Reservation; and (4) southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation. There are also a number of census block groups in the 11-county area where more than 50% of the total population is below the poverty level. These are located in (1) the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; (2) southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; (3) the northern parts of Navajo County and Apache County, Arizona; and (4) southwestern Navajo County on the Fort Apache Indian Reservation.

Changes to river recreation could impact Tribes in the vicinity of GCNRA and GCNP. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe, for employment and income, but as Table 4.14-5 shows, there are negligible

differences expected among the alternatives. NPS regulates the number of river boating trips that can be taken, with a set number of river trip launches per year, meaning that none of the alternatives are expected to impact overall levels of recreational river visitation. Although differences in time off river for river trips among the alternatives, or differences in stage levels, could change visitation patterns, either of these leading to potential damage and reduced access to culturally important plants and resources, these impacts are expect to be negligible for all alternatives except Alternative F, which may have a slight increase in the potential for effects to cultural sites based on more time off river (see Table 4.14-5). Changes to river stage levels, such as those caused by HFEs, could temporarily restrict Tribal access to culturally important resources, such as springs, minerals, and plants. Similar impacts may also occur if recreational visitors spend more time away from destination campsites with inundation by higher water levels (Section 4.8), but these impacts are expected to be small. Higher water levels may have positive impacts from flushing out springs that have cultural significance to Tribal members, such as Pumpkin Springs (Section 4.9).

Temporary changes in access to culturally important Tribal resources and other areas of significance to tribes may also impact Tribal members. As described in Section 4.9, for those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout or TMFs to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni Traditional Cultural Property. The Zuni have expressed their view on this subject in Section 3.9.6. As shown in Table 4.14-1, there are differences among alternatives in the frequency of TMFs and mechanical removal of trout; Alternatives A and F would have the fewest of these actions, and Alternatives D and G the most.

In addition, fluctuations in reservoir levels could impact Tribes and resources managed by them, such as the Navajo Antelope Point marina operations. As shown in Section 4.8, there are negligible differences among all alternatives for impact to the Antelope Point marina, except under Alternative F, which shows a small difference from Alternative A (1.1%). As presented in Table 4.8-3, impacts on tradespeople making and selling jewelry and souvenirs to the traveling public along various routes in the region, primarily those in the vicinity of GCNRA and GCNP, are likely to be negligible, with no differences between the alternatives.

Seven-State Region

A large number of minority and low-income individuals are located in the seven-state region in which electricity from Glen Canyon Dam is marketed. In the region as whole, 35.7% of the population is classified as minority, while 15.1% is classified as low income. According to CEQ guidelines, however, environmental justice concerns should be evaluated where there are

minority and low-income *populations*, where the number of minority and low-income *individuals* present in a geographic area are compared to a reference population (the number of minority and low-income individuals in the nation, for example), rather than only on the number of minority and low-income *individuals* present in a geographic area. The number of minority or low-income individuals does not exceed the respective national averages by 20 percentage points or more, and does not exceed 50% of the total population in the area, meaning that for the seven-state region as a whole, there are no minority or low-income populations based on 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. Within one state in the region, New Mexico, 59.5% of the total population is minority, meaning that according to 2010 Census and 2008–2012 American Community Survey data and CEQ guidelines, there is a minority population in the state.

Although there are no minority populations in any of the seven states except for New Mexico, and no low-income populations, there are a large number of Tribal members in the seven-state area, many of whom reside on Indian Reservations. Many of these individuals have low-income status.

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 65% of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from SLCA/IP; this includes power from Glen Canyon Dam (see Section K.4 in Appendix K). Nine Tribes operate their own electric utilities and receive power directly from WAPA; the remaining 48 have a benefit crediting arrangement. In a benefit crediting arrangement, the Tribe's electric service supplier takes delivery of the SLCA/IP allocation and in return gives an economic benefit or a payment to the tribe.

Tribes may be financially affected in one of three ways by the LTEMP alternatives: (1) a change in the rate they pay for SLCA/IP electric power if they operate their own utility; (2) a change in the payment they receive from their electric service provider if they have a benefit crediting arrangement; or (3) a change in both the payment they receive from their supplier for the benefit crediting arrangement and the electric rate their supplier charges if their supplier also receives an SLCA/IP allocation.

The benefit credit is computed by taking the difference between the SLCA/IP rate and the supplier rate and multiplying it by the Tribe's SLCA/IP allocation. Because the SLCA/IP rate is generally lower than the supplier's rate, the difference between the rates is considered a benefit by the Tribe and is the financial equivalent of a direct delivery of electricity.

Tribes whose supplier also receives a SLCA/IP allocation have a second financial impact. The retail electricity rate their supplier charges could change as a result of an alternative. The retail rate impact is computed by taking the difference in retail rates between an alternative and Alternative A and multiplying by the total electrical use on the Tribe's reservation. Therefore, the financial impact on these Tribes is the sum of the Tribal benefit credit and the retail rate impact.

The financial impact of all alternatives would be relatively small, but the impact on Tribal members would be greater than on non-Tribal residential customers (Table 4.14-8; see Section K.4 in Appendix K for a description of the analysis and results). Differences in impacts on the three groups are as follows:

- Tribal customers receiving power from a non-Tribal utility with an associated benefit credit: Financial impacts (increases in retail rates and reductions in benefit credit) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.63/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.05 (net benefit), $0.91, $0.68, $0.58, $3.26, and $2.84/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Tribal customers that purchase from Tribal-owned utilities: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.72/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of $0.02, $0.44, $0.39, $0.30, $2.00, and $2.37/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Non-Tribal customers: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of –$0.02/MWh (net benefit) under Alternative B to a $0.67/MWh increase under Alternative F. Alternatives C, D, E, and G would produce an increase in financial impact of $0.22, $0.15, $0.13, and $0.38/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.07 (net benefit), $0.62, $0.41, $0.38, $1.86, and $1.07/MWh under Alternatives B, C, D, E, F, and G, respectively.

In summary, for the majority of resource areas, impacts on minority and low-income individuals are likely to be negligible. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe for employment and income, but there are expected to be negligible economic differences expected among the alternatives. Fluctuations in reservoir levels affecting the Navajo Antelope Point marina operations are expected to be negligible under all alternatives except Alternative F, which shows a small difference from Alternative A. Impacts also are likely to be negligible on tradespeople making and selling jewelry and souvenirs to the traveling public along routes in the vicinity of the Grand Canyon itself, with no differences between the alternatives.

TABLE 4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers

Parameter	Average Value under Alternative A ($/MWh)	Change from Alternative A					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribal Customers with Benefit Credit (48 Utilities)							
Average Retail Rate ($/MWh)	91.82	–0.01	0.08	0.05	0.05	0.23	0.13
Average Benefit Credit ($/MWh)	8.84	–0.01	–0.27	–0.24	–0.18	–1.23	–1.45
Total of Retail and Benefit Impacts ($/MWh)	82.98	0.00	0.37	0.31	0.24	1.53	1.63
Maximum Impact: Hopi Tribe	72.67	–0.05	0.91	0.68	0.58	3.26	2.84
Tribal Customers without Benefit Credit (nine Utilities)							
Average Retail Rate ($/MWh)	95.09	0.00	0.40	0.33	0.26	1.63	1.72
Maximum Impact: Ak-Chin Indian Community	83.10	0.02	0.44	0.39	0.30	2.00	2.37
Non-Tribal Customers (142 Utilities)							
Average Retail Rate ($/MWh)	92.15	–0.02	0.22	0.15	0.13	0.67	0.38
Maximum Impact	73.74	–0.07	0.62	0.41	0.38	1.86	1.07

Differences in time off river and differences in stage levels, such as those caused by inundation during HFEs, could lead to damage and reduced Tribal access to culturally important plants and resources. However, the impacts are expected to be negligible for all alternatives except Alternative F, which may lead to a slight increase in impacts on cultural sites.

The financial impacts on Tribal members would be greater than those on non-Tribal residential customers, especially under Alternatives F and G. Financial impacts of other alternatives are all less than $1.00/MWh.

4.14.3 Alternative-Specific Impacts

4.14.3.1 Alternative A (No Action Alternative)

Use values associated with recreation in Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon are substantial and current use values would not change under Alternative A. Use values associated with general recreational activities in Lake Mead ($9,114.4 million) and Lake Powell ($5,016 million) constitute almost 97% of the value created by reservoir and river resources in the affected area under Alternative A. Under Alternative A, commercial and private whitewater boating would produce $286.9 million and $68.9 million in use value, respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

There would be no change in the estimated per-household willingness to pay values associated with the impact of dam operations under Alternative A on humpback chub populations and sandbars in the Grand Canyon.

Recreational expenditures by visitors to Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon create substantial employment and income in the six-county area in Arizona and Utah. Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and the largest amount of income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period.

The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and $0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts.

A total of 7,699 jobs and $311.3 million in income would be produced annually across all reservoir and river recreational activities under Alternative A over the 20-year LTEMP period.

Under Alternative A, there would be an estimated average 5.5 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year; there would be no HFEs after 2020. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Although no additional generating capacity would be required under Alternative A as a result of changes in Glen Canyon Dam operations among the eight largest WAPA customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative A over the 20-year LTEMP period. Using estimated capital and operating costs associated with

providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants with Alternative A would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on retail rates charged by the eight largest WAPA customer utilities or the electric bills paid by their residential customers, or subsequent impacts on employment or income, in the seven-state region.

In summary, with no change in reservoir levels or river conditions under Alternative A, there would be no change from current conditions in use values, economic activity, residential electricity bills, or environmental justice.

4.14.3.2 Alternative B

Under Alternative B, total use values associated with recreation in Lake Mead and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while remaining unchanged for Lake Powell (Table 4.14-2). General recreational activities in Lake Mead would produce $9,114.3 million in use value and $5,016.0 million at Lake Powell, while commercial and private whitewater boating would produce $270.2 million (5.8% decrease) and slightly less than $66.5 million (3.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative B on humpback chub populations and sandbars in the Grand Canyon are estimated to be $1.5 billion at the national level and $9 million at the local (eight-county) level.

Under Alternative B, recreational expenditures by visitors and the number of jobs and income that would be created would be the same as under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period. Impacts on river-based recreational activities would be the same as those under Alternative A.

Under Alternative B, there would be an estimated average 7.2 HFEs over the LTEMP period and a maximum of 4 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Because Alternative B would feature the same monthly volumes as Alternative A, there would be no change in use value and economic impact associated with reservoir-based recreational activities. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day

trips would be primarily due to larger fluctuations in flow that would occur in seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative B compared to Alternative A.

Although additional generating capacity would not be necessary under Alternative B as a result of changes in Glen Canyon Dam operations among the eight largest WAPA customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative B over the 20-year LTEMP period, as would be the case for Alternative A. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative B would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be slightly more Glen Canyon Dam generation capacity under Alternative B, retail rates charged by the eight largest WAPA customer utilities and the electric bills paid by their residential customers would fall, meaning the addition of less than 10 total (direct and indirect) jobs and an increase of $0.1 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative B, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to implementation of TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be similar to those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative B, there would be a decline in use values associated with Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating commercial whitewater 1-day trips, and Lake Mead recreation compared to Alternative A. There would be no change in use values associated with Lake Powell recreation, Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with Lake Powell and Lake Mead recreation, or river recreation. There would be an increase in economic activity as a result of lower residential electric bills compared to Alternative A.

4.14.3.3 Alternative C

Under Alternative C, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities would produce $9,145.2 million (0.3% increase) in use value at Lake Mead and $4,983.3 million (0.7% decrease) at Lake Powell, while commercial and private whitewater boating would produce $261.2 million (9.0% decrease) and $67.9 million (1.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative C on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.0 billion at the national level and $22 million at the local (eight-county) level.

Under Alternative C, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,544 jobs and $307.7 million in income annually over the 20-year LTEMP period, a difference of 0.04% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,700 jobs and $311.3 million in income would be produced annually across all reservoir and river recreational activities under Alternative C over the 20-year LTEMP period.

Under Alternative C, there would be an estimated average 21.3 HFEs over the LTEMP period and a maximum of 10 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Differences in use value and economic impact associated with reservoir-based recreational activities under Alternative C compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily due to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative C compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative C, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative C over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, and $875.3 million in earnings. Operation of new powerplants under Alternative C would create 1,065 total jobs, a difference of 3.9% compared to Alternative A, and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative C would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of 23 total (direct and indirect) jobs and $1.0 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative C there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating, and commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. Increased economic activity would result from customer utility capacity expansion compared to Alternative A, and reduced economic activity would come as a result of higher residential electric bills.

4.14.3.4 Alternative D (Preferred Alternative)[36]

Under Alternative D, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,139.7 million (0.3% increase) in use value and $4,996.6 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $254.4 million (11.3% decrease) $68.0 million (a 1.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative D on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.5 billion at the national level and $25 million at the local (eight-county) level. These are the highest values of any alternative.

Under Alternative D, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those for Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all reservoir and river recreational activities under Alternative D over the 20-year LTEMP period.

Under Alternative D, there would be an estimated average 21.1 HFEs over the LTEMP period and a maximum of 14 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative D compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, as well as reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative D compared to Alternative A.

[36] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on socioeconomic or environjmental justice impacts.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative D, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative D over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants under Alternative D would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative D would have impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities and would mean the loss of less than 10 total (direct and indirect) jobs and $0.4 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators or Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative D there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.5 Alternative E

Under Alternative E, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.5 million (0.3% increase) in use value and $4,990.1 million (0.5% decrease) at

Lake Powell, while commercial and private whitewater boating would produce $249.9 million (12.9% decrease) and $67.4 million (a 2.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative E on humpback chub populations and sandbars in the Grand Canyon are estimated to be $4.0 billion at the national level and $23 million at the local (eight-county) level.

Under the Alternative E, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all reservoir and river recreational activities under Alternative E over the 20-year LTEMP period.

Under Alternative E, there would be an estimated average 17.1 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative E compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative E compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative E, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative E over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings.

Operation of new powerplants under Alternative E would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative E would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of less than 10 total (direct and indirect) jobs and $0.3 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative E, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative E there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon private whitewater boating, commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.6 Alternative F

Under Alternative F, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,157.5 million (0.5% increase) in use value and $4,961.0 million (1.1% decrease) at Lake Powell, while commercial and private whitewater boating in the Upper Grand Canyon would produce $280.2 million (2.3% decrease) and $69.2 million (0.4% increase), respectively; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative F on humpback chub populations and sandbars in the Grand Canyon are estimated to be $2.4 billion at the national level and $11 million at the local (eight-county) level.

Under Alternative F, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,542 jobs and $307.6 million in income annually over the 20-year LTEMP period, a difference of 0.02% compared to Alternative A. Impacts on the various river-based recreational activities would be the same as those under Alternative A. A total of 7,697 jobs and $311.2 million in income would be produced annually across all reservoir and river recreational activities under Alternative F over the 20-year LTEMP period.

Under Alternative F, there would be an estimated average 38.1 HFEs over the LTEMP period and a maximum of 8 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative F compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the large shifts in monthly volumes; although the high volumes of May and June would result in higher use value during those months, the very low flows for much of the rest of the year would result in lower use value at those times. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative F compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative F, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,280 MW of new capacity would be built under Alternative F over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 10,286 total (direct and indirect) jobs in the seven-state region, a difference of 8.1% compared to Alternative A, and $909.6 million in earnings. Operation of new powerplants under Alternative F would create 1,114 total jobs and $75.7 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative F would only have negligible impacts on electric bills paid by residential customers of the eight largest WAPA

customer utilities, and would mean the loss of 41 total (direct and indirect) jobs and $1.9 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative F, although changes in reservoir visitation would be sufficient to affect Tribal marina operators. Access or damage to culturally important plants and resources would also be affected under Alternative F. No impacts on Tribal values related to TMFs or mechanical removal of trout would occur because these actions are not allowed under this alternative. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A.

In summary, under Alternative F there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values in Upper and Lower Grand Canyon private whitewater boating and in use values economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.7 Alternative G

Under Alternative G, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.3 million (0.3% increase) in use value and $4,997.1 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $247.6 million (13.7% decrease) and $68.5 million (a 0.6% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Estimated per-household willingness-to-pay values associated with the impact of dam operations under Alternative G on humpback chub populations and sandbars in the Grand Canyon are estimated to be $3.5 billion at the national level and $19 million at the local (eight-county) level.

Under Alternative G, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,550 jobs and $308.0 million in income annually over the 20-year LTEMP period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as

those under Alternative A. A total of 7,706 jobs and $311.6 million in income would be produced annually across all reservoir and river recreational activities under Alternative G over the 20-year LTEMP period.

Under Alternative G, there would be an estimated average 24.5 HFEs over the LTEMP period and a maximum of 18 HFE days in a calendar year. Although HFEs would preclude angling during their implementation, their impact on employment and income generated by shore and boat angling, and from angler spending on fishing licenses, is expected to be negligible.

Small reductions in use value and economic impact associated with reservoir-based recreational activities under Alternative G compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the equal monthly volumes that would occur year-round, and consequently lower flows during the more popular summer months. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative G compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative G, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest WAPA customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative G over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants with Alternative G would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative G would have impacts on electric bills paid by residential customers of the eight largest WAPA customer utilities, and would mean the loss of 25 total (direct and indirect) jobs and $1.2 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative G, and the impacts of changes in reservoir visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on

Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be higher (as much as $1.34/MWh) from those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A.

In summary, under Alternative G there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and in use values and economic activity associated with Lake Mead recreation. There would also be increased economic activity from customer utility capacity expansion, compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.15 AIR QUALITY

This section describes potential impacts of the LTEMP alternatives on ambient air quality in the immediate vicinity of GCNP and over the 11-state study area within the Western Interconnection, where the air quality would potentially be affected by the proposed action. The regional air quality setting is described in Section 3.15.

Issue: How do alternatives affect emissions from other facilities and air quality in the Grand Canyon area and in the 11-state study area?

Impact Indicators:

- Visibility effects from sulfates and nitrates
- SO_2 and NO_x emissions

4.15.1 Analysis Methods

Glen Canyon Dam hydropower generation does not generate air emissions. However, dam operations can affect emissions within the SLCA/IP system, which is referred to here as "the system." It also impacts emissions and ambient air quality over the 11-state Western Interconnection region, which includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets generation from other generating facilities (i.e., coal-fired, natural gas-fired,) in the Western Interconnection. Differences among alternatives in the amount of generation at peak demand hours could affect regional air emissions, if lost generation was offset by generation from coal, natural gas, or oil units.

Air quality issues within the study area are discussed in Section 3.15 and notably include visibility degradation in Federal Class I areas. Coal, natural gas, and oil units emit SO_2 and NO_x, which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an important role in visibility degradation by contributing to haze. Among anthropogenic sources,

sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor contributor. Effects on visibility are analyzed through a comparison of regional SO_2 and NO_x emissions under the various alternatives.

To compute total air emissions under the alternatives, emissions were summed from all generating facilities in the SLCA/IP system. This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities (results are discussed in Section 4.13). Emissions were computed according to the estimated electricity generation of each facility and for electricity traded on the spot market under each alternative by calendar year. The spot market represents the interface of the system with the greater Western Interconnection region and accounts for effects of Glen Canyon Dam operations outside of the system. For individual powerplants in the system, pollutant emission factors (in pounds per megawatt-hour [lb/MWh]) available in the *Emissions & Generation Resource Integrated Database* (eGRID) (EPA 2014a) were used to compute emissions. For unspecified powerplants (e.g., long term contract), composite emission factors were employed that are representative of power generation from all types of powerplants currently in operation over the Western Interconnection. Composite emission factors are estimated to be 0.74 and 1.07 lb/MWh for SO_2 and NO_x, respectively. For spot market purchases and sales, composite emission factors were used that are representative of power generation from gas powerplants currently in operation over the Western Interconnection, based on the assumption that spot market generation is primarily to serve peak loads. Composite emission factors are estimated to be 0.0083 and 0.266 lb/MWh for SO_2 and NO_x, respectively. For advanced natural-gas-fired simple cycle and combined cycle generating units to be built in the future, emission factors in EIA (2013) were used: 0.001 lb/MMBtu for SO_2 for both simple cycle (0.0098 lb/MWh) and combined cycle (0.0064 lb/MWh); 0.03 lb/MMBtu (0.29 lb/MWh) for simple cycle and 0.0075 lb/MMBtu (0.048 lb/MWh) for combined cycle for NO_x. Note the difference in the expression of emission factors employed from different sources. Emission factors for existing plants and the spot market are based on emissions per electricity output, while those for future plants are based on emissions per heat energy input (fuel burned). To make comparable estimates, the thermal efficiency of the plant must be taken into account for the latter case.

Potential impacts on regional ambient air quality associated with dam operations are compared in terms of air emissions among alternatives relative to air emissions for Alternative A (No Action Alternative).

4.15.2 Summary of Impacts

The geographic area of potential impacts consists of the GCNP vicinity and the 11-state Western Interconnection region. Table 4.15-1 presents potential impacts on ambient air quality that would likely result from each alternative. Due to very small differences in SO_2 and NO_x precursor emissions, negligible differences are expected among the alternatives with regard to visibility and haze in the region.

TABLE 4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality

Air Quality	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions	Negligible increase (0.01%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.01%) in SO_2 emissions and no change in NO_x emissions compared to Alternative A	No change in SO_2 emissions and negligible increase in NO_x emissions compared to Alternative A	Negligible increase (<0.005%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.04%) in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease (–0.03%)in SO_2 and negligible increase in NO_x emissions compared to Alternative A
Visibility[a]	No change from current conditions	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A
Air Quality in 11-State Western Interconnection Region							
SO_2 emissions (tons/yr)[b]	42,465	42,471	42,463	42,465	42,466	42,448	42,453
	No change from current conditions	Negligible increase (0.01%)	Negligible reduction (–0.01%)	No change from current conditions	Negligible increase (<0.005%)	Negligible reduction (–0.04%)	Negligible reduction (–0.03%)
NO_x emissions (tons/yr)[b]	78,496	78,501	78,496	78,503	78,500	78,487	78,498
	No change from current conditions	Negligible increase (0.01%)	No change from current conditions	Negligible increase (0.01%)	Negligible increase (<0.005%)	Negligible reduction (–0.01%)	Negligible increase (<0.005%)

[a] Visibility effects are estimated from expected changes in the emissions of sulfate and nitrate precursors, SO_2 and NO_x.

[b] Total air emissions and percent change in emissions (compared to Alternative A) from combustion-related powerplants in the system averaged over the 20-year LTEMP period.

Source: EPA (2014b).

Differences in emissions, and thus in impacts on air quality, under the LTEMP alternatives depend on four factors that may act to increase or decrease total emissions under a given alternative. These factors include:

- Total electricity generation at Glen Canyon Dam;
- Generation profile as characterized by the hourly, daily, and monthly release pattern;
- Amount and timing of needed replacement capacity needed to offset reduced Glen Canyon Dam capacity; and

- Amount of exports and imports of electricity to and from the spot market.

As total generation decreases, overall emissions increase because compensating generation includes a component of combustion sources within the system. The differences among the alternatives in total generation are relatively small (<2%), and are related to differences in the amount of water that bypasses the turbines during HFEs.

The generation profile of alternatives reflects the degree to which generation can meet peak demand. During low load periods Glen Canyon Dam electricity production displaces generation from baseload units such as coal-fired units that tend to have high emission rates in pounds (lb) of emissions per MWh generated; on-peak Glen Canyon generation displaces peaking unit production, typically natural gas-fired combustion turbines, which have lower emission rates than coal plants. Alternatives that have greater Glen Canyon Dam peaking generation have reduced Glen Canyon Dam baseload generation and vice versa, given approximately equal total flow volumes among the alternatives. Thus, fluctuating flow alternatives with greater Glen Canyon Dam peaking power and lower baseload power tend to result in higher SO_2 and NO_x emissions system-wide due the greater use of coal-fired facilities within the system to compensate for reduced baseload generation at Glen Canyon Dam. Coal-fired facilities have approximately an order of magnitude higher SO_2 and significantly higher NO_x emissions than gas-fired facilities for a given amount of generation. Coal plants also produce more CO_2, a greenhouse gas, than do gas-fired plants. Effects of greenhouse gas emissions are discussed in Section 4.16.

The amount and timing of needed replacement capacity can also have an effect on total emissions. Steady flow alternatives, which do not include load following have reduced effective capacity, or maximum generating level, which must be compensated for by the construction and operation of new generation facilities in the system to meet current and future demands during peak load periods. New capacity is required sooner under steady flow alternatives (Section K.1.10.2 in Appendix K). New units would tend to be cleaner, more efficient, and less expensive to operate and therefore would tend to displace generation from higher emitting old units that serve the same type of duty (i.e., peaking unit) and would thus tend to reduce system emissions slightly relative to fluctuating flow alternatives. Construction of new capacity and retirement of existing plants are included in the hydropower analysis (Section 4.13) and in this air quality analysis.

The relative amounts of exports and imports to and from the spot market also can affect total emissions. Alternatives with greater net exports (sales) from the SLCA/IP system to the spot market tend to have greater total emissions since fossil-fired powerplants in the SLCA/IP system tend to have higher emission rates than Western Interconnection powerplants in states which purchase the electricity, mostly in California. When the system buys external energy to serve electricity demand, it needs to produce less power from its own internal resources thereby reducing pollutants emitted by the system. Conversely, when the system sells power to the Western Interconnection, it increases power production to support the spot energy transaction. Emissions associated with spot market sales are accounted for because unit-level generation for all facilities in the system (including the amount required for a sale) is multiplied by plant-level

emission factors. On the other hand, this exported energy via a spot market transaction will reduce both generation and emissions in the overall 11-state Western Interconnection.

These factors have relatively small effects on emissions, and operate in sometimes opposing directions with regard to total system emissions of SO_2, NO_x and CO_2. Thus, although total emissions under the various alternatives are relatively similar, the relative differences result from a complex combination of these four factors that can only be understood through detailed modeling of emissions from individual generating facilities within the system under each of the alternatives. The following paragraphs present the results of such modeling.

Electricity generation averaged over the LTEMP period at Glen Canyon Dam for each alternative is shown in Figure 4.15-1. Little difference exists among alternatives, which range from 4,178 to 4,255 GWh per year. Other powerplants in the system can be fossil fuel–fired, renewable, hydro, or nuclear, and they depend on Glen Canyon Dam to provide uninterrupted power to their customers; power generation is thus similarly unchanged among alternatives. Under Alternative A, total SO_2 and NO_x emissions in the system averaged over the 20-year LTEMP period are estimated to be about 42,465 tons/yr and 78,496 tons/yr, which amount to about 10% and 3.0%, respectively, of total SO_2 and NO_x emissions over the Western Interconnection region (see Table 3.16-3). Thus, air emissions from power generators in the system are moderate contributors to total emissions in the Western Interconnection region. As shown in Table 4.15-1, air emissions under other LTEMP alternatives are similar to those under Alternative A. Differences from Alternative A range from –0.04 to 0.01% for SO_2 and from –0.01 to 0.01% for NO_x. Differences in average annual emissions range from –18 to 5 tons/yr for SO_2 and –10 to 6 tons/yr for NO_x, compared to those for Alternative A. Therefore, potential impacts of dam operations under various alternatives on regional air quality would be very small.

Table 4.15-2 presents a breakdown of emission sources by generation technology type for the generation facilities within the system and includes emissions for energy traded on the spot market using a composite emission factor for facilities in the Western Interconnection region. The table also shows power generation from Glen Canyon Dam under the various alternatives relative to Alternative A, which produces the most energy. Alternatives F and G produce relatively less hydropower energy than Alternative A (98.3% and 98.2%, respectively) because they have more HFEs in which a portion of released water bypasses the powerplant turbines.

SO_2 and NO_x emissions within the system are dominated by steam turbine technologies, mainly coal-fired powerplants (Table 4.15-2). Considering generation by facilities within the system (approximately 35 primary facilities), the differences among alternatives in estimated emissions are miniscule, ranging over only 0.05% for SO_2 and 0.02% for NO_x (system subtotal). Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies; these are attributed to small differences in baseload and peaking energy provided by Glen Canyon Dam. Gas turbine peaking plant technologies produce lower SO_2 and lower NO_x emissions than baseload coal-fired plants. Thus, offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a lower effect on total system emissions than does offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

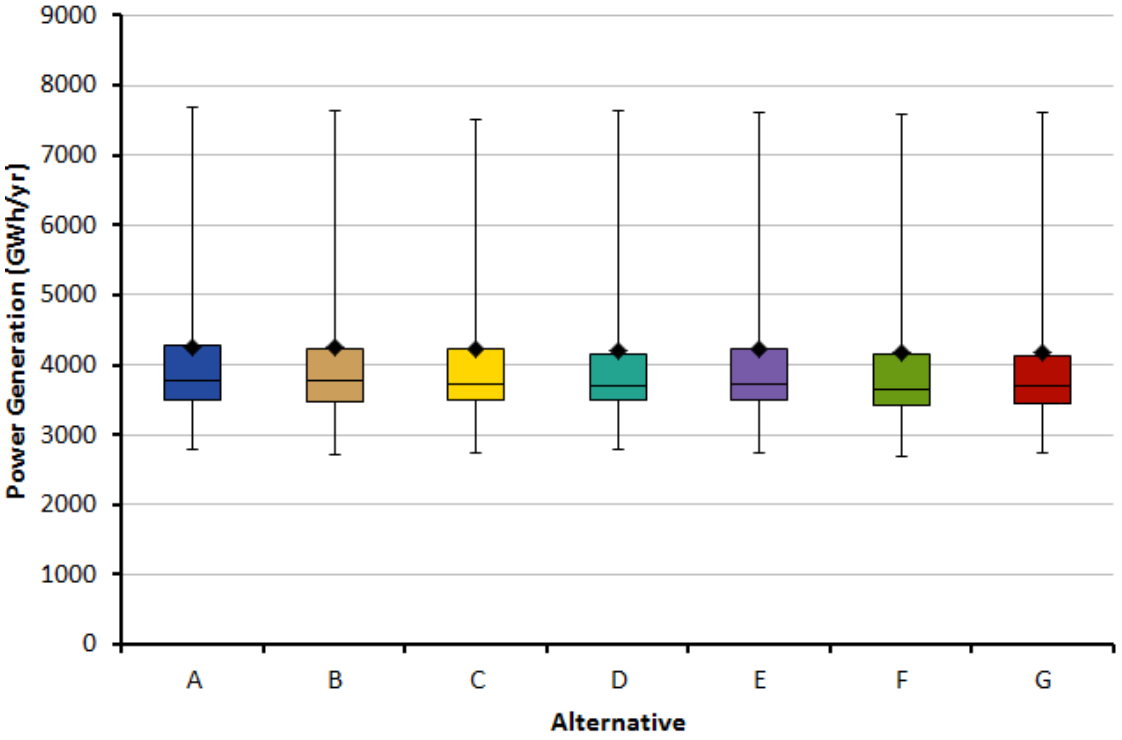

FIGURE 4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

This effect may be seen by comparing emissions subtotals by technology type under fluctuating flow and steady flow alternatives. For both SO_2 and NO_x, steam turbine (coal plant) emissions are slightly lower under Alternatives F and G, reflecting possible reductions in baseload emissions from coal plants offset by increased baseload energy from Glen Canyon Dam, even though these two alternatives generate <2% less Glen Canyon Dam energy than the fluctuating flow alternatives. Likewise, SO_2 emissions for gas technologies are slightly higher for Alternatives F and G, reflecting increased peaking generation from gas plants compensating for lack of peaking ability under these two alternatives.

The effects of the spot market on total system emissions are shown in Table 4.15-2. The spot market contribution to emissions is small (about <0.2% of total emissions from the system); however, for NO_x the spot market contributes about 60% more than the in-system component to differences among alternatives (21 tons/yr and 13 tons/yr, respectively). The spot market has no effect on differences in SO_2 emissions, since spot market emissions are very small and similar (4 tons/yr) (Table 4.15-1). The spot market component is shown as a negative value in the table, reflecting a net export of power from the system. When power is exported (i.e., sold) to a utility outside of the system, it is assumed that the purchaser will generate less energy from its own power resources, resulting in lower total emissions in the Western Interconnection region. Therefore, we apply an emissions credit for energy that is bought by utilities outside of the system. Because we do not model external utilities in detail, we cannot pinpoint the exact source

TABLE 4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative

	Alternative						
Generation Type	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Total Glen Canyon Dam Power Generation Relative to Alternative A (MW-hr/day) (% of Alternative A)	11,650 (100%)	11,616 (99.7%)	11,566 (99.3%)	11,525 (98.9%)	11,571 (99.3%)	11,449 (98.3%)	11,438 (98.2%)
SO_2 Emissions (tons per year)							
System Power Generation							
Combined Cycle	44	44	44	44	44	44	44
Composite[a]	606	607	606	607	607	608	606
Gas Turbine	13	13	13	13	13	15	14
Internal Combustion	1	1	1	1	1	1	1
Steam Turbine	41,805	41,810	41,802	41,804	41,805	41,785	41,792
System Subtotal	**42,469**	**42,474**	**42,467**	**42,469**	**42,470**	**42,452**	**42,457**
Spot Market[b]							
Sales (emissions subtracted)	–16	–15	–16	–16	–16	–16	–16
Purchases (emissions added)	12	12	12	12	12	12	12
Spot Market Subtotal	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**
Total (System + Spot Market)	**42,465**	**42,471**	**42,463**	**42,465**	**42,466**	**42,448**	**42,453**
NO_x Emissions (tons per year)							
System Power Generation							
Combined Cycle	655	654	656	657	656	658	658
Composite[a]	869	870	869	870	870	871	869
Gas Turbine	271	265	282	278	277	307	300
Internal Combustion	24	24	24	24	24	24	24
Steam Turbine	76,800	76,806	76,796	76,799	76,801	76,766	76,781
System Subtotal	**78,620**	**78,620**	**78,626**	**78,629**	**78,628**	**78,626**	**78,632**
Spot Market Sales[b]							
Sales (emissions subtracted)	–499	–492	–509	–503	–506	–520	–514
Purchases (emissions added)	375	374	378	377	378	381	380
Spot Market Subtotal	**–124**	**–118**	**–130**	**–126**	**–128**	**–139**	**–134**
Total (System + Spot Market)	**78,496**	**78,501**	**78,496**	**78,503**	**78,500**	**78,487**	**78,498**

[a] Unspecified generation type.

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

of this emission reduction. Therefore, we use composite emission factors representative of power generation in the 11-state Western Interconnection region. Note, however, that since we model all generating resources within the system we are accounting for the increased generation and hence emissions associated with the exported energy.

Net NO_x emissions related to spot market sales and purchases are lowest (greatest negative value) for the steady flow Alternatives F and G, and highest for the fluctuating flow Alternatives B and A. Net SO_2 spot market emissions are essentially the same across alternatives. This result can be explained by considering in-system generation selling to the spot market. Under steady flow Alternatives F and G, the Glen Canyon Dam powerplant does not provide peaking power, while under fluctuating flow Alternatives A-E it does. Since spot market sales typically serve peak demand, NO_x emissions from sales to the spot marker are therefore higher for Alternatives F and G, since other, typically gas-fired, facilities in the system provide peak generation. Such facilities generate NO_x emissions, but very little SO_2, so there is no effect on the latter emission.

Given the very small differences in the estimated emissions after considering all of the factors discussed above and in light of the uncertainty of emissions modeling, it may be concluded that emissions would be similar under all of the alternatives.

4.15.3 Alternative-Specific Impacts

Although differences are expected in potential ambient air quality and associated impacts among the various alternatives, potential air quality impacts are anticipated to be negligible. The modeled differences among alternatives are presented below. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively.

4.15.3.1 Alternative A (No Action Alternative)

Under Alternative A (No Action Alternative), annual power generation at Glen Canyon Dam would range from 2,781 to 7,677 GWh, with an average of 4,225 GWh, over the 20-year LTEMP period. Coal-fired steam plants account for the vast majority of these emissions; that is about 98% of both SO_2 and NO_x emissions. In addition, total LTEMP-related annual air emissions from power generation, system emissions plus changes in the Western Interconnection would range from 41,392 to 42,991 tons/yr with an average of 42,465 tons/yr for SO_2, and from 77,121 to 80,005 tons/yr with an average of 78,496 tons/yr for NO_x. These annual-average emissions for SO_2 would be about 10% and for NO_x would be about 3.0% of the total air emissions over the Western Interconnection region (see Table 3.16-3).

4.15.3.2 Alternative B

Under Alternative B, total LTEMP-related annual-average air emissions are 42,471 tons/yr for SO_2 and 78,501 tons/yr for NO_x; these values are about 0.01% higher than

those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative B and Alternative A.

4.15.3.3 Alternative C

Under Alternative C, total LTEMP-related annual-average air emissions are 42,463 tons/yr for SO_2 and 78,496 tons/yr for NO_x; these values are about 0.01% lower than and the same as those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than or the same as those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative C and Alternative A.

4.15.3.4 Alternative D (Preferred Alternative)[37]

Under Alternative D, total LTEMP-related annual-average air emissions are 42,465 tons/yr for SO_2 and 78,503 tons/yr for NO_x; these values are the same as and about 0.01% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.9% of that under Alternative A. Total annual emissions from power generation in the region are the same as or slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative D and Alternative A.

4.15.3.5 Alternative E

Under Alternative E, total LTEMP-related annual-average air emissions are 42,466 tons/yr for SO_2 and 78,500 tons/yr for NO_x; these values are about <0.005% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative E and Alternative A.

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[37] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on air quality.

4.15.3.6 Alternative F

Under Alternative F, total LTEMP-related annual-average air emissions are 42,448 tons/yr for SO_2 and 78,487 tons/yr for NO_x; these values are about 0.04 and 0.01%, respectively, lower than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative F and Alternative A.

4.15.3.7 Alternative G

Under Alternative G, total LTEMP-related annual-average air emissions are 42,453 tons/yr for SO_2 and 78,498 tons/yr for NO_x; these values are about 0.03 and <0.005%, respectively, lower and higher than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower or higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative G and Alternative A.

4.16 CLIMATE CHANGE

Issue: How could the LTEMP affect or be affected by climate change?

Impact Indicators:

- Changes in CO_2 and other GHG emissions under different LTEMP alternatives
- Climate-driven changes in hydrology and sediment inputs over the 20-year LTEMP period

There is the potential for the LTEMP to affect climate change indirectly through changes in dam operations, and for dam operations under the LTEMP to be affected by climate change. Although each of the LTEMP alternatives would generate approximately the same amount of electrical power,[38] there are relatively large differences in the monthly and within-day pattern of releases that affect hydropower capacity. These differences in available capacity affect how other power facilities in the region respond to changes in demand, and in this way can affect the total system emission of carbon dioxide (CO_2) and other greenhouse gases (GHGs) (Section 4.15 describes the effect of Glen Canyon Dam operations on the power system and the emissions of criteria pollutants). In addition to these potential effects on climate change, operations over the 20-year LTEMP period could be

[38] The relatively small expected differences among alternatives in the amount of total annual generation relate to the alternative-specific frequency of HFEs. Approximately 14,000 cfs of a 45,000-cfs HFE would be released through the bypass tubes, which do not generate power. Alternatives differ substantially in the frequency of HFEs (Section 4.2).

affected by climate-driven changes in hydrology (inflow patterns and evaporation rates) and sediment inputs. Reductions in inflow due to changes in precipitation and increases in evaporation rates resulting from increases in temperature could result in decreases in the elevation of Lake Powell, with subsequent reductions in power generation resulting from decreased head, and potentially an increase in the frequency of dropping below the power pool.

4.16.1 Analysis Methods

The analysis of GHG emissions and climate change was conducted based on the latest CEQ Guidance (CEQ 2016). The guidance recommends that NEPA analyses take into account available data and use GHG quantification tools for determining projected GHG emissions, which can be used as a proxy for assessing potential climate change effects of a proposed action and alternatives. In addition, when addressing climate change, agencies should consider: (1) the potential effects of a proposed action on climate change as indicated by changes in GHG emissions; and (2) the effects of climate change on a proposed action and its environmental impacts. These two components of the climate change analysis are provided in Sections 4.16.1.1 and 4.16.1.2, respectively.

4.16.1.1 Effects of LTEMP Alternatives on Climate Change

The buildup of heat-trapping GHGs can over time warm Earth's climate and result in adverse effects on ecosystems and human health and welfare. Thus, cumulative GHG emissions can be used as a surrogate to assess climate-change impacts. Such effects would be global and are not particularly sensitive to GHG source locations because GHGs are mostly long-lived and spread across the entire globe.

Glen Canyon Dam operation does not generate GHG emissions, but dam operations can indirectly affect climate change, regionally and globally, through varying contributions to the total mix of power generation in the region, which also includes coal-fired, natural gas–fired, hydroelectric, nuclear, and renewable generation sources. For the purposes of this analysis, the principal GHG of concern is CO_2, which accounts for more than 99% of GHG emissions related to power generation. However, facility- or technology-specific GHG emission factors also consider other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), albeit to a small degree.

To compute total GHG emissions under the alternatives, emissions were summed from all generating facilities primarily affected by Glen Canyon Dam operations, referred to as "the system," as was done for SO_2 and NO_x for the air quality analysis (Section 4.15). This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities, the results of which are discussed in Section 4.13. GHG emissions were computed according to the estimated annual electricity generation of each facility and for electricity traded on the spot market under each alternative. For individual powerplants, GHG emission factors (in lb/MWh) available in eGRID (EPA 2014a) were used to compute

GHG emissions. For unspecified powerplants (e.g., long-term contract), composite emission factors representative of power generation from all types of powerplants that are currently in operation over the 11-state Western Interconnection region (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) were employed. A composite emission factor for GHGs is estimated to be 963 lb/MWh (0.437 MT/MWh) for CO_2 equivalent (CO_2e).[39] For spot market purchases and sales, a composite GHG emission factor for gas powerplants operating in the Western Interconnection was used, and was estimated to be 888 lb/MWh (0.403 MT/MWh) CO_2e. For advanced natural gas–fired generating units projected to be built in the future, an emission factor from the EIA (2013) of 117 lb/MMBtu (0.053 MT/MMBtu) for CO_2 was used for both simple-cycle (1,141 lb/MWh [0.518 MT/MWh]) and combined cycle (752 lb/MWh [0.341 MT/MWh]) units.

Potential impacts on climate change associated with dam operations are evaluated for the LTEMP alternatives though a comparison of GHG emissions to those for Alternative A (no action alternative).

4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources

The effects of climate change on hydrology were treated as an uncertainty in the analyses of hydrology and downstream resource impacts, rather than by means of a full-fledged climate analysis and adaptation approach. The LTEMP EIS has the more limited scope of evaluating future dam operations, management actions, and experimental options to provide a framework for adaptively managing Glen Canyon Dam over the next 20 years to protect and minimize adverse impacts on downstream natural and cultural resources in GCNRA and GCNP. Accordingly, DOI used a sensitivity analysis approach to see how robust the alternatives would be with regard to their impact on resources under climate change.

The Basin Study (Reclamation 2012e) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. In addition, there could be changes to sediment input (especially from the Paria and Little Colorado Rivers), driven by complex local and regional climate changes, but the direction and magnitude of these changes are uncertain. Water supply, sediment supply, and temperature are important factors that affect all of the resources under consideration in the LTEMP EIS.

The approach used in this EIS treats climate change as an external uncertainty and analyzes the robustness of the alternatives to uncertainties in the water and sediment inputs. This approach required: (1) use of 21 hydrologic and 3 sediment scenarios based on historic conditions; (2) estimation of the likelihood of the scenarios under climate change; and (3) analysis of the impacts of alternatives under all hydrologic and sediment scenarios. The approach analyzed how robust the alternatives would be to climate change-driven hydrologic and

[39] CO_2e is a measure used to compare the emissions from various GHGs on the basis of their global warming potential, defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period (usually 100 years).

sediment inputs. For the climate-change analysis, the 21 hydrologic traces used in the LTEMP analysis were weighted according to their frequency of occurrence (based on mean annual inflow to Lake Powell) in the Basin Study's 112 simulations. Figure 4.16-1 shows the weights assigned to each hydrologic trace. As shown in Figure 4.16-2, the 21 hydrologic traces were not representative of the full range of expected inflow variation under a climate-change scenario and did not include the driest traces expected under climate change. About 30% of the forecast distribution was not captured by the historic traces.

Modeling results for downstream resource effects were generated for the 21 historic hydrology traces and 3 historic sediment traces. For the analyses presented in Sections 4.2 through 4.10, the hydrology traces were weighted equally to represent their equal probability of occurrence in the absence of climate change. The climate-change weights shown in Figure 4.16-1 were applied to the modeled results for each trace to represent their probability of occurrence under climate change.

4.16.2 Summary of Impacts

4.16.2.1 Effects of LTEMP Alternatives on Climate Change

Table 4.16-1 presents total estimated GHG emissions within the system for each alternative. These emissions are an indication of the potential relative impact of the alternatives on climate change.

For estimating GHG emissions attributable to Glen Canyon Dam operations, projected power generation at the dam was averaged over the 20-year LTEMP period (Figure 4.15-1). Little difference exists among the alternatives, which range from 4,178 to 4,255 GWh per year, amounting to 1.8%. Power generation from other powerplants in the system and in the Western Interconnection region also would be similar among alternatives. For Alternative A (no action alternative), total GHG emissions in the system averaged over the 20-year LTEMP period are estimated to be about 55,177,668 MT/yr, which amounts to about 4.5% and 0.81% of total GHG emissions over the Western Interconnection region and the United States, respectively (Table 3.15-3, Section 3.15.3). Thus, GHG emissions from power generation are relatively small contributors to total GHG emissions, both in the region (11 Western Interconnection states) and in the United States.

Changes in total GHG emissions (i.e., emissions from system generation, and spot market sales and purchases) under other LTEMP alternatives relative to Alternative A would range from an increase of 5,900 MT/yr (Alternative B) to 44,522 MT/yr (Alternative F). On a percentage basis, differences from Alternative A would range from 0.011% (Alternative B) to 0.081% (Alternative F). The system includes 35 power generation facilities analyzed individually. The spot market reflects the effects of Glen Canyon Dam operations on the larger Western Interconnection region and represents an offset of about 1% of system emissions (Table 4.16-1).

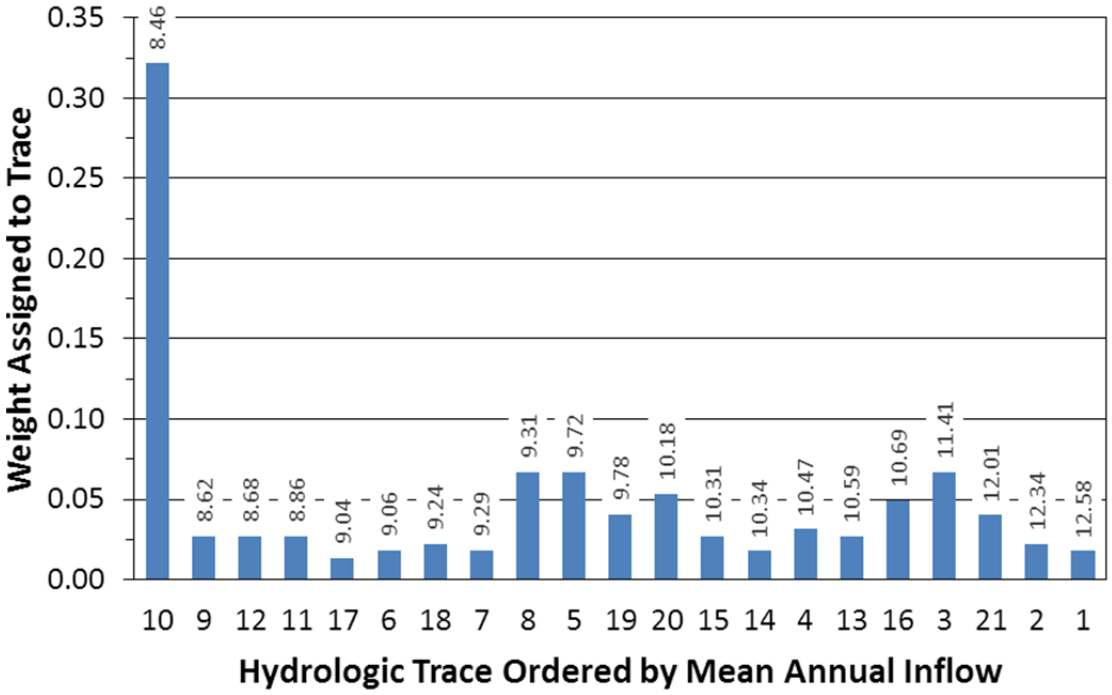

FIGURE 4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change (Numbers at top of bars are mean annual inflow of each trace in million acre-feet.)

In light of the 1.8% range in Glen Canyon Dam hydropower generation under the alternatives, and assuming that reduction in hydropower generation at Glen Canyon Dam is made up by fossil fuel generation facilities in the system, the smaller range in GHG emissions of only 0.081% suggests that reduced hydropower energy from, for example, Alternatives F and G does not result in a corresponding increase in GHG emissions from compensating generation at other thermal powerplants in the system. This result may be explained by examining the effects of powerplant mix and capacity expansion on emissions under the various alternatives. With respect to powerplant mix, the Glen Canyon Dam powerplant under the steady-flow Alternatives F and G does not serve peak loads, but does so under the fluctuating-flow Alternatives A through E, offsetting GHG emissions from other peaking facilities in the system, mainly gas turbines. Conversely, steady-flow alternatives can provide a higher level of baseload power, which can offset emissions from other baseload facilities in the system, mainly coal-fired facilities with relatively high GHG emissions compared to gas turbines. More detailed discussion of these factors is presented in Section 4.15.2.

Reviewing projected GHG emissions at specific powerplants within the system, the steady-flow Alternatives F and G, although they result in the highest overall GHG emissions, are expected to result in lower GHG emissions from baseload coal-fired plants (categorized as steam turbine technologies) and higher GHG emissions from gas turbine plants as compared to the fluctuating-flow Alternatives A through E. This comparison supports the conclusion that

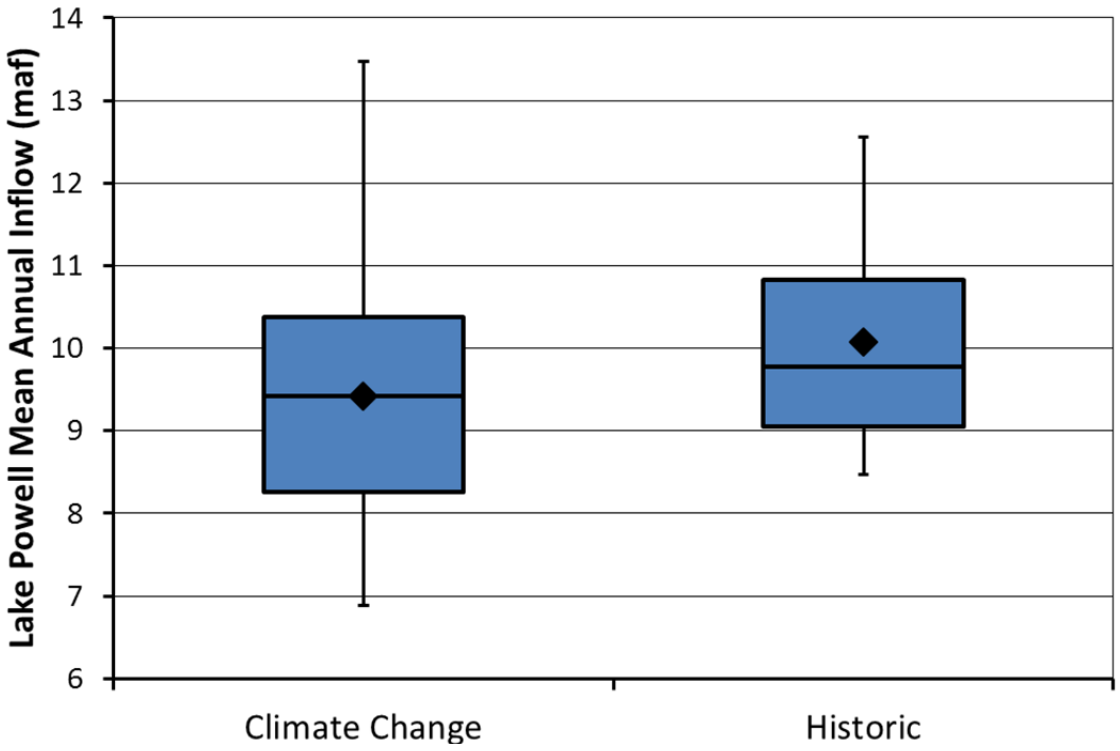

FIGURE 4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces (Means were calculated as the average for all years within each of the traces. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Alternatives F and G tend to offset a relatively greater amount of baseload power at combustion facilities in the system than do Alternatives A through E, while the latter alternatives offset relatively more emissions from gas turbines that provide peaking power.

GHG emissions under the alternatives can also be compared to both total 11-state GHG emissions at 1,226.3 million MT CO_2e in 2010 (see Table 3.15-3) and total U.S. GHG emissions at 6,810.3 million MT CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions from Alternative A range from 0.0005% (Alternative B) to 0.0036% (Alternative F) relative to total 11-state GHG emissions, and from 0.00009% (Alternative B) to 0.00065% (Alternative F) relative to total U.S. GHG emissions.

CO_2, CH_4, and N_2O are emitted from the reservoirs associated with the Glen Canyon Dam, Lake Powell, and Lake Mead. For example, CH_4 from large dams accounted for about 4% of human-caused climate change (Lima et al. 2008). GHG emissions from biomass decay, including CH_4, in such reservoirs, have been a subject of recent debate (Pacca and Horvath 2002). Through consumption of atmospheric CO_2 by photosynthesis in plankton and aquatic plants in reservoirs, net CO_2 emissions from dam operations may be small, and uptake by reservoirs can occasionally exceed emissions. Emissions of CH_4 are possible from turbines and

TABLE 4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions

	GHG Emissions by Alternative (MT/yr)[a,b]						
GHG Emissions Source	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Overall summary of impacts	No change from current conditions.	Compared to Alternative A, 0.011% increase in GHG emissions.	Compared to Alternative A, 0.033% increase in GHG emissions.	Compared to Alternative A, 0.042% increase in GHG emissions.	Compared to Alternative A, 0.030% increase in GHG emissions.	Compared to Alternative A, 0.081% increase in GHG emissions.	Compared to Alternative A, 0.074% increase in GHG emissions.
System power generation							
Combined cycle	5,871,619	5,867,894	5,875,470	5,878,837	5,876,226	5,880,006	5,885,763
Composite[c]	711,604	712,068	711,574	712,296	712,186	713,199	711,081
Gas Turbine	622,805	611,925	661,049	646,520	647,637	730,920	695,498
Internal combustion	1,726	1,721	1,680	1,728	1,711	1,688	1,706
Steam turbine	48,344,640	48,348,638	48,341,590	48,343,248	48,344,880	48,319,488	48,332,026
System subtotal	55,552,395	55,542,246	55,591,363	55,582,629	55,582,640	55,645,301	55,626,074
Spot market[d]							
Sales (emissions subtracted)	–1,512,509	–1,493,787	–1,543,444	–1,525,109	–1,536,444	–1,577,799	–1,560,383
Purchases (emissions added)	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal	**–374,727**	**–358,679**	**–395,534**	**–382,053**	**–388,469**	**–423,112**	**–407,447**
Total emissions (system + spot market)	**55,177,668**	**55,183,567**	**55,195,829**	**55,200,576**	**55,194,171**	**55,222,189**	**55,218,627**
Change in Total Emissions from Alternative A (MT/yr)[e]	0	5,900	18,161	22,908	16,503	44,522	40,960
	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Change as % of total 11-state GHG emissionsf	No change from current conditions	0.0005% increase	0.0015% increase	0.0019% increase	0.0013% increase	0.0036% increase	0.0033% increase

TABLE 4.16-1 (Cont.)

GHG Emissions Source	GHG Emissions by Alternative (MT/yr)[a,b]						
	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Change as % of total U.S. GHG emissions[g]	No change from current conditions	0.00009% increase	0.00027% increase	0.00034% increase	0.00024% increase	0.00065% increase	0.00060% increase

[a] GHG emissions are expressed in CO_2e.

[b] GHG emissions (metric tons) from combustion-related powerplants in the system or in the region averaged over the 20-year LTEMP period. To convert from metric ton to ton, multiply by 1.1023.

[c] Unspecified generation type.

[d] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

[e] Using an online tool from the EPA (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator), one can express a given amount of GHG emissions in metric tons in everyday terms. For example, 1 million MT/yr is estimated to be equivalent to the amount of CO_2 that is emitted as a result of the electricity use of 148,000 households. However, because the EPA cautions that these estimates are approximate and should not be used for emission inventory or formal carbon footprinting exercises.

[f] Total 11-state GHG emissions at 1,226.4 million MT/yr CO_2e in 2010 (see Table 3.15-3).

[g] Total U.S. GHG emissions at 6,810.3 million MT/yr CO_2e in 2010 (EPA 2013d).

spillways and downstream of dams. Reservoirs such as Lake Powell and Lake Mead would be expected to produce some amount of GHG emissions consistent with levels reported for reservoirs in the semiarid western United States (Tremblay et al. 2004), but the GHG emissions from these reservoirs are not anticipated to be different among the alternatives.

As discussed in this section, increases in GHG emissions among alternatives compared to Alternative A would be small, ranging from 5,900 MT/yr for Alternative B to 44,522 MT/yr for Alternative F, which corresponds to a 0.011% to 0.081% relative change from Alternative A. However, the totality of climate change impacts is not attributable to any single action. Albeit a small contribution, this project-related emission in combination with a variety of GHG emission sources around the world could exacerbate climate-related impacts, some of which are presented in Section 3.16. In contrast, climate change would be anticipated to have an impact on the proposed action and any alternative actions, such as hydrology and downstream resources, which are discussed in Section 4.16.2.2.

4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources

As discussed in Section 4.16.1.2, the climate-change analysis approach used the historic hydrology as its basis, but gave greater weight to drier years to represent their expected increased frequency of occurrence under a climate-change scenario. As shown in Figure 4.16-2, this approach underestimated the occurrence of the driest years, but it allows a determination of the robustness of the alternatives to climate-change uncertainty.

Figure 4.16-3 presents the differences between historic and climate-change-weighted values of mean daily flow and mean daily change in flow for the LTEMP alternatives as a percentage of the historic values for the 25th percentile and mean of the two variables. Negative values indicate a decrease in the value under the climate-change scenario, while positive values indicate an increase under the climate-change scenario. Of the values examined (minimum, maximum, 25th percentile, 50th percentile, 75th percentile, and mean), the 25th percentile (representing flow under drier conditions) was the most affected. There was no difference between historic and climate-change-weighted minimum and maximum values, but this is an artifact of the weighting approach used. Because mean monthly volume equals the mean daily flow times the number of days in each month, the percentage differences in that variable are identical to those shown for mean daily flow in Figure 4.16-3. The following conclusions can be drawn from the patterns observed in Figure 4.16-3:

- The 25th percentile values of mean daily flow (and mean monthly volume values) would be very similar from October through March under climate-change and historic scenarios for all alternatives. The differences for all alternatives between historic and climate-change scenarios would increase month-by-month through August. The trend is toward lower mean daily flows under climate change, which reaches a maximum difference of about 10% to 18% (decrease from historic values) in August. In general, the differences among alternatives with respect to the effects of climate change on mean daily flow would be similar.

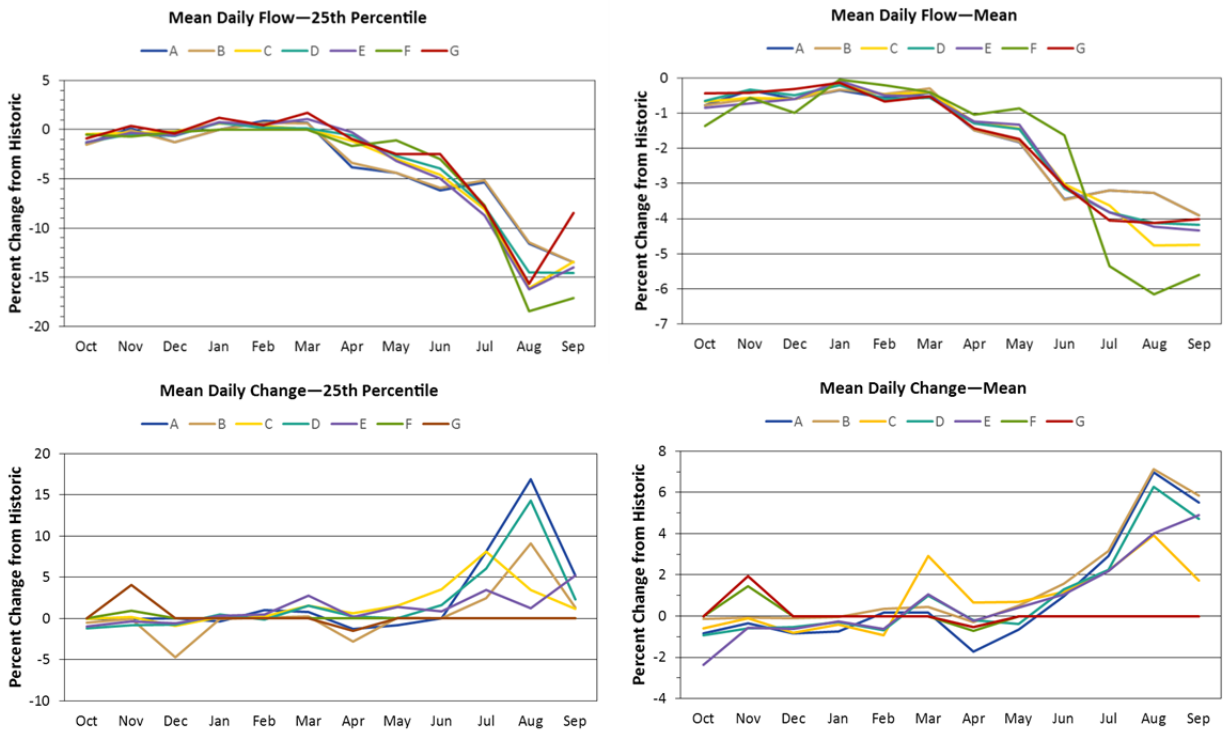

FIGURE 4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives

- Mean values of mean daily flow (and values of mean monthly volume) would follow a pattern similar to that of the 25th percentile values of mean daily flow, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternative F in July and August, when flow would be even lower with climate change than under other alternatives.

The 25th percentile values of mean daily change under the climate-change scenario would be very similar to historic values from October through June for all alternatives, but would be higher than historic for July, August, and September for all alternatives except for the steady-flow Alternatives F and G. Under the drier conditions of climate change and lower mean daily flows, there is more flexibility to provide a wider range of flows within a day and still meet other operational constraints. It should be noted that the differences in mean daily change would be less than 1,000 cfs.

- Mean values of mean daily change would follow a pattern similar to that of the 25th percentile values of mean daily change, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternatives A, B, and D in August, when daily change would be even higher with climate change than under other alternatives.

The monthly increase in climate-change effects in mean daily flow and mean monthly volume results from operation of the dam based on the inflow forecast for the water year. Typically, operations in October, November, and December use volumes for an 8.23-maf year, with adjustments made in later months as forecasts indicate a drier or wetter year (Figure 4.2-1). Early forecasts (e.g., January) are subject to considerable uncertainty, and it is usually not until the April forecast that a reasonable identification of the annual volume can be made. Using this operational strategy under climate change would result in less water needing to be released after April, and therefore an increasing deviation from the historic pattern.

These differences in hydrology would influence the relative effect of LTEMP alternatives on resources, but, in general, the analysis conducted for this EIS indicates the differences would be relatively small (<5%) and not differ greatly among alternatives. Table 4.16-2 provides an overview of the expected effects on downstream resources. Under climate change, the impacts of most or all LTEMP alternatives would be less on sediment resources, humpback chub, trout, riparian vegetation, Grand Canyon cultural resources, Tribal values, and most recreation metrics, but there would be a reduction in the value of hydropower generation and capacity and an increase in impacts on Glen Canyon cultural resources.

4.16.3 Alternative-Specific Impacts

There are expected to be some differences in the emissions of GHGs among the LTEMP alternatives, as presented in this section. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively. The effects of climate change on hydrology and downstream resources are also presented.

4.16.3.1 Alternative A (No Action Alternative)

Under Alternative A (no action alternative), annual power generation would range from 2,781 to 7,677 GWh, with an average of 4,255 GWh over the 20-year (2014–2033) period. Total annual GHG emissions in the system related to power generation at the Glen Canyon Dam would range from 52,014,751 to 59,909,459 MT (from 57,336,449 to 66,038,875 tons), with an average of 55,177,668 MT (60,822,967 tons). These annual average GHG emissions would be about 4.5% and 0.81%, respectively, of the total GHG emissions over the Western Interconnection region and in the United States (see Table 3.15-3 and Section 3.15.3).

Based on the modeling performed and climate change weights applied to account for the greater likelihood of drier conditions under climate change, the following conclusions can be made. Temperature suitability for native and nonnative fish would be improved and impacts on humpback chub lessened. The overall number of trout is expected to decline, but the number of large trout would be higher than under historic hydrology. The impacts on native vegetation would be less. There would be a greater potential for impacts on cultural resources in both Glen Canyon and Grand Canyon, but an improvement in Tribal values for all metrics evaluated. Most

TABLE 4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Hydrology	
Mean monthly volume and mean daily flow	Decrease in spring and summer, especially for Alternative F, with August being the month with the greatest departure from historic (11–19% reduction in 25th percentile values)
Mean daily change	Increase in July and August, especially for Alternatives A, B, and D (1–17% increase in fluctuating flow alternatives)
Sediment	
Sand load index (bar-building potential; higher is better)	Increase (2–4%) under Alternatives C–G; decrease (–2 to –3%) for Alternatives A and B
Sand mass balance index (higher is better)	Increase (4–9%) under all alternatives
Aquatic ecology	
Temperature suitability index—humpback chub (higher is better)	Increase under all alternatives (but especially Alternative F) in upstream reaches (RM 30–119); decrease at RM 157 under Alternatives A, B, and D, and all alternatives (except for Alternative F) at RM 213
Temperature suitability index—other native fish (higher is better)	Similar pattern as temperature suitability for humpback chub, but decrease at RM 157 only under Alternatives A and B; all alternatives would have decrease at RM 213
Temperature suitability index—coldwater nonnative fish (higher is better)	Increase under all alternatives at RM 0; decrease in all other downstream reaches
Temperature suitability index—warmwater nonnative fish (higher is better)	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Temperature suitability index—aquatic parasites (higher is better)	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Minimum number of adult humpback chub (higher is better)	Increase (0.2–2%) under all alternatives
Trout catch rate (age 2+, no./hr; higher is better)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout outmigrants (lower is better)	Increase (0.2–4%) under Alternatives C, D, E, and G; decrease (–1 to –4%) under Alternatives A, B, and F
Trout abundance (age 1+; higher or lower is better dependent on receptor)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout >16 in. total length (higher is better)	Increase (0.4–2%) under Alternatives A, B, C, and F; decrease (–0.1 to –1%) under Alternatives D, E, and G

TABLE 4.16-2 (Cont.)

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Riparian vegetation	
Native species diversity and cover (index, higher is better)	Increase (1%) under Alternatives A, B, D, and E; decrease (–0.2 to –1%) under Alternatives C, F, and G
Cultural resources	
Effect of flows on Glen Canyon resources (index, higher is better)	Decrease under all alternatives (–10 to –17%)
Wind transport of sand to protect resources (index, higher is better)	Increase (3–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–1 to –2%)
Tribal values	
Riparian vegetation diversity	Increase (0.2–2%) under all alternatives, but Alternative F (–0.2%)
Marsh index (higher is better)	Increase (1–34%) under all alternatives
Mechanical removal of trout (lower is better)	Increase (2%) under Alternative G; decrease (–6 to –16%) under Alternatives A, B, and D; no removal under Alternatives C, E, and F
TMFs (lower is better)	Decrease (–7 to –17%) under Alternatives B, C, D, E, and G; no TMFs under Alternatives A and F
Recreation	
Camping area index (higher is better)	Increase (4–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–0.02 to –2%)
Fluctuation index (higher is better)	Decrease (–0.1 to –4%) under Alternatives A–E; no change in steady flow Alternatives F and G
Glen Canyon rafting use (number of passenger days lost due to HFEs)	Increase (0.1%) under Alternative F; decrease (–0.2 to –8%) under Alternatives A–E and G
Glen Canyon inundation index (higher is better)	Increase (0.5–0.8%) under all alternatives
Hydropower	
Annual net present value of generation	Decrease (–3%) under all alternatives
Net present value of capacity	Decrease (–2 to –4%) under all alternatives

[a] These results were obtained by applying the climate weights for each trace shown in Figure 4.16-1 to the modeling results presented in the various resource sections of Chapter 4 (Sections 4.2–4.13).

recreation metrics would reflect greater impacts under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.2 Alternative B

Under Alternative B, total annual average GHG emissions are 55,183,567 MT (60,829,471 tons), which is about 0.011% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative B being different from that of Alternative A.

Under Alternative B, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative A.

4.16.3.3 Alternative C

Under Alternative C, total annual average GHG emissions are 55,195,829 MT (60,842,987 tons), which is about 0.033% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative C being different from that of Alternative A.

Under Alternative C, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved, and impacts on humpback chub lessened. The overall number of trout and the number of large trout are expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.4 Alternative D (Preferred Alternative)[40]

Under Alternative D, total annual average GHG emissions are 55,200,576 MT (60,848,219 tons), which are about 0.042% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about

[40] Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's impacts on climate change or the impacts of climate change on Alternative D.

98.9% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative D being different from that of Alternative A.

Under Alternative D, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be higher than under historic hydrology, but the number of large trout would be lower. The impacts on native vegetation would be slightly lower. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.5 Alternative E

Under Alternative E, total annual average GHG emissions are 55,194,171 MT (60,841,159 tons), which are about 0.030% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative E being different from that of Alternative A.

Under Alternative E, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative D.

4.16.3.6 Alternative F

Under Alternative F, total annual average GHG emissions are 55,222,189 MT (60,872,044 tons), which are about 0.081% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative F being different from that of Alternative A.

Under Alternative F, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be lower than under historic hydrology, but the number of large trout would be higher. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values related

to marsh vegetation, but a decrease in those related to overall riparian diversity. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.7 Alternative G

Under Alternative G, total annual average GHG emissions are 55,218,627 MT (60,868,117 tons), which are about 0.074% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1.

Under Alternative G, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher sand load index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout, including the number of large trout, is expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in the Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.17 CUMULATIVE IMPACTS

The CEQ defines a cumulative impact as "the impact on the environment that results from the incremental impact of [an] action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or nonfederal) or person undertakes such other actions" (40 CFR 1508.7). The assessments summarized in this section place the direct and indirect impacts of the alternatives, presented in the preceding sections of Chapter 4, into a broader context that takes into account the range of impacts of all actions within the Colorado River corridor, from Lake Powell and the Glen Canyon Dam downstream and west to Lake Mead, and the broader Colorado River Basin region (e.g., in the case of climate change).

4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts

Past and present (ongoing) actions in the project area have been accounted for in the baseline conditions described for each resource in Chapter 3. Ongoing and reasonably foreseeable future actions considered in the cumulative impact analysis include the projects, programs, and plans of various federal agencies and other entities as described in the following sections. Many of these projects, programs, and plans reflect shared management objectives and cooperation among federal and state agencies, American Indian Tribes, and stakeholders groups

that are intended to facilitate more effective and efficient management of the resources in the LTEMP project area. Past, present, and reasonably foreseeable future actions are described in the following sections and summarized in Table 4.17-1.

As described in resource-specific sections in this chapter, the LTEMP alternatives are expected to differ in the types and magnitude of impacts on specific resources. Against the backdrop of past, present, and reasonably foreseeable future actions, however, the incremental effects of the LTEMP alternatives, as described in the following sections, are expected to be relatively minor contributions to cumulative impacts along the Colorado River corridor or within the basin at large.

4.17.1.1 Past and Present (Ongoing) Actions

There are numerous actions documented in decisions, plans, policies, and initiatives that relate directly or indirectly to the operation of Glen Canyon Dam and management of the Colorado River ecosystem (see Section 1.10). These actions are listed below, and establish the current conditions or baseline for the LTEMP.

Glen Canyon Dam 1996 Record of Decision

In 1995, Reclamation published an EIS on the impacts of Glen Canyon Dam operations (Reclamation 1995). The ROD for that EIS (Reclamation 1996) selected the MLFF alternative as the operational regime to be implemented, and in 1996, Reclamation began implementing MLFF. The goal of selecting the preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability. The ROD also specified a number of environmental and monitoring commitments—including adaptive management, monitoring/protection of cultural resources, flood frequency reduction measures, beach/habitat-building flows, a new population of humpback chub, further study of selective withdrawal, and emergency exception criteria—to avoid or minimize environmental impacts from the preferred alternative. The new operating regime was selected to create conditions that promote the protection and improvement of downstream resources while maintaining some flexibility in hydropower production. The ROD estimated that there would be a loss of hydropower benefits (between $15.1 and $44.2 million annually) resulting from selection of MLFF as the future operating regime (Reclamation 1996).

Flaming Gorge Dam Record of Decision

Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River upstream of Lake Powell, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper

TABLE 4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions		
Glen Canyon Dam 1996 ROD (Reclamation 1996)	MLFF to reduce daily flow fluctuations and provide high steady releases of short duration at Glen Canyon Dam	In 1995, Reclamation published an EIS on the impacts of Glen Canyon Dam operations (Reclamation 1995). The ROD for that EIS (Reclamation 1996) selected the MLFF alternative as the operational regime to be implemented, and, in 1996, Reclamation began implementing operating criteria under the MLFF alternative. The goal of selecting the preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability.
Flaming Gorge Dam ROD (Reclamation 2006a)	Flow modifications to achieve more natural flows and temperatures (to preserve and protect fish species) in the Green River, a major tributary of the Colorado River	Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper Colorado River Endangered Fish Recovery Program to protect and assist in recovery of the populations and designated critical habitat of four endangered fishes, while maintaining all authorized purposes of the Flaming Gorge Unit of the CRSP, including those related to the development of water resources in accordance with the Colorado River Compact. The selected alternative (Action Alternative) was anticipated to result in minimal negative impacts to land use, recreation, mosquito control, and hydropower generation.
Aspinall Unit ROD (Reclamation 2012f)	Flow modifications to simulate more natural spring flows and moderate base flows in the lower Gunnison River, a tributary to the Colorado River	The Aspinall Unit consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and Powerplants on the Gunnison River, a tributary of the Colorado River. Reclamation published a ROD in 2012 detailing its decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River. Under the ROD, the Aspinall Unit is operated to meet specific downstream spring peak flow, duration flow, and base flow targets (at the USGS Whitewater gage), as outlined in the project's FEIS preferred alternative. Base flow is maintained to provide adequate fish passage at the Relands Fish Ladder on the Gunnison River near its confluence with the Colorado River. The selected alternative (Alternative B) ensures that operations at the Aspinall Unit will continue to honor its existing water and power contracts while minimizing environmental impacts; however, minor impacts on hydropower, and on recreation and sport fisheries, as well as a minor reduction in water stored in Blue Mesa Reservoir are anticipated.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Navajo Generating Station (NGS) (TWG 2013; EPA 2014c)	Reductions in air emissions and generation capacity	The NGS is a 2,250-MW coal-fired powerplant located on the Navajo Reservation near Page, Arizona. The powerplant is operated by SRP and serves electric customers in Arizona, Nevada, and California; it also supplies energy to the Central Arizona Project. In 2014, the EPA took final action to require an 80% reduction in NO_X emissions from NGS to reduce its impact on visibility at 11 national parks and wilderness areas. Appendix B of the NGS technical working group agreement proposes several alternatives to help the NGS achieve this goal through a reduction in generation output or other operating strategies. The reduction of generation output at the NGS will reduce levels of NO_X pollutants in the region.
Interim Guidelines (Reclamation 2007a,b)	Determines the annual volume for release from Glen Canyon Dam	Adopted in 2007, these Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as Intentionally Created Surplus, intended to minimize the severity and likelihood of potential future shortages. Annual volumes may impact recreation economics and water quality in Lake Mead and Lake Powell and water temperatures in the Colorado River; equalization years may increase trout populations below Glen Canyon Dam and increase sandbar erosion. Effects are expected to be independent of the LTEMP alternatives.
Tamarisk Management and Tributary Restoration (GCNP) (NPS 2002a,b, 2014g)	Reduction of tamarisk trees in the project area Increased diversity of native plant species	The NPS continues its efforts to eradicate tamarisk in the GCNP with the goal of restoring more natural conditions inside the canyons along the Colorado River in the GCNP. Over the past 10 years, the NPS has completed work in 130 project areas, removing more than 275,000 tamarisk trees from over 6,000 ac. Although control methods have been effective, overall return of native diversity has been slow. NPS anticipates overall beneficial effects on native vegetation, soil characteristics, water quality, wetlands, wildlife, wilderness, and visitor experience (NPS 2002b). Adverse impacts are expected to be negligible to minor and short in duration (with the exception of microbiotic soil crusts). No significant adverse effects on threatened, endangered, and sensitive species or ethnographic resources are expected. NPS monitors and mitigates the impacts of tamarisk management on an ongoing basis.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Colorado River Management Plan (NPS 2006b,d)	Established visitor capacity based on size and distribution of campsites Established 6.5-month no-motor season Year-round use provides opportunities for a variety of visitor experiences including motorized and non-motorized trips that range from 6 to 25 days	The goal of the CRMP is to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through the GCNP by establishing visitor capacity based on size and distribution of campsites, overall resource conditions, and visitor experience variables. Recreational use patterns are based on daily, weekly, and seasonal launch limits and seasonal differences in commercial and noncommercial levels. The actions would have beneficial effects on cultural resource sites, traditional cultural properties, ethnobotanical resources, and other elements important to Tribal assessments of canyon environmental health. Beneficial impacts on commercial operators (revenues and profits) and adjacent lands were also anticipated. Impacts on visitors' use and experience were determined to be negligible to moderate and adverse to beneficial, depending on perspective and desired experience. Adverse impacts on natural resources (biological soil crusts, aquatic resources at attraction sites, special status species, and the soundscape) would range from negligible to major.
Backcountry Management Plan (for GCNP) (NPS 1988[a])	Allocates and distributes backcountry and wilderness overnight use in campsites along the Colorado River	The goal of the BCMP is to protect and preserve the park's natural and cultural resources and values and integrity of wilderness character by providing a framework for consistent decision making in managing the park's backcountry, providing a variety of visitor opportunities and experiences for public enjoyment in a manner consistent with park purposes and preservation of park resources and values and providing for public understanding and support of preserving fundamental resources and values for which Grand Canyon was established. Proposed actions would address both beneficial and adverse effects to: wildlife populations and habitat by minimizing human-caused disturbances and habitat alteration, minimizing impacts to native vegetation, reducing exotic plant species spread, and preserving fundamental biological and physical processes; enhancing wilderness character and values; developing and implementing an adaptive management process that includes monitoring natural, cultural, and experiential resource conditions and responding when resource degradation has resulted from use levels; preserving and protecting natural soil conditions by minimizing impacts to soils from backcountry recreational activities; minimizing adverse chemical, physical, and biological changes to water quality in tributaries, seeps, and springs; and preserving cultural resource integrity and condition.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Abandoned Mine Lands Closure Plan (NPS 2010b)	Closure of mine openings	The NPS will address health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 AMLs in GCNP. Closure of mine openings[b] would have a long-term beneficial impact on historic structures by protecting mine features from vandalism; however, impacts associated with closure construction activities (installing gates, grates, or cupolas or moving earth, rocks, or tailings piles), while localized, would range from negligible to mostly minor, with some possible moderate adverse (i.e., measurable and perceptible) effects. Beneficial impacts would also be expected on bats and other wildlife by providing protection from disturbance, although NPS notes that closure construction could have minor long-term adverse effects, especially to other wildlife that use the openings for nesting, denning, or shade (effects would be partially mitigated by avoiding closing mine features that are used by a listed species). Because several AML sites are located near trails and river access points in GCNP, they are easily accessible by visitors (although no safety incidents have been documented). Impacts of AML closure, therefore, are expected to be beneficial overall because they would reduce the likelihood of injury from visitor access. Visitors wishing to experience bats and other wildlife, however, may incur localized short-term negligible to minor adverse effects (especially during closure construction when small areas would be closed to visitors). NPS notes that other sites would remain open to visitors, thus affording other opportunities to experience bats and wildlife and mitigating these impacts.
Fire Management Plan (GCNP) (NPS 2012f)	Reduction of wildfire risk in GCNP Ecosystem Restoration	The NPS manages wildland fire risk in GCNP using an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). It also supports the objects of the Resource Management Plan (NPS 1997). This plan may have beneficial or adverse impacts related to fire reduction, such as decreased runoff of sediments, decreased flooding, maintaining or restoring habitat in uplands.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Uranium Mining and Public Lands Withdrawal (DOI 2012b)	Withdrawal of federal lands in the Grand Canyon region from location and entry Continued exploration and mining on state and private lands	In January 2012, the Secretary of Interior withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period. The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). It would have no effect on the exploration and development of any non-federal lands within its exterior boundaries; the withdrawal area would remain available for the development of federal leasable and salable minerals. Active exploration for uranium on state and private lands in the region would not be affected by the withdrawal. Potential impacts of uranium mining are currently difficult to quantify because of the uncertainties of subsurface water movement, radionuclide migration, and biological exposure pathways. Based on its study of groundwater near historic uranium mining sites in northern Arizona, the USGS concluded the likelihood of adverse impacts on water resources (from water use and degradation or impairment) is likely to be low, but if water resources were affected, the risk to the greater ecosystem, Tribes, and tourists could be significant (Bills et al. 2010; DOI 2012b). Other potential (but localized) impacts include impacts on aquatic and other biota and habitats associated with drainages in the event of accidental releases of hazardous materials into local drainages.
Comprehensive Fisheries Management Plan (below Glen Canyon Dam) (NPS 2013e)	Potential stocking of sterile rainbow trout in Lees Ferry Translocation of native fish species Removal of high-risk nonnative fish from areas important for native fish Beneficial use of all nonnative fish removed Implementation of an experimental adaptive strategy for evaluating the suitability of razorback sucker in western portions of the Grand Canyon	The main purpose of the plan is to maintain a thriving native fish community within GCNP while also maintaining a highly valued recreational trout fishery community in the Glen Canyon reach. The actions would have a beneficial effect on native and endangered fish populations, as well as visitor experience (by avoiding quality decline of the rainbow trout fishery), and no significant adverse effect on public health, public safety, or threatened or endangered species. They would, however, contribute to long-term ethnographic resource cumulative impacts resulting from fish management (specifically euthanizing fish), which constitutes an adverse effect under Section 106 of the NHPA. This effect would be mitigated to the extent possible through an MOA between the NPS, SHPO, and Tribes (NPS 2013h).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Lower Colorado River Multi-Species Conservation Program (DOI 2005)	Management of take permits (while conserving critical habitat and protecting threatened and endangered species)	The program is a cooperative species conservation effort between federal and non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development and to provide the basis for incidental take permits while conserving critical habitat and working toward the recovery of threatened and endangered species. Potential beneficial impacts to special status species in Lower Basin.
Reasonably Foreseeable Future Actions		
Special Flight Rules in the Vicinity of GCNP, AZ (14 CFR Part 93, Subpart U)	Reduction of noise in GCNP	Rules to be established to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (PL 100-91). Would establish a system of routes, altitudes, flight allocations and flight free zones in the air space in and around GCNP.
Lake Powell Pipeline Project (UBWR 2015)	Construction/operation of pipeline and penstock Construction/operation of hydropower stations Construction/operation of transmission lines Increased water withdrawal from Lake Powell (adjacent to Glen Canyon Dam)	The Utah State legislature has authorized the UBWR to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. The proposed pipeline is currently being evaluated for potential effects on water storage in Lake Powell and related resources, the availability of water for downstream users, habitat conditions, and aquatic species and resources, including sport fisheries (UBWR 2011a,b).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions (Cont.)		
Grand Canyon Escalade (Confluence Partners, LLC 2012a)	Construction/operation of multiple elements (tramway, riverwalk, road, parking lots, and buildings) Increased visitation up to 10,000 people per day Trespass into GCNP Increased jobs and gross revenues (to the Navajo Nation)	A developer, Confluence Partners, LLC, working with the Navajo Nation has proposed the 420-ac development project on the Grand Canyon's eastern rim, on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking lots. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural resources (e.g., impacts on Little Colorado River and other humpback chub habitats; wildlife disturbance due to noise and loss of habitat) and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in impacts on the local economy through increased tourism and job creation.
Red Gap Ranch Pipeline (City of Flagstaff City Council 2013)	Increased groundwater withdrawal from the C-aquifer on the Coconino Plateau Construction/operation of multiple elements (wells, roads, pipelines, and a treatment facility)	In anticipation of a future water supply shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 ac-ft of groundwater each year from the C-aquifer on the Coconino Plateau. A NEPA review, currently underway, is evaluating the impacts of groundwater withdrawal from the aquifer on base flow feeding the Little Colorado River, Clear Creek, and Chevelon Creek, which ultimately flow into the Colorado River. These withdrawals could affect habitats of humpback chub and other native fish, especially in the Little Colorado River. The NEPA review is also evaluating the impacts of groundwater conveyance on biological and cultural resources on the Red Gap Ranch property.
Page-LeChee Water Supply Project (NPS 2009b)	Construction/operation of water intakes and pumping station Construction/operation of a conveyance pipeline	The Page-LeChee would improve the existing water supply system for the city of Page and the LeChee Chapter of the Navajo Nation. It would increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA. While the proposal would allow higher diversions of water from Lake Powell, actual consumptive use would continue to be subject to the city's contract with the Bureau of Reclamation.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions (Cont.)		
Four Corners Power Plant (FCPP) and Navajo Mine Energy Project (OSMRE 2015a, b)	Reduced NO_x and PM pollutants emissions Coal-mining activities and associated land disturbance and air emissions	The FCPP, located just north Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), historically consisted of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities. The proposed lease amendment would extend the life of the powerplant to 2041. Under the proposed alternatives, air emissions would not exceed NAAQS and deposition impacts with 50 km (31 mi) of the FCPP are expected to be negligible. The Arizona Public Service Company closed three of the five generation units (Units 1, 2, and 3) at the end of 2013, and over the next couple of years is scheduled to install SCR controls on the remaining two units (Units 4 and 5) to reduce NO_x and PM pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). Development of a new coal mine would result in land disturbance and air emissions.
Clean Power Plan Proposed Rule (EPA 2014b)	Reduced CO_2 emissions	The Clean Power Plan Proposed Rule would reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The draft plan would establish state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b). The EIA (2015) estimates the proposed rule would result in a reduction of U.S. power sector CO_2 emissions to about 1,500 million MT/yr by 2025 (levels not seen since the early 1980s). The U.S. Supreme Court granted a stay in February 2016, halting implementation of the plan.
Human Activities Affecting Climate		
	Increased temperatures (air and surface water) Increased variability in precipitation and stream flows Drought conditions and water loss (through evaporation and evapotranspiration) Increased risk of wildfires Decreased snowpack and stream flows (due to less late winter precipitation and snowpack sublimation)	The southwest is already experiencing the effects of climate change, with the decade from 2001 to 2010 being the warmest on record (Garfin et al. 2014; World Meteorological Organization 2014; NAS 2007). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern. Changes in temperature and precipitation patterns could take a toll on the diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation. The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014).

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Human Activities Affecting Climate (Cont.)		
	Seasonal shifts in snowmelt and high stream flows (to earlier in the year)	
	Increased flooding potential (due to earlier snowmelt)	
	Decreased spring and summer runoff (due to decreased snowpack)	
	Lowered reservoir levels (Lakes Powell and Mead)	
	Increased agricultural water demand (due to increased temperatures)	
	Reduced agricultural yields Insect outbreaks	
	Increased production rates of algae and invertebrates	
	Spread of nonnative species adapted to warmer temperatures	
	Increased wildfires	
	Reduced plant and animal diversity (widespread tree mortality)	
	Heat threats to human health	

[a] New BCMP expected to be implemented with ROD in 2016.

[b] NPS notes that except for backfilling, most closure types would be reversible, thereby reducing the impacts of closure on those sites eligible for the *National Register* (NPS 2010b).

Colorado River Endangered Fish Recovery Program to protect and assist in recovery of the populations and designated critical habitat of four endangered fishes, while maintaining all authorized purposes of the Flaming Gorge Unit of the CRSP, including those related to the development of water resources in accordance with the Colorado River Compact. The selected alternative (Action Alternative) was anticipated to result in minimal negative impacts to land use, recreation, mosquito control, and hydropower generation (Reclamation 2006a).

Aspinall Unit Record of Decision

The Aspinall Unit, managed and operated by Reclamation (in cooperation with various other federal agencies), consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and Powerplants on the Gunnison River, a tributary of the Colorado River upstream of Lake Powell. It was originally authorized by the Colorado River Storage Project Act of 1956. In 2012, Reclamation published a ROD that details the decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River (Reclamation 2012f). The selected alternative (Alternative B) ensures that operations at the Aspinall Unit will continue to honor its existing water and power contracts while minimizing environmental impacts; however, minor impacts on hydropower, and on recreation and sport fisheries, as well as a minor reduction in water stored in Blue Mesa Reservoir are anticipated (Reclamation 2012f).

Navajo Generating Station

The Navajo Generating Station (NGS) is a 2,250-MW coal-fired powerplant located on the Navajo Reservation near Page, Arizona. The powerplant is operated by SRP and serves electric customers in Arizona, Nevada, and California. It also supplies energy to the Central Arizona Project, which diverts water from the Colorado River at Lake Havasu near Parker to agricultural land Indian Tribes in southern Arizona (SRP 2016; Reclamation 2016). In 2014, the EPA took final action to require an 80% reduction in NO_X emissions from NGS to reduce its impact on visibility at 11 Class I federal areas (national parks and wilderness areas) (EPA 2014c). Appendix B of the NGS technical working group (NGSTWG 2013) proposes several alternatives to help the NGS achieve this goal through a reduction in generation output (e.g., ceasing generation on one NGS unit) or other operating strategies. The reduction of generation output at the NGS will reduce levels of NOx pollutants in the region.

Interim Guidelines for Coordinated Operation of Lake Powell and Lake Mead

In 2005, spurred by a multi-year drought, decreasing system storage, and growing demands for Colorado River water, the Secretary directed Reclamation to work with the Basin States to develop additional strategies for addressing the coordinated management of the reservoirs of the Colorado River system. In response, Reclamation began to develop and adopt interim operational guidelines that would address the operation of Lake Powell and Lake Mead

during drought and low-reservoir conditions. Adopted in 2007, these Interim Guidelines would be used each year (through 2025 for water supply determinations and through 2026 for reservoir operating decisions) in implementing the LROC for the Colorado River reservoirs pursuant to the 1968 Colorado River Basin Project Act. The ROD (2007b) did not modify the authority of the Secretary to determine monthly, daily, hourly, or instantaneous releases from Glen Canyon Dam.

The completed Interim Guidelines determine the availability of Colorado River water for use in the Lower Basin, on the basis of Lake Mead's water surface elevation, as a way to conserve reservoir storage and provide water users and managers with greater certainty regarding the reduction of water deliveries during drought and other low-reservoir conditions. The Interim Guidelines also proposed a coordinated operation plan for Lake Powell and Lake Mead, basing releases and conserved amounts on predetermined levels in both reservoirs, which would minimize shortages in the Lower Basin and decrease the risk of curtailments in the Upper Basin. In addition, the Interim Guidelines established a mechanism for storing and delivering conserved water from Lake Mead, referred to as "intentionally created surplus," intended to minimize the severity and likelihood of potential future shortages. Nothing in this LTEMP EIS is intended to affect or will affect future decisions that may be made regarding the implementation of the LROC after the Interim Guidelines expire in 2026.

Drought conditions in the Colorado River Basin between 2000 and 2007, coupled with increased demands for Colorado River water supplies, resulted in decreased reservoir storage in the basin from 55.8 million ac-ft in 1999 (94% of capacity) to 32.1 million ac-ft in 2007 (54% of capacity). The interim guidelines incorporate three main elements: (1) shortages to conserve reservoir storage; (2) coordinated operation of Lakes Powell and Mead on the basis of specified reservoir conditions to minimize shortages in the Lower Basin and avoid the risk of curtailments of use in the Upper Basin; and (3) water conservation in the Lower Basin to increase retention of water in Lake Mead. The interim guidelines presented in Section XI of the ROD (Reclamation 2007b) define "normal conditions" in Lake Mead as reservoir levels above elevation 1,075 ft AMSL and below elevation 1,145 ft AMSL. They quantify surplus and shortage conditions against these levels and define apportionments to Lower Basin states on this basis.

Tamarisk Management and Tributary Restoration Project at Grand Canyon National Park

The NPS continues its efforts to eradicate tamarisk in side canyons, tributaries, developed areas, and springs above the pre-dam water level in GCNP (NPS 2002a,b, 2014g). Tamarisk is a nonnative shrub that was introduced to the United States in the 19th century as an erosion control agent. Since its introduction, the plant has spread throughout the west and has caused major changes to natural ecosystems. The shrub reached the GCNP in the 1920s and by the time Glen Canyon Dam was completed in 1963, it had become a dominant riparian zone species along the Colorado River. The NPS's ongoing goal is to restore more natural conditions inside canyons along the river in GCNP and to prevent further loss or degradation of existing native biota. To this end, restoration biologists use an adaptive strategy to manage and control tamarisk in the

GCNP. Control measures involve a combination of mechanical and chemical methods tailored to site-specific conditions and plant size. These include pulling, cutting to stump level, applying herbicide, and girdling (leaving the dead tree in place for wildlife habitat) (NPS 2014g).

The tamarisk leaf beetle (*Diorhabda* spp.) was not intentionally introduced in GCNRA or GCNP, but was discovered in 2009 near Navajo Bridge and at RM 12, and at several locations, including Lees Ferry, in 2010. It is currently found throughout Glen and Grand Canyons (Section 3.6.2). The beetle causes early and repeated defoliation of tamarisk, eventually resulting in mortality. Although the beetle has been associated with widespread defoliation of some tamarisk communities along the river, its long-term effects on tamarisk abundance and distribution in Glen and Grand Canyons is not currently known.

Colorado River Management

The CRMP specifies the actions that NPS follows to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through GCNP (NPS 2006a,b). The CRMP describes management goals for two geographic sections of the Colorado River: (1) Lees Ferry to Diamond Creek, and (2) Diamond Creek to Lake Mead. The selected action for the Lees Ferry to Diamond Creek section (RM 0 to 226) defines mixed motor/no motor seasons and reduces the maximum group size for commercial groups. It establishes use patterns based on daily, weekly, and seasonal launch limits, provides year-round noncommercial use and a 6.5 month non-motorized use period during the shoulder and winter seasons. Management of the Lower Gorges section from Diamond Creek to Lake Mead (RM 226 to 277) involves cooperation between the NPS and the Hualapai Tribe, and provides opportunities for shorter whitewater and smoothwater trips (NPS 2006b).

Backcountry Management Plan

The Backcountry Management Plan defines the concepts, policies, and operational guidelines NPS follows to manage visitor use and protect natural resources in the backcountry and wilderness areas of the GCNP (NPS 1988). The objectives of the Backcountry Management Plan are to provide a variety of backcountry recreational visitor opportunities that are compatible with resource protection and visitor safety. The plan supports the objectives of the CRMP and is currently undergoing revision. A Draft EIS on the proposed plan was issued in late 2015 (NPS 2015b).

Abandoned Mine Lands Closure Plan

In 2010, the NPS finalized an EA that evaluated methods to correct health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 abandoned mine lands (AMLs) in GCNP (NPS 2010b). The resources affected by AML closure are historic structures (mine features such as adits, shafts, and cairns, among others) and

districts, bats and other wildlife (including federally listed species and species of management concern), visitor experience (including health and safety), and wilderness.

Fire Management at Grand Canyon National Park

The NPS manages wildland fire risk in GCNP through its Fire Management Program, as detailed in its Fire Management Plan (NPS 2012d). The Fire Management Plan employs an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). The Fire Management Plan also supports the objectives of the Resource Management Plan (NPS 1997). These include protecting human health and safety and private and public property; restoring and maintaining park ecosystems in a natural and resilient condition; interpreting and educating Tribes, stakeholders, and the public about the importance of the natural fire regime; and promoting a science-based program that relies on current and best-available information, as described in Table 3.2 of NPS (1995).

Uranium Mining and the Northern Arizona Withdrawal of Public Lands

Uranium mineralization in the Grand Canyon region is associated with geologic features called breccia pipes. A breccia pipe is a cylindrical, vertical mass of broken rock (breccia) that typically measures tens of meters across and hundreds of meters vertically. There are 1,300 known or suspected breccia pipes in the Grand Canyon region (Spencer and Wenrich 2011). Development of uranium minerals associated with breccia pipes dates back to the 1940s. By the late 1980s, more than 71 breccia pipes had been found to contain ore-grade rock (DOI 2012b). As of 2010, over 23 million lb of uranium (U_3O_8) had been produced from nine breccia pipes (Spencer and Wenrich 2011); the estimated mean undiscovered uranium endowment for the region is about 933.6 million lb (Otton and Van Gosen 2010)

In January 2012, the Secretary of Interior withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period (DOI 2012b). The withdrawal includes 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel). The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). The withdrawal would have no effect on the exploration and development of any non-federal lands within its exterior boundaries (with the exception of about 23,993 ac of split estate lands where locatable minerals are owned by the federal government), and the withdrawal area would remain available for the development of federal leasable and salable minerals (e.g., oil and gas leases and sand and gravel permits). The public land laws would still apply (DOI 2012b).

Although 3,156 mining claims predate BLM's notice of withdrawal in 2009, most of these did not have valid existing rights at the time of the notice and, therefore, cannot be

developed during the withdrawal period. The BLM estimates that 11 mines, including four existing uranium mines, could still be developed under the full withdrawal, a level similar to that in the 1980s when the high price of uranium spurred interest in mining (DOI 2012b). Arizona State land parcels and private lands in the region could also be developed (NPS 2013k). Thus, uranium mining, while reduced, will continue throughout the withdrawal period.

Active exploration for uranium in the region is currently focused on state and private lands located within the Cataract Canyon/Havasu Creek surface and groundwater basins, to the south of GCNP. These lands are adjacent to the Havasupai Reservation, Hualapai Reservation, and the Kaibab National Forest, and are operated near the Boquillas Ranch and other private lands owned by the Navajo Nation (NPS 2013k).

Comprehensive Fisheries Management below Glen Canyon Dam

The NPS is implementing its Comprehensive Fisheries Management Plan for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The plan was developed in coordination with the Arizona Game and Fish Department, the FWS, Reclamation, and the USGS GCMRC; its purpose is to maintain a thriving native fish community within GCNP, while also maintaining a highly valued recreational trout fishery in the Glen Canyon reach, defined as the 16.5 mi of river downstream from Glen Canyon Dam on the Colorado River in the GCNRA, including Lees Ferry and the mouth of the Paria River (NPS 2013e, 2013h).

The plan's management goals for the Colorado River and its tributaries in GCNP are as follows:

1. Meet or exceed population and demographic goals for the appropriate GCNP recovery unit for existing ESA-listed fish species, maintain self-sustaining populations, and restore distribution of those species to the extent practicable;

2. Maintain or enhance viable populations of existing native fish and restore native fish communities and native fish habitat in GCNP to the extent practicable;

3. Restore self-sustaining populations of extirpated fish species, including Colorado pikeminnow, razorback sucker, bonytail, and roundtail chub, as appropriate and to the extent feasible (if feasibility studies determine each species can be reasonably restored without impacting existing ESA-listed species);

4. Foster meaningful Tribal relations and integrate Tribal knowledge and perspectives into park management decisions and practice; and

5. Prevent further introductions of nonnative (exotic) aquatic species, and remove when possible, or otherwise contain, individuals or populations of nonnative species already established in GCNP.

The plan's management goals for the Colorado River and Paria River in GCNRA are as follows:

1. Maintain a highly valued recreational rainbow trout fishery with minimal emigration of rainbow trout downstream to GCNP;

2. Restore and maintain healthy, self-sustaining native fish communities; native fish habitat; and the important ecological role of native fish to the extent possible;

3. Foster meaningful Tribal relations and integrate Tribal knowledge and perspectives into park management decisions and practices; and

4. Prevent further introductions of nonnative (exotic) species.

Lower Colorado River Multi-Species Conservation Program

The Lower Colorado River Multi-Species Conservation Program (LCRMSCP) implements and coordinates the Secretary of the Interior's statutory responsibilities under the ESA (DOI 2005). The program is a cooperative species conservation effort between six federal agencies (Reclamation, BIA, NPS, BLM, WAPA, and the FWS) and numerous non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development (lead agency: Reclamation) and to provide the basis for incidental take permits (lead agency FWS) while conserving critical habitat and working toward the recovery of threatened and endangered species as well as reducing the likelihood of additional species being listed. Measures to mitigate the impacts of the incidental take of species covered under the Program are contained in its Habitat Conservation Plan (LCRMSCP 2004). The Habitat Conservation Plan and other program information are available at http://www.lcrmscp.gov/index.html.

4.17.1.2 Reasonably Foreseeable Future Actions

Special Flight Rules in the Vicinity of Grand Canyon National Park

The NPS will establish new rules to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (P.L. 100-91). The rules would create a system of routes, altitudes, flight allocations, and flight-free zones in the air space in and around GCNP.

Lake Powell Pipeline Project

In 2006, the Utah State legislature passed the Lake Powell Pipeline Development Act to authorize the Utah Board of Water Resources (UBWR) to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. At full development, the pipeline is expected to annually deliver up to 82,000 ac-ft to Washington County Water Conservancy District and 4,000 ac-ft to Kane County Water Conservancy District. The proposed project would consist of (1) building and operating 139 mi of 69-in. diameter pipeline and penstock, 35 mi of 30-in. to 48-in. diameter pipeline, and 6 mi of 24-in. diameter pipeline; (2) a combined conventional peaking and pumped storage hydropower station; (3) five conventional in-pipeline (booster) hydropower stations; and (4) transmission lines. The booster pumping stations along the length of the pipeline would provide the 2,000-ft lift needed to move the water over the high point within the Grand Staircase-Escalante National Monument. From the high point, water would flow through a series of hydroelectric turbines to make use of the 2,900-ft drop in elevation from the high point to the end of the pipeline in St. George (UBWR 2015; FERC 2011). The Lake Powell intake would be located near the south end of the reservoir adjacent to Glen Canyon Dam (UBWR 2011a). UBWR plans to have its licenses, permits, and ROD issued sometime in 2015 so construction can begin in 2020 (water delivery would not begin until 2025) (UBWR 2015).

Grand Canyon Escalade

Private developers have proposed to the Navajo Nation, a 420-ac development project, known as the Grand Canyon Escalade, on the Grand Canyon's eastern rim on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include a 1.4-mi-long, eight-person tramway (gondola) to transport visitors 3,200 ft from the rim to the canyon floor. On the rim, the development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking for cars and RVs. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk (with an elevated walkway) along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts to the local economy through increased tourism and job creation.

Red Gap Ranch Pipeline

In 2006, Reclamation completed a study that projected a water supply shortfall of about 3,370 ac-ft/yr for the City of Flagstaff (and other towns in Coconino County) by the year 2050 (Reclamation 2006b). To address its shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch (about 34 mi to the east), on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 ac-ft of groundwater each year from the C-aquifer (on the Coconino Plateau) and send it via pipeline to the City (City of

Flagstaff City Council 2013). Because the pipeline crosses federal land and is partially funded with federal dollars, the proposed project is currently undergoing a NEPA review (EA). The scope of the EA is to evaluate the impacts of groundwater withdrawal on the base flow that feeds the Little Colorado River, Clear Creek, and Chevelon Creek (which ultimately feed the Colorado River), as well as the impacts the conveyance of groundwater (including the construction of pipelines, roads, and a treatment facility) could have on biological and cultural resources on the Red Gap Ranch property.

Page-LeChee Water Supply Project

The Page-LeChee water supply project is a water supply facility providing domestic water supply for the city of Page and the LeChee Chapter of the Navajo Nation (NPS 2009b). The proposed project would improve the existing system (consisting of three pumps operating at 3,050 gpm) and increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA (from Lake Powell to a tie-in point on the existing system near U.S. 89 between the Glen Canyon rim and the water treatment plant in Page). Although the proposal would allow higher diversions of water from Lake Powell, actual consumptive use would continue to be subject to the city's contract with Reclamation.

Four Corners Power Plant and Navajo Mine Energy Project

The Office of Surface Mining Reclamation and Enforcement (OSMRE) has completed a final EIS for the lease amendment with the Navajo Nation that would extend the life of the Four Corners Power Plant (FCPP) to 2041 (OSMRE 2015a, b). The FCPP, located just north of Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), historically consisted of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities, including Morgan Lake and Morgan Lake Dam, fly ash storage silos and bottom ash dewatering bins, three switchyards, an intake canal, and access road (OSMRE 2015b). The Arizona Public Service Company closed three of the five generation units (Units 1, 2, and 3) at the end of 2013, and over the next couple of years is scheduled to install selective catalytic reduction (SCR) controls on the remaining two units (Units 4 and 5) to reduce NO_X and particulate matter (PM) pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). The proposed action would also include the renewal of the transmission line right-of-way that connects the powerplant to the power grids in Arizona and New Mexico and the development of a new 5,600-ac mine area, the Pinabete Mine Permit area, to supply coal to the powerplant for up to 25 years (beginning July, 2016). The Pinabete Mine area is a surface coal mining and reclamation operation located near the existing Navajo Mine in San Juan County, New Mexico (OSMRE 2015c), and would result in land disturbance and air emissions in the project area.

EPA's Clean Power Plan Proposed Rule for Existing Power Plants

The Clean Power Plan Proposed Rule is being developed by the U.S. Environmental Protection Agency (EPA) under Section 111(d) of the Clean Air Act (CAA) to reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The final plan, released in October 2015, establishes state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b, 2015c). The EIA (2015) estimates the proposed rule would result in a reduction of power sector CO_2 emissions to about 1,500 million MT/yr by 2025, levels not seen since the early 1980s. The U.S. Supreme Court stayed implementation of the Clean Power Plan on February 9, 2016, pending judicial rule (EPA 2016).

4.17.2 Climate-Related Changes

The southwest is already experiencing the effects of climate change (Garfin et al. 2014). The decade from 2001 to 2010 was the warmest on record, with temperatures almost 1.1°C higher than historic averages (Garfin et al. 2014; World Meteorological Organization 2014). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern, prompting federal and state agencies, Tribes, and other stakeholders to develop adaptation and mitigation strategies to address imbalances between water supply and demand in the coming years (Garfin et al. 2014; NAS 2007; Reclamation 2007b, 2012c). Section 4.16 provides a discussion of climate change as related to the LTEMP.

Higher temperatures in the Colorado River Basin have resulted in less precipitation falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011). These effects in turn have exacerbated competition among users (farmers, energy producers, urban dwellers), as well as effects on ecological systems, during a time when due to a rapidly rising population water demand has never been higher (Garfin et al. 2014).

As discussed in the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012e), the general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (due to lower precipitation), greater evaporation and evapotranspiration losses (due to higher temperatures), and increased demand (due to increased population size). Combined, these factors increase the probability and likely duration of delivery shortages in coming decades. It has been estimated that the shortfall created by future supply and demand imbalances could range from 2.3 to 4.1 maf per year, during any given deficit period (Reclamation 2012e). When climate change considerations are taken into account, this value increases to around 7.4 maf per year during the deficit period (Reclamation 2012e). In 2007, DOI adopted interim guidelines (Reclamation 2007b) to allocate shortages and specify modifications to the apportionments to the Lower Basin states in the event of water shortage conditions at Lake Mead (see section above).

Changes in temperature and precipitation patterns attributed to climate change could also take a toll on the region's rich diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation (during summer heat waves). The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014). Such effects are likely to continue well into the foreseeable future (NAS 2007). These changes would be the same under all LTEMP alternatives and would be unaffected by the alternatives.

4.17.3 Cumulative Impacts Summary by Resource[41]

The following sections discuss the past, present, and reasonably foreseeable future actions, including the LTEMP alternatives, that could contribute to cumulative impacts on resources within the project area. Table 4.17-2 provides a summary of these contributions by resource area.

The physical presence and design constraints of Glen Canyon Dam have created a new baseline condition for resources within the Colorado River corridor, from Lake Powell and the dam downstream and west to Lake Mead. Current safety and design requirements limit flow through the dam to no more than 45,000 cfs, about 53% of its historical maximum flow. Management of water flow within the river system is also constrained by the various treaties, decrees, statutes, regulations, contracts, and agreements that are collectively known as the Law of the River. Recent drought conditions in the Colorado River Basin have necessitated further regulation (i.e., the 2007 Interim Guidelines) to allocate shortages and reduce apportionments to the Lower Basin states during periods of declining reservoir storage at Lake Mead. The water supply and demand equation is further stressed by the challenges of increasing demand in the seven Basin States (due to a rising population) and the temperature variability and drought attributed to climate change, which are projected to reduce flows into the foreseeable future.

As described in resource-specific sections in this chapter, the LTEMP alternatives are expected to differ in the types and magnitude of impacts on specific resources. Against the backdrop of past, present, and reasonably foreseeable future actions, however, the incremental effects of the LTEMP alternatives, as described in the following sections, are expected to be relatively minor contributions to cumulative impacts along the Colorado River corridor or within the basin at large.

4.17.3.1 Water Resources

Although LTEMP alternatives differ in monthly, daily, and hourly flows, all alternatives must be consistent with and subject to the Law of the River as identified in GCPA

41 Adjustments made to Alternative D after modeling was completed (see Section 2.2.4) are not expected to result in a change in Alternative D's cumulative impact.

TABLE 4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Water Resources	Colorado River between Glen Canyon Dam and Lake Mead; Lakes Powell and Mead	Projected future changes in flow due to increased water demand (as a result of population growth and development), and decreased water supply, drought, and increased water temperature attributed to climate change could be the greatest contributors to adverse impacts on Colorado River flows, storage in Lakes Powell and Mead, and water quality (temperature and salinity). The 2007 Interim Guidelines and related water conservation efforts, should provide more predictability in water supply to users in the Basin States (especially the Lower Basin) through 2026, and may also benefit water temperature and water quality in Lakes Powell and Mead. Future water depletions from Lake Powell including those from the proposed Lake Powell Pipeline Project and Page-LeChee Project could affect availability of water for release from Glen Canyon Dam.	The proposed action is consistent with the 2007 Interim Guidelines for annual water deliveries. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions. With the exception of Alternative B, the LTEMP alternatives would result in slightly greater summer warming and a slightly increased potential for bacteria and pathogens along shorelines.
Sediment Resources	Colorado River between Glen Canyon Dam and Lake Mead; inflow deltas in Lake Mead	Potential future hydrology in the Colorado River (as determined by the 2007 Interim Guidelines), including the effects of climate change, could affect tributary sediment delivery (supply), fine sediment transport, sandbar formation, and lake delta formation over the long term. Glen Canyon Dam and Lake Powell trap most of the mainstem Colorado River sediment supply (post-dam sediment supplies less than 10% of the pre-dam supply). Implementation of HFEs could result in an improvement in sandbar building.	LTEMP alternatives are expected to improve sediment conditions to varying degrees by conserving sediment and building sandbars at higher elevations. Alternatives with the most HFEs (Alternatives C, D, E, F, and G) have the highest sandbar building potential. Alternative A has the lowest sandbar building potential. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Natural Processes	Colorado River ecosystem in Glen, Marble, and Grand Canyons	Projected future changes in flow due to increased water demand (as a result of population growth and development) and decreased water supply (and sediment supply), drought, and increased water temperature attributed to climate change would contribute to adverse impacts on natural processes through changes in Colorado River flows, sediment supply, and temperature. Implementation of HFEs could result in an improvement in sandbar building. Tamarisk control and fisheries management actions could improve natural processes by restoring native species.	Compared to Alternative A, Alternatives C, D, F, and G are expected to increase sediment conservation, increase the stability of nearshore habitats, and provide slightly warmer water temperatures. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Aquatic Ecology	Colorado River between Glen Canyon Dam and Lake Mead	Aquatic resources would be affected by changes in flow due to increased water demand (as a result of population growth and development); decreased water supply, drought, and increased water temperature attributed to climate change; and other foreseeable actions (related to fish management and uranium mining). The potential for urban and agricultural runoff also increases with population growth, producing adverse effects on water quality, which could ultimately affect aquatic biota and habitat. Drought conditions (and actions such as the Lake Powell pipeline project) would result in lower reservoir elevations and benefits to aquatic resources associated with warmer release temperatures. Warmer water temperatures, however, could also result in adverse effects if they increase the distribution of nonnative species adapted to warm water (e.g., fish parasites). 2007 Interim Guidelines determine annual volume and equalization years may increase trout production and river temperature both of which may impact humpback chub populations. Uranium mining could also have adverse (though local) effects on aquatic biota and habitats associated with ephemeral drainages (in the event of an accidental release of hazardous materials). Translocation of native fish species (humpback chub) from the Little Colorado River to other tributaries within the Grand Canyon would have a beneficial (protective) impact on aquatic resources.	Compared to Alternative A, Alternative D would have lower trout numbers, slightly higher humpback chub numbers, and increased food base productivity. Alternatives with higher fluctuation levels (Alternatives B and E) have lower trout numbers and slightly higher humpback chub numbers than Alternative A, but less nearshore habitat stability and aquatic productivity. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Vegetation	Riparian zone along the Colorado River between Glen Canyon Dam and Lake Mead	Lower regional precipitation with climate change would result in a shift to more drought-tolerant species in the New High Water Zone; those in the Old High Water Zone would continue to decline. Drought conditions would favor nonnative tamarisk (which is tolerant of drought stress). However, tamarisk control efforts by the NPS and possibly the effects of the tamarisk leaf beetle and splendid tamarisk weevil would increase tamarisk mortality and improve conditions for native shrubs over time. Feral burros contribute to impacts on riparian vegetation in the Old High Water Zone (by reducing vegetation and decreasing species diversity); recreational visitors may also contribute to vegetation loss and the introduction of exotic plant species.	Most alternatives, including Alternative A, result in a decrease in native community cover and wetlands. Alternative D is the only alternative that results in an overall improvement in vegetation. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wildlife	Colorado River corridor between Glen Canyon Dam and Lake Mead	Cumulative impacts on aquatic resources and riparian vegetation (as described in the above entries) affect riparian and terrestrial wildlife. Wildlife may also be affected by other future actions and basin-wide trends. Increased water demand and lower flows downstream of Glen Canyon Dam could stress riparian and wetland vegetation, affecting both wildlife habitats and the wildlife prey base. Warmer discharges (attributed to climate change) would likely increase algae and invertebrates, increasing the prey base for some species. Vegetation management could adversely affect birds in the short term, but are expected to provide benefits in the long term. Wildlife disturbance could result from various actions, including uranium mining, the Grand Canyon Escalade Project, and recreational activities (hiking, rafting, fishing, and camping). Habitat loss is a concern for those projects involving the construction of roads, effluent ponds (mining), and buildings.	Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less-even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Cultural resources	Cultural sites within Glen and Grand Canyons	Cultural resources (primarily archaeological sites) are in an ongoing state of deterioration due to natural erosive processes or, in some cases, human causes related to the presence and operation of Glen Canyon Dam or park visitation. Visitor traffic along the Colorado River can result in deterioration of sites as artifacts exposed by erosion are moved or removed from the site. These effects are somewhat mitigated through enforcement of NPS's Colorado River Management Plan and Backcountry Management Plan in GCNP (with similar enforcement in GCNRA). The effects of climate change on landscape features containing archaeological remains are unclear. Ongoing dam operations may affect sediment availability for site stabilization in GCNP and lowered reservoir levels may affect archaeological sites along shorelines in GCNRA and LMNRA.	Alternatives with extended-duration HFEs (Alternatives D and G) could adversely impact terraces that support cultural resources in Glen Canyon. Alternatives with more HFEs (e.g., Alternatives C, D, E, F, and G) could provide for greater protection of sites by providing more sand for wind transport to these sites. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Tribal resources	Glen, Marble, and Grand Canyons	Many Tribes regard the Canyons as sacred space, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important resources. Development related to projects like the Lake Powell Pipeline and uranium mining in the region, as well as fish/vegetation management practices, have ongoing adverse impacts on Tribe members. Actions and basin-wide trends affecting aquatic life, vegetation, and wildlife (as described above) would also affect resources of value to Tribes.	All alternatives except Alternative F include either mechanical removal of trout or TMFs and may have an adverse impact to Tribes. Alternatives that include vegetation treatments (all action alternatives), and alternatives that improve vegetation conditions (Alternatives B and D), could lead to a more natural riparian ecosystem and provide a benefit. No alternative would affect Tribal water rights. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Recreation, visitor use and experience	Colorado River and associated recreational sites between Glen Canyon Dam and Lake Mead	The HFE protocol has had a beneficial effect on camping and beach access (and therefore visitor use and experience) because it has a direct effect on sediment transport and deposition. Other actions taken by the NPS, as described in various management plans (tamarisk management, GCNP backcountry, noise and special flight rules, fire), also benefit visitor use and experience. The CRMP (which regulates boating and rafting) and the Comprehensive Fisheries Management Plan and Non-Native Fish Control Program are protective of natural/cultural resources and also have long-term beneficial effects on recreation and visitor experience. Warming water temperatures (and reduced flows below Glen Canyon dam) attributed to climate change could affect the health of the trout fishery below the dam, thus contributing to adverse cumulative impacts on recreation related to the trout fishery.	Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wilderness	Colorado River and associated recreational and wilderness sites between Glen Canyon Dam and Lake Mead	The HFE protocol and other actions taken by the NPS, as described in various management plans (the CRMP, tamarisk management, GCNP backcountry, noise and special flight rules, fire) would benefit wilderness values and experience (although noise and visual effects associated with some actions diminish these values over the short term). The Grand Canyon Escalade would contribute to adverse impacts on visitors seeking solitude or a wilderness experience due to its visual and noise effects and the presence of infrastructure, all of which are incompatible with the character of GCNP. Basin-wide effects related to climate change (e.g., reduced water availability) could diminish wilderness values and experience by reducing opportunities for solitude.	Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Visual resources	Shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead; shorelines of Lakes Powell and Mead; and the general landscape in the project area	Projected future declines in reservoir levels due to increased water demand, decreased water supply, the planned Lake Powell Pipeline project, and drought attributed to climate change could increase the likelihood of exposure of calcium carbonate rings and sediment deltas in Lakes Powell and Mead. Infrastructure associated with the Lake Powell Pipeline project (pipeline, facilities, viewing platforms, and transmission lines), uranium mining, vegetation changes, and elements of the Grand Canyon Escalade development would also add to visual contrast and noticeable changes in the existing landscape.	LTEMP alternatives do not vary with respect to their impacts on visual resources. the proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Hydropower	Utilities and their customers who purchase power generated by Glen Canyon Dam WAPA, Upper Colorado Basin Fund, environmental programs funded by CRSP power revenues; Upper Basin State apportionment-funded projects	Operating criteria imposed by the 1996 ROD for Glen Canyon Dam to comply with the Grand Canyon Protection Act have placed multiple restrictions on the variability of water released from the dam, thus restricting dam operational flexibility. Under the current operating regime (MLFF), fluctuations in release rates, ramp rates, and maximum hourly increases/decreases are restricted and the maximum release rate for power generation is limited to 25,000 cfs. Maximum releases above 25,000 cfs occur through bypass tubes to achieve a constant release rate. Bypassing water around generators produces no energy, which can result in additional purchases of replacement power. Increased demand for electricity in the service territories of the eight largest WAPA customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years. Changes in operations due to environmental concerns at other generating stations (the Aspinall Unit and Flaming Gorge Dam) have also resulted in reductions in generating capacity at these facilities, necessitating the purchase of replacement capacity from other sources and increasing wholesale power rates. Changes at NGS to meet air emissions requirements may result in a reduction in generation output at the facility and its contribution to power in the Western Interconnection. This could result in excess transmission capacity within the Western Interconnection.	LTEMP alternatives vary with respect to hydropower production, hydropower capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G), especially if more water is released in the high-demand months of July and August. Alternatives A and B would have the least effect on the value of generation, the value of capacity, and retail rates, while Alternatives F and G would have the highest. However, the proposed action's contribution to cumulative impacts would be small compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Socioeconomics and environmental justice	Six-county region in the vicinity of the Colorado River between Lakes Powell and Mead; recreational resources, including Lake Powell, Lake Mead, and the Grand Canyon (Colorado River)	Projected future changes in reservoir levels and river flow due to increased water demand, decreased water supply, and drought attributed to climate change could be the greatest contributors to adverse impacts on the recreational use values associated with fishing, day rafting, and whitewater boating. The Grand Canyon Escalade would likely increase recreational visitation and expenditure rates along the Colorado River. The annual release volume from Glen Canyon Dam, as determined by the 2007 Interim Guidelines, also affects recreation economics. NPS regulates the number of boating trips (specified in the CRMP and the Comprehensive Fisheries Management Plan). Therefore, regional economics of these activities are not expected to change in the foreseeable future.	LTEMP alternatives result in relatively minor changes in use value and economic activity associated with reservoir and river recreation, and in residential retail rates. Environmental justice issues are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), or result in increased economic impacts on Tribes associated with the cost of electricity (Alternatives F and G). The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Air quality and climate change	GCNP and the 11-state Western Interconnectionion region	The construction of new (and the renewal of existing) fossil fuel-fired powerplants to meet increased energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change (which increase the potential for wildfires and dust storms), could increase visibility degradation in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility degradation (haze) in the region, including GCNP. Other significant contributors would include wildfires, controlled burns, windblown dust, and emissions from metropolitan areas (manufacturing, coal-fired powerplants, and combustion sources like diesel engines). Hydropower generation at Glen Canyon Dam does not generate air emissions; however, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units. Under baseline operations (Alternative A), emissions of SO_2 and NO_x generated by powerplants affected by Glen Canyon Dam operations would be about 9.9% and 3.0% of the total emissions over the Western Interconnectionion region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline. Increases in GHG emissions associated with changes in operations under LTEMP alternatives would be negligible. The EPA's Clean Power Plan Proposed Rule (currently stayed by the U.S. Supreme Court) would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants. The closure of three coal-burning units at the FCPP would reduce levels of NO_x and PM pollutants that contribute to regional haze and visibility issues in the GCNP. The reduction of generation output at the NGS to meet air emissions requirements will reduce levels of NO_x in the region.	LTEMP alternatives are expected to have negligible differences with respect to their impacts on air emissions including GHGs. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

Section 1802(b). As a consequence, the impacts of alternatives do not vary in their contribution to cumulative impacts on water supply and delivery.

Current water quality conditions and characteristics of Lake Powell (Section 3.2.2.1), Colorado River below Glen Canyon Dam (Section 3.2.2.2), and Lake Mead (Section 3.2.2.3) reflect the effects of past and present (ongoing) actions. Before Glen Canyon Dam was constructed, the river was characterized by wide natural fluctuations in water quality characteristics (e.g., temperature, salinity, turbidity, and nutrients). In the post-dam era, these variations are moderated and the river has seen an overall improvement in water quality. Future water quality would likely be affected most by increased water demand and climate change. Although most alternatives would likely result in a slightly increased potential for bacteria and pathogens along shorelines, the contribution of continued operations under the LTEMP to cumulative impacts on water quality is expected to be negligible regardless of which alternative is selected.

As the population in the Basin States grows and expands, municipal, industrial, and agricultural water demand continues to increase. In its 2013 study, Reclamation concluded that the total consumptive use and loss (i.e., surface water and groundwater depletions and evaporative losses) for the Arizona portion of the Upper Colorado River Basin (covering about 6,900 mi^2) was 35,037 ac-ft, more than half of which is water pumped directly from Lake Powell and used by the Navajo Generating Station (Reclamation 2014e).

Urban runoff, industrial releases, and municipal discharges are considered some of the leading nonpoint sources of contaminants to surface waters (EPA 2004). Areas of intensive agriculture can have an adverse effect on the water quality as a result of the salinity, nutrients, pesticides, selenium, and other trace elements that are common constituents in agricultural runoff. As a result, water management and efficient water use become important variables in the Colorado River supply and demand equation (Beckwith 2011). The 2007 Interim Guidelines, and related water conservation efforts, should provide more predictability in water supply to users (especially in the Lower Basin) through 2026.

The general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (e.g., lower precipitation) and greater losses (e.g., evapotranspiration associated with higher temperatures and increased demand from the growing population). Climate change is expected to result in more frequent and severe drought conditions in the Southwest. Meeting increasing water needs (e.g., the Lake Powell Pipeline project and the Page-LeChee water supply project) will likely lead to lower reservoir levels in Lake Powell, which may already be affected by increased evaporation associated with higher air temperatures. As discussed in Section 4.2.2, decreasing the elevation of Lake Powell can lead to warmer water discharges from Glen Canyon Dam and increased water temperatures downstream.

4.17.3.2 Sediment Resources

The construction and presence of Glen Canyon Dam has affected Glen, Marble and Grand Canyons by (1) reducing the sediment supply, and by (2) reducing the annual peak flows.

Among the actions considered under LTEMP, HFE releases (which are highest under Alternatives C, D, E, F, and G) have the greatest impact on sediment resources (and sandbar building potential), although variability in hydrology or sediment supply from tributary inputs has a greater impact than HFEs. Cumulative impacts that affect this variability in hydrology and sediment supply (such as climate change) have the potential to affect sediment resources in the future.

It has been estimated that the post-dam sand supply to Marble Canyon is less than 10% of the pre-dam supply (Topping et al. 2000a; Topping, Rubin, Nelson et al. 2000; Wright, Schmide et al. 2008), with the majority of the sediment evacuation between the dam and Phantom Ranch (RM 87) occurring during the three decades following dam construction. The reduced sediment supply would move downstream at different rates in the various LTEMP alternatives, but sediment supply to Marble and Grand Canyons would not differ among the alternatives. The 1996 ROD modifications to the flow regime resulted in benefits for the building and retention of sandbars.

Future climate change implications on sediment resources are highly variable and cannot be accurately quantified. Conceptually, climate change can affect the sediment resource in two ways: by changing the hydrology in the drainage area upstream of Glen Canyon Dam, and by changing the hydrology in the drainage area downstream of Glen Canyon Dam, especially in the drainage area of primary sediment contributors such as the Paria River and the Little Colorado River. A drier future hydrology in these drainage areas could decrease the availability of sand in Marble and Grand Canyons.

4.17.3.3 Natural Processes

Cumulative impacts on natural processes (water flow, water temperature, and sediment supply) reflect those discussed under water resources (Section 4.17.3.1) and sediment resources (Section 4.17.3.2). Although some of the LTEMP alternatives could affect these resources (e.g., potential sandbar growth through implementation of HFE releases, which is greatest under Alternatives C, D, E, F, and G), the incremental effects of the alternatives are not anticipated to contribute significantly to cumulative impacts on natural processes along the Colorado River corridor or within the basin at large. Implementation of HFEs could result in an improvement in sandbar building over the long term. Tamarisk control and fisheries management actions could improve natural processes by restoring native species. Climate change (and its effects on water flow, water temperature, and sediment supply), however, would likely have a greater effect on natural processes than any of the LTEMP alternatives.

4.17.3.4 Aquatic Ecology

Section 3.5.1 describes the current conditions of the aquatic food base in the Colorado River downstream of Glen Canyon Dam. The current state of the aquatic food base reflects the effects of past and present (ongoing) actions; Section 4.5.3 discusses potential impacts of the various LTEMP alternatives. The aquatic food base may also be affected by other reasonably

foreseeable actions, particularly climate change, dam modification, water use, introduction of nonnative species, and uranium mining.

Population growth, industrial development, and the warming associated with climate change will act in concert to increase demand for water (Schindler 2001). The potential for urban and agricultural runoff also increases with population growth, producing adverse effects on water quality, which could ultimately affect aquatic biota and habitat. Climate change is also expected to result in more frequent and severe drought conditions in the Southwest, which will continue to tax water supplies. Combined with increased evaporation associated with higher temperatures, meeting water needs would lead to lower reservoir levels in Lake Powell. The Lake Powell Pipeline Project would also contribute to lower Lake Powell reservoir elevations (FWS 2011c). Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. The Red Gap Ranch Pipeline, which would withdraw groundwater contributing to the base flow of the Little Colorado River, could reduce habitat availability and suitability in the Little Colorado River with subsequent adverse effects on humpback chub and designated critical habitat, although the magnitude of these impacts have not been quantified.

Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; FWS 2011c). Lower levels of Lake Powell may also result in increases in the composition and density of zooplankton downstream of Glen Canyon Dam, because waters would be withdrawn closer to the surface (Reclamation 1995). However, warmer temperatures, particularly in winter, may allow many invertebrate species to complete their life cycles more quickly (Schindler 2001). For example, if stream temperatures are raised by only a few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in February or March and face death by freezing or be prevented from mating because of being inactivated by low air temperatures. In addition, increases in stream temperatures may cause an exaggeration in the separation of the emergence of males and females (e.g., males may emerge and die before females emerge) (Nebeker 1971). Temperatures above the optimum can lead to the production of small adults and lower fecundity (Vannote and Sweeney 1980).

Warmer water temperatures can expand the distribution of nonnative species adapted to warmer temperatures. This includes fish parasites such as the Asian tapeworm, anchor worm, and nonnative crayfish. Increased zooplankton due to climate change may increase abundance of cyclopoid copepods. All cyclopoid copepod species appear to be susceptible to infection by, and therefore serve as intermediate hosts for, the Asian tapeworm (Marcogliese and Esch 1989). Crayfish can prey on fish eggs and larvae and can diminish the abundance and structure of aquatic vegetation such as filamentous algae through grazing (FWS 2011c). Nonnative crayfish are present in Lake Powell (northern or virile crayfish [*Orconectes virilis*]) and Lake Mead (red swamp crayfish [*Procambarus clarkii*]). Warmer temperatures may allow the crayfish to expand into the mainstem of the Colorado River either downstream of Lake Powell or upstream of Lake Mead.

As discussed in Section 3.5.1, some nonnative species introductions occurred in order to supplement the aquatic food base (e.g., *Gammarus*, snails, and midges); while accidental introductions have occurred via fish stocking and recreational fishing, often with detrimental effects on both lower trophic levels or fish species (e.g., the New Zealand mud snail and parasitic

trout nematode [*Truttaedacnitis truttae*]). The quagga mussel (*Dreissena bugensis*), which is established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach.

Concern has been raised about the diatom *Didymosphenia geminata* ("didymo") becoming established in the Colorado River. High-density blooms of didymo are frequent in rivers directly below impoundments. In these river reaches, stable flows and fairly constant temperatures favor development of large masses of didymo (see Spaulding and Elwell 2007). Didymo can form nuisance benthic growths that extend for more than 1 km and persist for several months (Spaulding and Elwell 2007). Mayflies, stoneflies, caddisflies, and dragonflies have an inverse relationship with didymo coverage, while midges and aquatic worms dominate didymo-covered areas (Larson and Carreiro 2008). Nevertheless, the presence of didymo has been associated with increased periphyton biomass and increased invertebrate densities and richness (Kilroy et al. 2009; Gillis and Chalifour 2010). Given the large amounts of non-nutritious stalk material present on stream substrates in affected areas, didymo is predicted to have deleterious effects on native fish, especially those that inhabit benthic habitats, consume benthic prey, and nest beneath or between cobbles (see Spaulding and Elwell 2007). Didymo is present in waters from 4 to 27°C (39 to 81°F) (Spaulding and Elwell 2007), so warming would not be a factor in its occurrence in the Colorado River. However, development of didymo blooms likely requires both low mean discharge and variation in discharge. Scouring events usually remove didymo stalk material from substrates (Kirkwood et al. 2007).

Uranium mining peaked in the 1980s in the Grand Canyon region, but there is now a renewed interest due to increases in uranium prices. Increased uranium mining (on state and private lands) could increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Uranium, other radionuclides, and metals associated with uranium mines can affect the survival, growth, and reproduction of aquatic biota.

Aquatic biota and habitats most likely to be affected during mine development and operation are those associated with small, ephemeral, or intermittent drainages. Impacts on aquatic biota and habitats from the accidental release of regulated or hazardous materials into ephemeral drainages would be localized and small, especially if a rapid response to a release is undertaken. The accidental spill of uranium ore into a permanent stream or river such as Kanab Creek would potentially pose a localized short-term impact on the aquatic resources. However, the potential for such an event is extremely low. Most ore solids would settle in the waterbody within a short distance from a spill site (Edge Environmental, Inc. 2009). It is expected that expedient and comprehensive cleanup actions would be required under U.S. Department of Transportation regulations and that an emergency response plan would be in place for responding to accidents and cargo spills (Edge Environmental, Inc. 2009). Overall, the potential for impacts on aquatic biota from an accidental spill would be small to negligible. Spencer and Wenrich (2011) estimated that if an ore load is washed into the Colorado River and is pulverized and dissolved (a scenario that is extremely unlikely to impossible), the uranium concentration in the river would increase from the current 4.0 ppb to only 4.02 ppb (undetectable against natural variations). Predicted no chemical effect concentrations for aquatic vascular plants, aquatic invertebrates, and fish are ≥5.0 ppb; the lowest chronic concentrations are well above that

concentration (see Hinck et al. 2010). For these reasons, the impacts from uranium mining on aquatic biota in the Colorado River or its major tributaries would be expected to be localized and would not be expected to reduce the viability of affected resources.

The incremental effects of the LTEMP alternatives on fish are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Examination of the various hydrologic traces used to model effects of alternatives on aquatic resources indicated that hydrology (i.e., whether a 20-year trace was drier or wetter on average) had a greater influence on the model results than the operational differences among alternatives. Similarly, climate change has the potential to have greater effects on fish resources than any of the alternatives because of its direct influences on hydrologic patterns. For example, more frequent droughts and warmer atmospheric temperatures have the potential to result in greater increases in the temperature of water being released from the dam than the operational actions being considered, and this in turn may improve thermal suitability for humpback chub, humpback chub aggregations, and native fish. However, any subsequent benefits may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. There are a number of other actions being taken within the Colorado River Basin that could also contribute to significant cumulative effects on fish populations or fish communities. For example, actions to increase the number of self-sustaining populations of humpback chub within the basin (e.g., translocation of humpback chub from the Little Colorado River to other tributaries within the Grand Canyon) have the potential to increase overall numbers of humpback chub and could provide some level of protection against catastrophic events in the Little Colorado River that could greatly reduce or eliminate the population of humpback chub in the Grand Canyon.

4.17.3.5 Vegetation

In addition to effects of releases from Glen Canyon Dam and NPS's experimental vegetation treatment program, factors that would impact riparian plant communities include the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.), which occur along much of the Colorado River below Glen Canyon Dam. By late 2012, the tamarisk leaf beetle had been found in many locations in the Grand Canyon, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Tamarisk leaf beetle is not expected to have impacts on populations of other plant species, such as native shrubs (Dudley and Kazmer 2005). Fire management policies for GCNP include fuel reduction by removal of dead woody material as well as fire suppression; however, riparian areas are generally avoided (NPS 2012d).

The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics as well as site-specific factors. The potential reduction in the dominance of tamarisk in many areas and the decrease in total area of tamarisk-dominated communities along the Colorado River could result in an increase in native species or, more likely, other nonnative species, especially where soils have high nitrogen levels (Hultine et al. 2010; Shafroth et al. 2005, Shaforth, Brown et al. 2010; Belote et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013). Many nonnative species are already present along portions of the Colorado River and Lake Mead (Table 4.6-5). Short-term changes in nutrient dynamics in the riparian ecosystem could also occur with increased activity of tamarisk leaf beetles, with subsequent effects on the future

development of native or nonnative communities (Uselman et al. 2011). Soil seed banks may contain a high diversity of species and would potentially influence subsequent plant community composition; however, the regrowth of native species may be slow (Reynolds and Cooper 2011; Belote et al. 2010).

As discussed in Section 4.6, hydrologic conditions have a greater effect on native community types in the Fluctuation Zone and New High Water Zone than do the operational characteristics of the LTEMP alternatives. Within each alternative, the occurrence of flows with significant effects on riparian vegetation, such as extended high flows and extended low flows, are determined in large part by the inflow to Lake Powell as a result of hydrologic variation (Section and 4.2). Other events, such as spill flows (flows >45,000 cfs that would necessitate use of the spillway) could have pronounced effects on riparian vegetation, but these too result from hydrologic variation and not characteristics of the alternatives. However, with forecasting capabilities currently used by the Bureau of Reclamation, it is unlikely that spill flows would occur in the future. Within a year, under any alternative, monthly operations may be increased or decreased based on changing annual runoff forecasts, and application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

Feral burros contribute to cumulative impacts on riparian vegetation, especially vegetation in the Old High Water Zone. Researchers documented vegetation impacts from feral burros as early as 1974, noting vegetation destruction and decreases in species diversity. These impacts, along with impacts on soils, remain visible on the landscape today with very little vegetation recovery (Leslie 2004).

Visitation from commercial and private river trips, as well as backcountry hikers and anglers, also can affect vegetation. Visitors have created trails and added to the loss of vegetation in upland and Old High Water Zone areas. Administrative actions such as tamarisk eradication projects and archaeological site monitoring programs can also contribute to vegetation impacts. The intentional or unintentional spread of exotic plant species by humans coming into the area of effect contributes to the current levels of impacts along the Colorado River corridor. This can have localized, adverse, short- or long-term, year-round effects on vegetation by visitors in the riparian zone, and has effects in camping areas, trails, and in popular visitation areas (NPS 2006b).

Riparian ecosystems are expected to be affected by long-term changes in the climate across the Colorado River watershed. Under a climatic trend of lower precipitation, there would likely be fewer years with extended high flows and an increase in the number of years with extended low flows under any of the alternatives. It is also possible that, with lower regional precipitation, there could be fewer sediment-triggered HFEs if the Paria River delivers less sediment. Riparian plants in the Old High Water Zone are expected to continue to decline. The New High Water Zone would tend to experience a shift toward more drought-tolerant species, such as arrowweed and mesquite. Tamarisk is tolerant of drought stress, and has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where water tables are lowered. Thus, tamarisk may be maintained under drier climate conditions, although recruitment events may be limited and, as noted above, effects of

defoliation may greatly affect tamarisk-dominated communities. Communities that require a shallow water table or relatively frequent inundation, such as marsh, shrub wetland, and cottonwood-willow woodland, would likely decline.

Natural events, such as floods inside canyons and rockfalls, scour vegetation; this can add to the loss of diverse and intact native vegetation and contribute to the spread of invasive, exotic plant species. In addition, as noted in Section 3.6.2, years with unusually high inflow into Lake Powell, such as 1983, may result in emergency dam releases greater than 45,000 cfs that would have major and lasting effects on vegetation (Mortenson et al. 2011; Ralston 2012).

The effects of the LTEMP alternatives on riparian vegetation communities are relatively small compared to the effects of other factors, especially future hydrology. For this reason, the incremental effects of the alternatives on native and nonnative plant species are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives, including Alternative A, are expected to result in a decrease in native community cover and wetlands. Alternative D is the only alternative that is expected to result in an overall improvement in vegetation.

4.17.3.6 Wildlife

Section 3.7 describes the current condition of wildlife in the Grand Canyon, which reflects the effects of past and present cumulative impacts; Section 4.7 discusses the potential impacts the various LTEMP alternatives may have on wildlife. Because the assessment of impacts on wildlife is based partly on an evaluation of impacts on the aquatic food base, fish (Section 4.5.2), and riparian vegetation (Section 4.6), cumulative impacts on those resources will also result in cumulative impacts on wildlife. Wildlife may also be affected by other reasonably foreseeable future actions and basin-wide trends contributing to cumulative impacts (Sections 4.17.1.2 and 4.17.2), particularly water use, climate change, vegetation management, AML closure, fire, trout management, introduction or spread of nonnative species, human-associated noise and visual disturbance (e.g., from recreation), and uranium mining.

Population and industrial growth, coupled with climate change, will act in concert to increase water demand in the region (Schindler 2001) and lower flows downstream of Glen Canyon Dam. This could stress existing riparian and wetland vegetation, leading to plant community alterations that would affect both wildlife habitats and the wildlife prey base. Climate change would not affect all wildlife species uniformly. Some species would experience distribution contractions and likely shrinking populations while other species would increase in suitable areas and thus possibly experience increases in population numbers. Generally, the warmer the current range is for a species, the greater the projected distributional increase (or lower the projected loss) will be for that species due to climate change (van Riper et al. 2014).

Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; also see FWS 2011c) leading to increases in the prey base

for some wildlife species such as amphibians, lizards, waterfowl, insectivorous songbirds, and bats.

Riparian vegetation management activities (e.g., removal of nonnative plants and planting of native plants) would modify the cover, stratification, and distribution of plant communities along the Colorado River. Eradication of tamarisk could affect birds by altering prey availability, increasing nest abandonment and predation, and reducing the quantity of riparian habitat available to breeding birds (Paxton et al. 2011). In the long term, riparian vegetation management may diversify riparian habitats and establish a more productive wildlife community. Additional factors that could affect riparian wildlife habitat include the tamarisk leaf beetle and splendid tamarisk weevil, which occur along much of the Colorado River below Glen Canyon Dam and result in defoliation and mortality of tamarisk (Section 4.17.3.4). Widespread tamarisk mortality would likely result in a net loss in riparian habitat for at least a decade or more (Paxton et al. 2011). It seems unlikely that the effects of large-scale defoliation in areas dominated by tamarisk will be compensated for by use of tamarisk beetles as a food resource by birds (Puckett and van Riper 2014).

The highly flammable tamarisk has created a fire hazard previously absent along the river. This threatens breeding bird populations, as well as other wildlife. In addition, if native or mixed habitat stands burn, monotypic tamarisk will likely recolonize, eliminating the crucial structure necessary for southwestern willow flycatchers and other nesting birds (e.g., thermal buffering through shading becomes insufficient and will be further exacerbated by warming climate trends) (Schell 2005).

The quagga mussel (*Dreissena rostriformis bugensis*), which is currently established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach. An established population of quagga mussels may increase the prey base available to diving ducks. Warmer temperatures may allow crayfish inhabiting Lake Mead and Lake Powell to expand into the mainstem of the Colorado River, providing an additional prey item for some wildlife species.

In the past, uranium mining led to localized peregrine falcon nest failures in areas such as Kanab Canyon and its multiple side canyons, where numerous mining claims existed (Payne et al. 2010). Although 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel) would be withdrawn from locatable mineral exploration and development (i.e., uranium mining), increased uranium mining on non-federal (state and private) lands remaining open to mining could locally affect wildlife habitat (e.g., habitat loss and fragmentation) and increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Edge habitat associated with uranium mines and associated access roads may provide habitat for brown-headed cowbirds (Payne et al. 2010), which are brood parasites of songbirds. Grazing and recreation, including use of commercial pack-stock, also increase brown-headed cowbird populations (Schell 2005). Habitat loss from uranium mines and associated access roads could affect the distribution and movement of big game mammals (e.g., elk, mule deer, bighorn sheep, and mountain lions), and potentially increase their mortality from vehicle collisions or poaching

(Payne et al. 2010). There could be a potential contaminant exposure issue associated with amphibians (or other wildlife) attracted to uranium mine effluent ponds (Payne et al. 2010). In general, any impacts on wildlife from uranium mining would be localized and should not affect the viability of affected resources, especially with the use of best management practices to control mine discharges and proper mine reclamation.

The Grand Canyon Escalade Project and its associated facilities near the confluence of the Little Colorado River could cause both a localized loss of wildlife habitat and source of wildlife disturbance due to human presence. Wildlife species in the Grand Canyon are currently exposed to various sources of manmade noise ranging from human conversation to aircraft flyovers. The potential effects of noise on wildlife include acute or chronic physiological damage to the auditory system, increased energy expenditures, physical injury incurred during panicked responses, interference with normal activities (e.g., feeding), and impaired communication (AMEC Americas Limited 2005). The response of wildlife to noise would vary by species; physiological or reproductive condition; distance; and the type, intensity, and duration of the disturbance. Regular or periodic noise could cause adjacent areas to be less attractive to wildlife and result in a long-term reduction in use by wildlife in those areas. Responses of wildlife to disturbance often involve activities that are energetically costly (e.g., flying or running), altering their behavior in a way that might reduce food intake, communication, and nesting (Hockin et al. 1992; Brattstrom and Bondello 1983; Cunnington and Fahrig 2010; Francis et al. 2009; Maxell 2000).

Recreational activities such as hiking, rafting, fishing, and camping can result in disturbance to wildlife. For example, hikers, rafters, anglers, and researchers can disturb bald eagles; however, southwestern willow flycatchers are not apparently sensitive to rafts or boats passing their breeding sites, but people moving through occupied habitat can disturb the birds or impact a nest (Holmes et al. 2005). Impacts on reptiles and amphibians can include occasional opportunistic collecting or harassment by recreationists. As demand for reptiles in the pet trade increases and collectors seek new sources of supply, many national parks are experiencing problems with illegal reptile collection, especially of rattlesnakes (NPS 2014h). Recreationists can affect birds and other wildlife by removing or modifying vegetation within both the new and old high-water zones (e.g., for campsites and trails) (NPS 2005a).

During winter 1990–1991, more eagles were detected in reaches with low human use compared to reaches with high to moderate human use between Glen Canyon Dam and the Little Colorado River. No eagles were found within 1 km of intensively used areas near Lees Ferry and Navajo Bridge. Repeated flushing by bank fishermen, hikers, or boats could have caused wintering eagles to avoid reaches heavily used by anglers (Brown and Stevens 1997). Winter camping, especially in important eagle activity areas, can disturb bald eagles and has the potential to seriously disrupt a wintering eagle concentration (Sogge and Tibbitts 1994).

The effects of the LTEMP alternatives on wildlife are relatively small compared to the effects of other factors, especially future hydrology, and are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less even monthly release volumes (Alternatives A and B), would have greater

impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages.

4.17.3.7 Cultural Resources

The proposed action is not expected to significantly change the ongoing cumulative impacts on historic properties. Past dam operations resulted in transformations to the environment that may contribute to the nature, severity, and rate of erosive forces having the potential to act upon and influence the integrity of these historic properties. The past action primarily affecting these resources was the construction and operation of the Glen Canyon Dam and the resulting loss of sediment in the river channel below the dam.

The river immediately downstream from Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows. These pulse flows, coupled with other dam operation activities, transformed the pre-dam Glen Canyon, which had plentiful sand, native species, and active natural processes, to a present-day Glen Canyon that is incised, narrowed, and armored (Grams et al. 2007). The Glen Canyon Dam has prevented sediment-laden extreme high flows that occurred periodically in the past and allowed for both deposition and erosion at higher elevations, as well as extreme low flows that exposed sandbars and allowed wind transport to higher elevation terraces.

For GCNRA, these transformations include bed incision and reduction in the base level of erosion, sediment evacuation and exposure of terrace faces, and changes in gully type and formation processes. The degree to which these transformations may contribute to impacts on historic properties remains poorly understood, and is the subject of ongoing research. For GRCA, these transformations are primarily tied to loss of low-elevation sandbars and the degradation of the pre-dam river terraces that were home to peoples for the past 10,000 years.

In addition, the effects from visitors remain a persistent issue, although not overarching. The proposed action pertains to the operation of Glen Canyon Dam and does not alter any policies concerning visitor use of the river. The concern over visitor effects is exacerbated by erosion, which continues to expose additional portions of archaeological sites. The more artifacts are exposed at a site, the more opportunities exist for a visitor to pick up an artifact and move it. Only education can make visitors aware of the need to leave the artifacts as they lie.

Historic properties in the APE remain in a continual state of deterioration. The erosive forces that created the Grand Canyon continue to operate throughout both GCNRA and GCNP and continue to destabilize the historic properties found there. The degradation of historic properties due to natural causes remains the biggest challenge faced by historic property managers. Rain events cause gullying and remove the sediment that surrounds the historic properties along the Colorado River. Little can be done to slow these climatic processes although implementing management strategies to stabilize and minimize sediment losses may be effective tools in the future.

4.17.3.8 Tribal Resources

Actions contributing to cumulative impacts on Tribal resources include the continued use or reopening of breccia pipe uranium mines adjacent to the park, the development of new mines on state land lying within the Grand Canyon watershed, continued traffic of visitors to sites sacred to the Tribes, and specific projects, including the Lake Powell Pipeline, the Grand Canyon Escalade, and the Red Gap Ranch Pipeline.

Uranium prospecting and mining in the Grand Canyon watershed could contribute to cumulative effects on Tribes. Uranium mining has the potential to contaminate water sources that supply aquifer systems that feed springs, seeps, and their associated ecosystems within the Grand Canyon National Park (GCNP 2013). Many Tribes consider drilling or mining to be wounding the earth (BLM 2011). In 2012, the decision was made to withdraw over a million acres of federal lands surrounding GCNP in northern Arizona from uranium mining for the next 20 years. However, four existing mines were grandfathered and continue to operate intermittently as the price of uranium fluctuates. In addition, the withdrawal of federal lands has resulted in the concentration of new uranium exploration on state lands, some of which are within the Grand Canyon watershed. Past mining has resulted in the contamination of springs and seeps feeding the Grand Canyon, reducing their sacred nature. Uranium mining is currently taking place at sacred sites, including the Red Butte Traditional Cultural Property south of GCNP. Tribes in the region have expressed concern that contamination in the drainage to Havasu Canyon or in other watersheds and aquifers would be devastating to the downstream resources of importance to the Havasupai (Havasupai Tribal Council 2015). However, the LTEMP alternatives do not include any action that would result in water contamination and none are expected to contribute to cumulative impacts.

Continued use of the riparian zone by visitors to the Canyons has the potential to result in damage to places of cultural importance to the Tribes. Continued disturbance over time and space could result in the loss of the function and sacredness of traditional cultural places. These potential losses can be partially mitigated by the education of canyon visitors regarding the sanctity of the Canyons.

Actions affecting aquatic life, vegetation, and wildlife would also affect resources of value to Tribes (see Sections 4.5, 4.6, and 4.7). For example, changes in the tamarisk population due to the tamarisk leaf beetle and splendid tamarisk weevil, as well as long-term changes in the climate could contribute to cumulative impacts on riparian ecosystems across the Colorado River watershed. A summary of such impacts on Tribal resources is provided in Section 4.9.3.

The Lake Powell Pipeline proposes to carry water from Lake Powell to Sand Hollow Reservoir near St. George, Utah, to help meet water demand in southwestern Utah (UBWR 2011c). Impacts on historic properties have not been assessed for this project. Impacts on other resources of Tribal importance from the pipeline could include loss of some wildlife habitat and temporary loss of vegetation and riparian communities. The Red Gap Ranch Pipeline, which would withdraw and convey groundwater to augment Flagstaff's water supply, could affect springs of importance to Tribes, although the impacts of this action have not yet been assessed.

LTEMP alternatives that include mechanical trout removal or TMFs (all Alternatives except F), may have an adverse effect that would add to the cumulative impacts on Tribal resources (see also Table 4.9-2).

4.17.3.9 Recreation, Visitor Use, and Experience

Section 3.10 presents the recreational resources and activities that could be affected by the LTEMP alternatives. Most of the LTEMP alternatives would result in fewer navigation concerns, lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). Section 4.10 presents the estimated incremental effects of the alternatives on those recreational resources and activities. The following paragraphs analyze the potential cumulative effects of past, present, and future actions on recreation resources that may also incur incremental effects from the LTEMP alternatives. Other resources analyzed separately that could incur cumulative effects that might also affect recreation include sediment, water quality, and the trout fishery below Glen Canyon Dam.

Some of the past and present actions described in Section 4.17.1.1, including natural events, could have effects on recreation. The past and present actions that could affect camping and beach access are those that affect sediment transport and deposition. Among these, the 2007 Interim Guidelines affect sediment retention and deposition through required equalization flows, which tend to erode beaches, while the 2011 HFE protocol would benefit beach and campsite building through sediment deposition. Such effects are already captured in the analysis of the LTEMP alternatives, which are subject to the provisions of ongoing programs.

Among ongoing actions that could affect recreation, visitor use, and experience, is the 2006 CRMP, which sets the number of annual launches for commercial and noncommercial boating and rafting.

The Comprehensive Fisheries Management Plan and the Non-native Fish Control Program would protect and benefit recreational fishing below Glen Canyon Dam. These two management programs would limit the effects of the LTEMP alternatives on the recreational fishery. Most of the alternatives incorporate management actions consistent with these plans, including TMFs and mechanical removal of trout. These plans and actions would tend to reduce cumulative impacts on the trout fishery through active management.

Of the reasonably foreseeable future actions, the proposed Grand Canyon Escalade project, including a gondola running from the canyon rim to the canyon floor near the confluence of the Little Colorado River and the Colorado River would contribute to cumulative impacts on recreational resources. The nature of effects, positive or negative, would depend on the perspective of a particular visitor. Users of the facility would benefit from the services offered. Adverse effects on wilderness experience are discussed in Section 4.17.10. Overall, however, effects of the Escalade project on recreationists are expected to be negative, because the vast majority of visitors come to experience natural beauty and solitude, which is incompatible with development within the Grand Canyon.

Climate change could affect recreation resources in a number of ways, some of which would add significantly to effects from ongoing actions and trends discussed. Warming temperatures could reduce runoff and water supply to the Colorado River and increase water demand from municipalities and for cooling, further reducing supply. Reduced availability of water could lower the elevation of Lake Powell, leading to warming and reduced flows below the Glen Canyon Dam. Warming could reduce DO levels in tailwaters. These factors could affect the health of the trout fishery below the dam and could affect boating through lower flows and higher daily fluctuations, as discussed in the previous paragraph. The combination of climate change and increasing water demands from regional population growth could increase the cumulative effects of reduced water availability.

The LTEMP alternatives would vary with respect to recreation, but would not significantly add to cumulative effects on recreation. Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G).

4.17.3.10 Wilderness

Wilderness character, as used in this EIS, is defined in Section 3.11 as the wilderness values and experience that may be impacted by LTEMP alternatives. Section 4.11 analyzes potential direct impacts on wilderness values and experience of the alternatives. In this section, potential cumulative effects on wilderness experience caused by other past, present, or future actions in the region are analyzed; aspects of the analysis of cumulative effects on recreation (Section 4.17.3.10) are also relevant to this discussion.

The GCNP Backcountry and Fire Management Plan would tend to benefit visitor use and experience under all the LTEMP alternatives through the protection of wilderness and visual resources and soundscapes, while mitigating to some extent visitor effects on the same resources.

The 2006 CRMP, which regulates commercial and noncommercial boating and rafting, would also tend to enhance visitor experience while protecting natural and cultural resources. By limiting the number of rafters on the river, this plan would protect wilderness experience and solitude. The 2010 Abandoned Mine Closure Plan could also enhance wilderness experience and protect natural resources through restoration of a more natural state. Similarly, the 2012 withdrawal of approximately a million acres of federal land in the vicinity of GCNP from entry for uranium mining would enhance wilderness values regionally by limiting industrial development in areas surrounding the parks.

With respect to foreseeable actions in the study area, the proposed Noise and Flight management alternatives could have a substantial beneficial effect on wilderness values in GCNP. The proposed Grand Canyon Escalade development on 420 acres near the confluence of the Little Colorado and Colorado Rivers could have adverse effects on wilderness values and experience in that area. Visitors seeking solitude or a wilderness experience could be adversely

affected by the visual and noise effects and the presence of infrastructure, which is incompatible with the character of GCNP.

Basin-wide trends that could affect wilderness values and experience would be primarily those related to climate change. Wilderness and wilderness experience would be adversely affected to the extent that warming and reduced water availability promote the growth of invasive and nonnative species, which would alter the native character of vegetation. Low water availability could cause crowding and loss of solitude on the river due to reduced navigability and delays at rapids from periodic low flows.

The LTEMP alternatives vary with respect to their impact on wilderness experience. Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. None of the alternatives would significantly contribute to the cumulative impacts for this resource.

4.17.3.11 Visual Resources

The current condition of visual resources is described in Section 3.12; this reflects the effects of past and present cumulative impacts on resources within the project area. Section 4.12 discussed the potential impacts of the various LTEMP alternatives on visual resources within the project area. Visual resources within the shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead, the shorelines of Lake Powell and Mead, and the general landscape of the area may also be affected by reasonably foreseeable actions and basin-wide factors contributing to cumulative impacts, including the Lake Powell Pipeline Project, uranium mining, the Grand Canyon Escalade development, water use, and climate change.

Increased water demands from population and industrial growth, coupled with conditions brought on by climate change such as severe drought and higher temperatures, could lead to lower Lake Powell reservoir levels. In addition, the Lake Powell Pipeline Project would likely result in slightly lower Lake Powell reservoir levels (UBWR 2011a,b). Additional impacts could result from the pipeline alignment, proposed facilities, and transmission lines associated with the Lake Powell Pipeline Project. No new infrastructure is proposed by any of the LTEMP alternatives; however, if water is transferred to Sand Hollow Reservoir from Lake Powell, the water level in Lake Powell could become lower, resulting in a slight increase in the height of the calcium-carbonate ring that surrounds Lake Powell and increasing the exposure of sediment deltas. These actions could also slightly increase the months of exposure of Cathedral-in-the-Desert.

Uranium mining operations have the potential to change the landscape character in the project area. The Grand Canyon Escalade development project includes a gondola, riverwalk, amphitheater, visitor center, and retail complex. The development would be visible from six of the seven eastern viewpoints in GCNP (Confluence Partners, LLC 2012b) and would cause a visual contrast with the surrounding natural environment of the Grand Canyon and Colorado

River. Impacts on the landscape under the proposed LTEMP action are negligible and are not expected to contribute to cumulative impacts affecting the landscape character.

4.17.3.12 Hydropower

Power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon powerplant are described in Section 3.13; Section 4.13 presented the potential impacts that change in dam operations under the LTEMP alternatives would have on the economic value of hydropower resources and on electricity capacity expansion necessary for the eight largest WAPA customer utilities to replace lost hydropower generation, as well as the resulting impacts on retail electricity rates charged by the eight largest customer utilities. Increased demand for electricity in the service territories of the eight largest WAPA customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years (Section 4.13).

The incremental impact of the LTEMP alternatives generating capacity over the 20-year period would be relatively small (<1% of baseline) and variable. Changes in operations at Glen Canyon Dam (relative to current baseline conditions under Alternative A) would reduce available generating capacity at Glen Canyon Dam under all LTEMP alternatives except Alternative B. This reduction in capacity would be replaced by purchases from other sources or construction of new capacity.

The LTEMP alternatives vary with respect to hydropower production, hydropower capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G), especially if more water is released in the high-demand months of July and August. Alternatives A and B would have the least effect on the value of generation, the value of capacity, and retail rates, while Alternatives F and G would have the highest.

Changes in operations under LTEMP alternatives could reduce available generating capacity, necessitating the purchase of replacement capacity from other sources and potentially increasing the wholesale power rates to entities allocated preference power. The average change in the retail rate (residential and commercial utility bills) varies from a decrease of 0.27% in Alternative B to an increase of 1.21% in Alternative F. The average change in the monthly residential electricity bill varies from a decrease of $0.27 in Alternative B to an increase of $1.02 in Alternative F.

Since the implementation of MLFF, between 1997 and 2005, multiple restrictions have been placed on the variability of water released from the dam, thus restricting dam operational flexibility. Under the current operating regime, described in more detail in Section 3.13.1.3, fluctuations in release rates, ramp rates, and maximum hourly increases/decreases are restricted and the maximum release rate for power generation is limited to 25,000 cfs. Maximum releases above 25,000 cfs occur through bypass tubes to achieve a constant release rate. Bypassing water around generators produces no energy, which can result in additional purchases of replacement

power. The average annual costs associated with reductions in electricity generation over this time period have ranged from $38 million to $50 million (in 2009 dollars) (Veselka et al. 2010).

Changes in operations at the Flaming Gorge Dam and the Aspinall Unit are expected to result in a reduction of generating capacity 529,800 and 9,914 MWh (on an average annual basis), respectively (Reclamation 2005b, 2012i). These reductions in capacity will necessitate replacement by purchases from other sources or construction of new capacity over the 20-year period.

Changes at NGS to meet air emissions requirements may result in a reduction in generation output at the facility and its contribution to power in the Western Interconnection. This could result in excess transmission capacity within the Western Interconnection.

4.17.3.13 Socioeconomics and Environmental Justice

Actions and basin-wide trends contributing to cumulative impacts in the project area (including Lake Powell, Lake Mead, and the stretch of the Colorado River between them) are those that affect the economic valuation of its recreation resources and its recreational visitation and expenditure rates. Those actions and trends having a high, adverse, and disproportionate impact on minority and low-income populations are also of concern. The most significant trends affecting recreation are those related to climate change (decreased water supply and drought), because they have a direct effect on reservoir levels (exposed beaches and mudflats) and the seasonal timing of fluctuations in river flow. Regional economics (i.e., expenditures by visitors) for various types of recreational activities, including angling, rafting, and boating, as well as expenditures on gasoline (for vehicles and boats), camping fees or motel expenses, guide services, and fishing license fees are somewhat controlled by NPS regulations; the number of boating trips are controlled as specified in the CRMP and the Comprehensive Fisheries Management Plan cited in Table 4.17-1. These are not expected to change significantly under any of the LTEMP alternatives.

The impact analysis determined on the basis of the 2010 Census that minority or low-income populations exist in some block groups within San Juan (Utah) and Coconino (Arizona) counties (Section 4.14.2.4). Impacts on Tribes are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), which affect Tribal values, or result in increased economic impacts on Tribes associated with the cost of electricity (especially Alternatives F and G).

4.17.3.14 Air Quality and Climate Change

The current condition of local and regional air quality is described in Section 3.15; Section 4.15 presented the potential impacts of the LTEMP alternatives on visibility within the project area (GCNP and the six-state area). Air quality is affected by air emissions from both natural (e.g., wildfires and windblown dust) and manmade (e.g., power generation from fossil fuel-fired plants) sources. The primary cause of visibility degradation in the region is the

scattering and absorption of light by fine particles. Other important contributors to visibility degradation include combustion-related sources, fugitive dust sources, and particulate organic matter. Emissions of SO_2 and NO_x from fossil fuel combustion are the major manmade causes of visibility impairment; these emissions have been substantially reduced in the six-state area in the past decade in response to state and federal requirements (Section 3.15.2).

The construction of new powerplants (and the renewal of existing coal-fired plants permits) to meet energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change that could increase the potential for wildfires and dust storms, could increase visibility impacts in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility impairment (haze) in the region, including GCNP. Other significant contributors to visibility degradation include wildfires, windblown dust, and emissions from metropolitan areas (automobiles, manufacturing, coal-fired powerplants, and combustion sources like diesel engines).

Although hydropower generation at Glen Canyon Dam does not generate air emissions, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units (Section 4.15.1). Under baseline operations (Alternative A), emissions of SO_2 and NO_x would be about 10% and 3.0% of the total emissions over the Western Interconnection region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline.

The EPA's Clean Power Plan Proposed Rule (currently stayed by the U.S. Supreme Court) would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants (to 30% below 2005 levels by 2030). The closure of three coal-burning units at the FCPP may also have a beneficial impact by reducing levels of NO_x and PM pollutants that may contribute to regional haze and visibility issues in the GCNP. The change to control technology or reduction of generation output at the NGS to meet air emissions requirements will also reduce levels of NO_x pollutants in the region.

The incremental impact of the LTEMP alternatives on air quality over the 20-year period is based on the emissions associated with power generation needed from other powerplants to meet uninterrupted power demand of customers in the region. There is negligible difference in the additional power generation needed among the alternatives (4,172 to 4,250 GWh per year); the differences in SO_2 and NO_x precursor emissions are also negligible (Table 4.15-1).

GHG emissions under all the LTEMP alternatives can be compared to total U.S. GHG emissions at 6,810.3 MMt CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions relative to total U.S. GHG emissions are less than 1%, and range from 0.8089% (Alternative A) to 0.8094% (Alternatives F and G). Therefore, potential impacts of dam operations on climate change under the various alternatives are expected to be very small.

4.18 UNAVOIDABLE ADVERSE IMPACTS

On the basis of the assessments presented in Sections 4.1–4.17, each of the alternatives is expected to result in some unavoidable adverse impacts on resources. These adverse impacts result from the flow and non-flow actions included in each alternative and could be minimized through adaptive management and implementation of mitigation measures.

All of the alternatives, including Alternative A, would result in continued reductions (for continued compliance with the Grand Canyon Protection Act) in hydropower production relative to pre-1996 ROD operations that more closely matched generation with electrical demand, due to restrictions on maximum and minimum flow, within-day fluctuation levels, and ramping rates. Steady flow alternatives (Alternatives F and G) would result in the greatest adverse impacts on hydropower value. Alternative B would result in an increase in hydropower energy and capacity compared to Alternative A; Alternatives D and E would produce less energy and capacity than Alternative A; Alternative C would produce less than Alternatives D and E, but more than Alternatives F and G. Alternative F would produce less energy and capacity than any of the alternatives.

Under all of the alternatives, sediment availability in the river channel below the dam would continue to be limited due to the presence of the dam. No operational alternative can reverse the reduction in sediment availability. Because of this sediment-depleted condition, all of the alternatives would continue to produce a net loss of sand from the Colorado River ecosystem. Alternatives C, D, E, F, and G retain more sandbars than Alternative A or Alternative B.

Implementation of mechanical removal of trout and TMFs would represent an unavoidable adverse impact on certain Tribes if these actions are needed to manage the trout fishery and mitigate trout impacts on humpback chub, because these actions are not in keeping with important Tribal values. The adverse impacts of mechanical removal could be mitigated with the provision of beneficial use (e.g., making euthanized fish available for human consumption). Any other mitigation to avoid adverse impacts would need to be identified in discussion with the Tribes.

The remaining unavoidable adverse impacts on certain resources are those associated not with the alternatives themselves; instead, they are consequences of existing operational rules (i.e., requirements of the Law of the River and the 2007 Interim Guidelines; Reclamation 2007a), 1996 Glen Canyon Dam ROD (Reclamation 1996), and the presence of Glen Canyon Dam and current dam infrastructure. For example, temperature and sediment impacts of all alternatives are related to the inability of operations themselves to provide for warmer temperatures or restore sediment supplies. Infrastructure changes, which are not within the scope of the LTEMP EIS, could mitigate those impacts; however, without that infrastructure, these adverse impacts are unavoidable.

4.19 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Under all alternatives, different restrictions on flow fluctuations result in tradeoffs between peak hydropower production and productivity of the environment, which is largely related to increased nearshore habitat stability, aquatic food base productivity, and sandbar building downstream from the dam. For example, alternatives that have increased flow fluctuations or uneven monthly release volumes, such as Alternatives A and B, benefit peak hydropower energy and capacity and other resources (such as humpback chub) but result in less habitat stability and sandbar building. Alternatives with steady flows, such as Alternatives F and G, have the greatest reduction in peak hydropower energy and capacity, but result in more habitat stability and sandbar building downstream from the dam, and corresponding benefits for other resources such as recreation, aquatic food base, and trout. As a result, each of the alternatives presents a different balance between impacts on resources that appear to benefit from increased fluctuations and those that benefit from reduced fluctuations. Alternatives C, D, and E represent alternatives with more even monthly release volumes, and in the case of Alternatives C and D, fluctuation levels that are comparable to or lower than those under Alternative A. These alternatives were designed to strike a more even balance among resource impacts. However, regardless of the alternative, experimental flow and non-flow actions associated with alternatives (e.g., HFEs, TMFs, mechanical trout removal) would be tested in an attempt to maintain a balance that improves long-term productivity of the environment downstream of Glen Canyon Dam. Similarly, experimental elements of the alternatives are designed to improve our understanding of how resources respond to operations and how management actions can be best used to avoid, minimize, or mitigate impacts on resources and the long-term productivity of resources analyzed in the LTEMP EIS.

4.20 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Any experiment or operation that bypasses Glen Canyon Dam generators (e.g., HFEs that exceed powerplant capacity through generator bypass) would cause an irretrievable loss of hydropower production. Hydropower production forgone on a given day due to flows that reduce flexibility (e.g., lower summer flow or reduced fluctuations under certain alternatives) would create an irretrievable loss (see Section 4.13.2.1).

There could be some small differences among alternatives in total air emissions (<0.1% difference in emissions of SO_2, NO_x, or GHGs) that are related to differences among alternatives in the amount of energy and capacity that would be provided by Glen Canyon Dam. As part of an integrated electric grid, any loss of generation or capacity from Glen Canyon Dam must be offset by generation from a mix of other sources, including renewable energy sources and fossil-fuel-fired powerplants. The portion of the energy that comes from fossil-fuel-fired powerplants would produce these small differences in emissions; see sections 4.15 and 4.16.

Archeological sites by their nature are non-renewable, therefore any loss due to dam operations would be irretrievable. See Section 4.8.3 for the relative performance in comparison to Alternative A.

No other instances of irreversible or irretrievable commitments of resources are expected under any of the alternatives. Although operations, flow actions, non-flow actions, and experiments could result in unexpected impacts on natural and cultural resources, a long-term monitoring program implemented as part of the ongoing Glen Canyon Dam Adaptive Management Program would be used to inform the need for changes in operations and actions to minimize impacts and improve downstream resources in accordance with the objectives of this EIS. Safeguards have been incorporated into alternatives, including implementation considerations that would preclude taking specific actions if implementation would result in unacceptable adverse impacts, and off-ramps that would be used to alter operations or stop actions to prevent irreversible losses.

5 CONSULTATION AND COORDINATION

One intent of the National Environmental Policy Act of 1969, as amended (NEPA), is to encourage the participation of federal and state agencies and affected citizens in the assessment procedure, as appropriate. Consultation, coordination, and public involvement are integral to identifying relevant issues and concerns and ensuring that these issues are addressed. For this Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), this was accomplished primarily through public meetings and workshops, informal and formal agency meetings, webinars, individual contacts, website updates, news releases, and *Federal Register* notices.

Acting as joint-lead agencies, the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) have prepared this EIS in close coordination with several federal and state agencies (see Section 1.3). Development of this EIS also included input from Tribal governments, local agencies, programs, nongovernmental organizations, and the general public. This chapter summarizes the formal consultation and coordination that have occurred during the preparation of this EIS.

5.1 CONSULTATION AND COORDINATION WITH OTHER AGENCIES AND PROGRAMS

5.1.1 U.S. Department of the Interior

The U.S. Department of the Interior (DOI), through Reclamation and NPS, has prepared this EIS, with assistance from Argonne National Laboratory (Argonne) and the U.S. Geological Survey (including staff from the Patuxent Wildlife Research Center, Grand Canyon Monitoring and Research Center, and Southwest Biological Science Center). Reclamation has the primary responsibility for operating Glen Canyon Dam. NPS has the primary responsibility for managing downstream resources and visitors for the Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area. As joint leads, both agencies have been equally involved in all aspects of the development of the LTEMP and EIS.

5.1.2 Cooperating Agencies

On December 8, 2011, in accordance with Title 40 *Code of Federal Regulations,* Part 1501.6 (40 CFR 1501.6) of the Council on Environmental Quality (CEQ) regulations for implementing NEPA and 43 CFR 46.225 of the DOI's regulations for implementing NEPA, Reclamation and NPS invited 25 federal, Tribal, state, and local government agencies to participate in the development of the EIS as Cooperating Agencies. Fifteen of these agencies expressed interest in participating as Cooperating Agencies. The Cooperating Agencies, which include three federal entities, five state agencies, and six Tribes, are listed in Table 5.1-1, along with descriptions of their participation.

All Cooperating Agencies have had the opportunity to participate in regular meetings and workshops and webinars related to the development of this EIS, participate in monthly meetings with the joint leads, and review and comment on the Draft EIS. Beginning in February 2012, the Cooperating Agencies met every month during the preparation of the EIS. In addition, more than 30 meetings, workshops, and webinars were conducted with stakeholders and Cooperating Agencies to assist in the development of alternatives and performance measures, conduct the Structured Decision Analysis (SDA), and provide general status updates. Federal Cooperating Agencies (i.e., Bureau of Indian Affairs [BIA], U.S. Fish and Wildlife Service [FWS], and Western Area Power Administration [WAPA]) also participated in the process of alternative development for the EIS.

5.1.3 American Indian Tribes

As part of the government's Treaty and Trust responsibilities, the Federal Government works on a government-to-government basis with American Indian Tribes. The government-to-government relationship and the process for developing open and transparent communication, effective collaboration, and informed federal decision-making with Indian Tribes was identified in Executive Order (E.O.) 13175, "Consultation and Coordination with Indian Tribal Governments" (U.S. President 2000); E.O. 13007, "Indian Sacred Sites" (U.S. President 1996); Secretarial Order (S.O.) 3206, "American Indian Tribal Rights, Federal-Tribal Trust Responsibilities, and the Endangered Species Act" (DOI 1997); S.O. 3317, "Department of the Interior Policy on Consultation with Indian Tribes" (DOI 2011a); and the President's "Memorandum on Government-to-Government Relations with Native American Tribal Governments" (U.S. President 1994a). In addition, Section 106 of the National Historic Preservation Act (NHPA) requires federal agencies to consult with Indian Tribes on undertakings on Tribal lands and on historic properties of significance to the Tribes that may be affected by an undertaking (36 CFR 800.2 (c)(2)). Both Reclamation and NPS coordinate and consult with all Tribal governments, Native American communities and organizations, and Tribal individuals whose interests might be directly and substantially affected by activities within their jurisdiction.

Government-to-government consultation was conducted throughout development of this EIS, in accordance with provisions of the Executive Orders and Secretarial Orders listed above as well as Section 106 of the NHPA, and any additional applicable natural and cultural resource laws (e.g., NEPA, the Endangered Species Act [ESA], NHPA, and Migratory Bird Treaty Act), as well as agency-specific guidance, such as:

- DOI, Departmental Manual, *Departmental Responsibilities for Indian Trust Resources*, 512 DM 2 (1995).

- DOI, Departmental Manual, *Departmental Responsibilities for Protecting/ Accommodating Access to Indian Sacred Sites*, 512 DM 3 (1998).

TABLE 5.1-1 Summary of Cooperating Agency Involvement

Cooperating Agency	Type	Summary of Involvement
Arizona Game and Fish Department (AZGFD)	State	AZGFD is a Cooperating Agency in recognition of its role in conserving, enhancing, and restoring Arizona's diverse wildlife resources and habitats. AZGFD is also a member of the Glen Canyon Dam Adaptive Management Work Group (AMWG). AZGFD participated in several stakeholder meetings, and representatives offered expertise during development of resource goals, performance metrics, and the aquatic modeling approach.
Bureau of Indian Affairs (BIA)	Federal	BIA is a Cooperating Agency in recognition of its administration of federal trust responsibility to Indian Tribes. BIA assisted in government-to-government consultations and served in an advisory capacity to Reclamation and the Indian Tribes.
Colorado River Board of California (CRBC)	State	CRBC is a Cooperating Agency in recognition of its responsibility for maintaining or increasing the quantity of California's Colorado River water resources. CRBC is also a member of the Glen Canyon Dam AMWG and represents California as part of the group of seven Basin States that have interests in the Colorado River. CRBC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
Colorado River Commission of Nevada (CRCN)	State	CRCN is a Cooperating Agency in recognition of its responsibility for acquiring and managing water and hydropower resources from the Colorado River. CRCN is also a member of the Glen Canyon Dam AMWG and represents Nevada as part of the group of seven Basin States that have interests in the Colorado River. CRCN contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.
The Havasupai Tribe	Tribe	The Havasupai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Havasupai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and have contributed written portions to the EIS.
The Hopi Tribe	Tribe	The Hopi Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and Technical Working Group (TWG). Hopi representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
The Hualapai Tribe	Tribe	The Hualapai Tribe is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Hualapai representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.
The Kaibab Band of Paiute Indians	Tribe	The Kaibab Band of Paiute Indians is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Kaibab representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and provided comments on performance metrics and resource goals.
The Navajo Nation	Tribe	The Navajo Nation is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. The Tribe is also a member of the Glen Canyon Dam AMWG and TWG. Navajo representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, and provided comments on performance metrics and resource goals.
The Pueblo of Zuni	Tribe	The Pueblo of Zuni is a Cooperating Agency in recognition of its relationship with the Colorado River and the Canyons. The Tribe has interests in aspects of the operation of Glen Canyon Dam and Colorado River resources below the dam. Zuni representatives have participated in Cooperating Agency meetings and meetings and webinars pertaining to Tribal values, provided comments on performance metrics and resource goals, and have contributed written portions to the EIS.
Salt River Project (SRP)	Public Utility	SRP is a Cooperating Agency in recognition of its role as one of the primary public utility companies in Arizona. SRP participated in several Cooperating Agency and stakeholder meetings and provided comments on performance metrics and modeling results.
Upper Colorado River Commission (UCRC)	Inter-State	UCRC is a Cooperating Agency in recognition of its role as part of the group of seven Basin States that have interests in the Colorado River. UCRC is also a Glen Canyon Dam AMWG member. UCRC contributed to the development of the Resource Targeted Condition Dependent Alternative, which served as the basis of Alternative E, and, as part of the Basin States group, provided comments on performance metrics and modeling results.

TABLE 5.1-1 (Cont.)

Cooperating Agency	Type	Summary of Involvement
U.S. Fish and Wildlife Service (FWS)	Federal	FWS is a Cooperating Agency in recognition of its jurisdiction by law and special expertise with respect to the ESA and biological resources within the study area. FWS has participated in the formation and development of LTEMP resource goals and objectives, performance metrics and alternatives, as well as the development of the aquatic modeling approach. In addition, a representative from FWS serves as the Tribal Liaison and has participated in government-to-government meetings with the Tribes.
Utah Associated Municipal Power Systems (UAMPS)	Public Utility	UAMPS is a Cooperating Agency in recognition of its role as a purchaser of electricity from the Colorado River Storage Project. UAMPS is also a member of the AMWG. UAMPS participated in Cooperating Agency and stakeholder meetings and provided comments on the performance metrics.
Western Area Power Administration (WAPA)	Federal	WAPA is a Cooperating Agency in recognition of its role in marketing and transmitting electricity from the Glen Canyon Dam. WAPA representatives participated in the development of alternatives and hydropower performance metrics and provided funds for the hydropower systems analysis.

- DOI, Order No. 3317, *Policy on Consultation with Indian Tribes*, December 1, 2011 (DOI 2011a).

- Reclamation, *Indian Policy of the Bureau of Reclamation*, 1998 (revised 2001).

- Reclamation, *Protocol Guidelines, Consulting with Indian Tribal Governments*, 2001 (Reclamation 2012g).

- *Programmatic Agreement among the Bureau of Reclamation, the Advisory Council on Historic Preservation, the National Park Service, the Arizona State Historic Preservation Officer, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Navajo Nation, San Juan Southern Paiute Tribe, Shivwits Paiute Tribe, and Zuni Pueblo Regarding the Operation of Glen Canyon Dam*, 1994 (Reclamation 1994).

- NPS, *Management Policies 2006* (NPS 2006d).

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS. The letters, sent by the joint-lead agencies, provided notification of the intent to prepare the LTEMP EIS; initiated government-to-government consultation; and invited the Tribes to identify concerns related to historic properties, including traditional cultural properties and archaeological sites, natural resources, relevant Indian Trust assets, and other issues of importance.

A total of 31 Tribes responded to the invitation. Six Tribes agreed to participate as Cooperating Agencies (see Section 5.1.2); three Tribes (the Fort Mojave Tribal Council, Pueblo of Zia, and Gila River Indian Community) agreed to participate as Consulting Tribes; eight Tribes (Pueblo of Santa Clara, Ute Indian Tribe, Ute Mountain Ute, Pueblo of Nambe, Yavapai Apache, Paiute Indian Tribe of Utah, the Pueblo of Santa Ana, and the Fort Yuma Quechan) declined participation, but asked to remain on the mailing list; and 14 Tribes (Ak Chin Indian Community, Cocopah Indian Tribe, Fort McDowell Yavapai Tribal Council, Jicarilla Apache Nation, Ohkay Owingeh, Southern Ute Tribal Council, the Pueblo of Acoma, the Pueblo of Laguna, the Pueblo of Sandia, Yavapai-Prescott Indian Tribe, Chemehuevi Tribal Council, Tohono O'odham Nation, the Pueblo of Pojoaque, and the White Mountain Apache) declined participation in the LTEMP EIS. The joint leads have yet to receive a response to the request for consultation from the remaining 12 Tribes (Colorado River Indian Tribes, Las Vegas Tribe of Paiute Indians, Moapa Band of Paiute Indians, Salt River Pima-Maricopa Indian Community, San Carlos Apache Tribe, San Juan Southern Paiute Tribe, the Pascua Yaqui Tribe, the Pueblo of Cochiti, the Pueblo of Jemez, the Pueblo of San Felipe, the Pueblo of Tesuque, and Tonto Apache).

Cooperating and consulting Tribes were invited to attend meetings, workshops, and webinars, and to review various documents related to the development of the LTEMP EIS. A series of workshops, conference calls, and webinars were held with Tribes to identify Tribal resource goals and ways to measure the relative performance of alternatives against those goals. A list of major face-to-face meetings, webinars, and conference calls involving Tribes is provided in Appendix N, Table N-2. Meeting notes and other important documents related to the LTEMP EIS development process were sent to those Tribes who wished to remain on the mailing list. Reclamation and NPS will continue to provide consultation opportunities for interested Tribes and keep all Tribal entities informed about the NEPA process for the EIS. A full summary of Tribal communication as of March 2015 is provided in Appendix M.

5.1.4 Other Consultations

5.1.4.1 National Historic Preservation Act (NHPA)

Section 106 of the NHPA of 1966, as amended, and its implementing regulations, requires federal agencies to address the effect of projects on historical properties (i.e., resources determined eligible or listed on the *National Register of Historic Places* [NRHP]) and to give the State Historic Preservation Officers (SHPOs), Advisory Council on Historic Preservation (ACHP), and Traditionally Associated American Indian Tribes, as necessary, a reasonable opportunity to comment on such effects. Reclamation has the lead for Section 106 compliance and initiated the process of consultation with the Arizona SHPO. Consultations regarding eligibility of cultural resources to the NRHP and the effect of the proposed federal action are ongoing. In addition, consultations occurred with Tribal Historic Preservation Officers and Indian Tribes with concerns under E.O. 13007, "Indian Sacred Sites" (U.S. President 1996), the Native American Graves Protection and Repatriation Act, and Section 106 of the NHPA.

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS (see Section 5.1.3). As part of the consultation process for this EIS, Reclamation will continue to identify concerns, assess the potential for cultural resources impacts, develop appropriate mitigation measures, and seek concurrence with the determination of effect. If adverse effects are identified, Reclamation would continue consultation to seek options to avoid, minimize, or mitigate the adverse effects on historic properties. Reclamation, in consultation with interested parties, is developing a Programmatic Agreement to address any cultural resource effects and mitigation measures. Reclamation and NPS conducted a number of formal and informal consultation meetings with Tribes (Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni) just prior to and after the release of the DEIS.

5.1.4.2 State and Local Water and Power Agency Coordination

Reclamation and NPS have had various discussions with state and local water agencies regarding the proposed federal action. The seven Basin States in particular have been continuously engaged throughout the scoping and alternatives development processes. This engagement has consisted of conference calls, webinars, and face-to-face meetings to discuss process, resource goals, alternative characteristics, metrics to determine the relative performance of alternatives against those metrics, and the overall modeling approach used to quantify impacts.

One of the alternatives considered in the LTEMP EIS (Alternative E) was developed by the Basin States (as the Resource-Targeted Condition-Dependent Alternative) and submitted to the joint-lead agencies. The joint-lead agencies shared initial impact analysis results and insights that were ultimately used by the Basin States to further refine Alternative E.

The Colorado River Energy Distributors Association (CREDA) is an organization that represents consumer-owned electric systems that purchase federal hydropower and resources of the Colorado River Storage Project. While not a Cooperating Agency, CREDA, a member of the Glen Canyon Dam Adaptive Management Work Group (AMWG), submitted Alternative B, and Reclamation and NPS worked closely with CREDA to define and model resource effects of this alternative. CREDA has also participated in stakeholder meetings and provided comments on the performance metrics.

5.1.4.3 U.S. Fish and Wildlife Service (FWS)

FWS participated in the formation and development of LTEMP alternatives, providing expertise in several workshops and webinars. FWS also worked with the joint-lead agencies and subject matter expert groups in the development of resource goals and objectives and performance metrics to evaluate the alternatives. FWS provided expertise during the development of the aquatic modeling approach used in this EIS.

Reclamation and NPS consulted with FWS on the effects of the LTEMP on species listed under Section 7 of the ESA (The Biological Assessment is included in Appendix O of this EIS). This consultation was a continuation of ongoing consultation that has occurred since 1995. Reclamation has consulted with FWS on a total of five experimental actions. The Biological Opinion prepared for the LTEMP supersedes the 2011 opinion on the high-flow experimental protocol and nonnative fish protocols.

5.2 PUBLIC INVOLVEMENT

Public involvement in the NEPA process is intended to give the public the chance to provide input throughout the development of an EIS and the decision-making process for actions with environmental effects. An objective of public involvement is to obtain information from the public to assist the decision-maker (Secretary of the Interior) throughout the entire process, culminating in a Record of Decision and eventual implementation of the selected alternative. The primary goals of public involvement are:

1. *Credibility and transparency*: creating an open and visible decision-making process for groups with divergent viewpoints.

2. *Identifying public concerns and values*: providing a mechanism by which the involved agencies can understand the problems, issues, and possible solutions from the perspectives of the public.

3. *Developing a consensus*: providing a process for reaching a consensus on specific actions.

In order to identify issues, address public concerns, obtain public input, and keep the public informed, several opportunities were provided for public participation during the preparation of this EIS. These included an early and open public scoping process and public meetings related to development of preliminary alternatives. The public scoping process is described below in Section 5.2.1.

5.2.1 Public Scoping Process and Comments Received

The process of soliciting input from the public is called scoping. Public scoping is a phase of the NEPA analysis process and was intended to give the public the chance to comment on the LTEMP, recommend alternatives, and identify and prioritize the resources and issues to be considered in the EIS analyses. Consistent with CEQ requirements (40 CFR 1501.7) and DOI NEPA regulations at 43 CFR Part 46, an early and open public scoping process was carried out to determine the resources or issues to be evaluated in the LTEMP EIS, the alternatives to be included in the LTEMP EIS, and concerns or observations regarding Glen Canyon Dam operations and downstream resources. Reclamation and NPS have considered the public scoping comments in developing this EIS.

Reclamation and NPS published a Notice of Intent (NOI) to prepare the LTEMP EIS in the *Federal Register* (Volume 76, page 39435) on July 6, 2011 (DOI 2011b). The NOI provided initial information on the purpose and need of the LTEMP EIS, explained the decision for Reclamation and NPS to co-lead the project, and encouraged the participation of stakeholders in the development of the LTEMP EIS. The public scoping period started with the publication of the NOI and ended on January 31, 2012.

Early in the scoping process, Reclamation and NPS established a website for the LTEMP EIS (http://ltempeis.anl.gov) that provided background information about the project, information on public involvement, answers to frequently asked questions, and links to documents for review. During the public scoping process, a link to the project's online comment form was provided and made available on the NPS's Planning, Environment, and Comment website. In addition, project updates and announcements were made available via an email subscription list, press releases, and social media (e.g., Twitter and Facebook).

"A Notice to Solicit Comments and Hold Public Scoping Meetings on the Adoption of a Long-Term Experimental and Management Plan for the Operation of Glen Canyon Dam" was published in the *Federal Register* (Volume 76, page 64104) on October 17, 2011 (DOI 2011c), which provided the date, time, and place for six public meetings to be held to solicit public input on the scope of the EIS, including potential alternatives and issues to be addressed within the document. Meetings were held in the following locations:

- Phoenix, Arizona (November 7, 2011)
- Flagstaff, Arizona (November 8, 2011)
- Page, Arizona (November 9, 2011)
- Salt Lake City, Utah (November 15, 2011)
- Las Vegas, Nevada (November 16, 2011)
- Lakewood, Colorado (November 17, 2011)

The notice also indicated that there would be one web-based public meeting (November 15, 2011) for those who could not attend in person. The public was also notified of the meetings via a press release, local media outlets, and an op-ed article disseminated for publication in local and regional newspapers.

At the public meetings, the public could view exhibits about the project, discuss issues informally, and ask questions of technical experts and managers. A total of 221 people attended these meetings. For the web-based meeting, the public was able to listen to, via the Internet, a live overview presentation of the LTEMP EIS and to ask questions of technical experts and managers.

A total of 447 individuals, recreational groups, environmental groups, power customers or organizations, federal and state government agencies, and other organizations provided scoping comments on the LTEMP EIS. Although no formal campaign letters were received, some commenters chose to incorporate in their submissions entire letters or portions of letters from various other commenting organizations.

Comments received during the public scoping period covered a wide range of topics and issues and represented a variety of views and interpretations. Comments addressed various aspects of the proposed action, including the purpose and need (as stated in the July 6, 2011, NOI [DOI 2011b]); environmental issues; dam operations and hydropower; geographic and temporal scope; policy and regulatory concerns; LTEMP approach and considerations; alternatives; other issues; and stakeholder involvement. A detailed summary of comments received can be found in *Summary of Public Scoping Comments on the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement* (Argonne 2012), available on the LTEMP website (http://ltempeis.anl.gov).

In general, the most frequent topic for comments on the LTEMP EIS was related to environmental issues. Comments and concerns frequently raised by the public included restoration of the downstream Colorado River ecosystem; reestablishment of ecosystem patterns and processes to their pre-dam range of natural variability; elimination or minimization of further beach erosion; facilitation of sediment redeposition; in situ maintenance and preservation of the integrity of cultural and archeological resources; elimination of adverse impacts on and assistance in the recovery of native species; nonnative fish management; and assistance in repropagation of native riparian plant communities.

5.2.2 Public Meetings on Alternatives

Members of the public were invited to participate in a 2-day open public meeting on preliminary alternative concepts, hosted by Reclamation and NPS. The meeting was held on April 4 and 5, 2012, at the High Country Conference Center in Flagstaff, Arizona. More than 70 people attended the meeting, including members of the public, stakeholders, and project staff from Reclamation, NPS, and Argonne.

During this meeting, alternatives being considered for inclusion in the LTEMP EIS were presented and discussed. Stakeholders and other attendees who had alternatives to propose were able to present those ideas at the meeting; four individuals representing different stakeholder groups presented their ideas. Following the presentations, meeting attendees broke into smaller groups and focused on evaluating and refining the preliminary alternative concepts. These small groups reported their discussions in an open forum during the meeting.

Reclamation and NPS evaluated the feedback received at this meeting and used it to develop the final set of alternatives considered in this EIS (discussed in detail in Chapter 2). Maintaining that all alternatives meet the purpose and need of the proposed action, this evaluation resulted in new alternative concepts, the modification of existing concepts, and the combination of some concepts into single alternatives.

Regular updates of the LTEMP EIS process were provided at public meetings of the Glen Canyon Dam AMWG. LTEMP EIS joint leads regularly presented the status of preliminary EIS-related materials (e.g., purpose and need, resource goals, and preliminary draft alternatives) and coordination activities with the Cooperating Agencies. These meetings are described in more detail in Section 5.2.3.

5.2.3 Glen Canyon Dam Adaptive Management Working Group

The Glen Canyon Dam AMWG is a federal advisory committee. As an advisory committee, the AMWG has provided a forum for discussion of key issues related to the operation of Glen Canyon Dam among the federal agencies, Indian Tribes, environmental groups, recreational interest groups, federal power purchase contractors, and other stakeholders who have interests in the resources of the Colorado River. AMWG members meet several times throughout the year to discuss competing issues on how to protect downstream resources and strike a wise balance on river operations. Their recommendations are regularly provided to the Secretary by the Secretary's Designee, who often brings these competing issues to a consensus (Reclamation 2014d).

Separate meetings regarding the LTEMP EIS have been held with the Glen Canyon AMWG because of its status as a Federal Advisory Committee. These meetings occurred on February 18–22, 2013, May 8, 2013, August 8–9, 2013, February 18–20, 2014, May 27, 2014, August 27–28, 2014, February 25–26, 2015, and May 28, 2015. These meetings were conducted to provide an explanation of alternatives, performance criteria, and SDA; conduct swing-weighting exercises; answer budget questions; and provide general status updates.

5.2.4 Public Involvement on the LTEMP DEIS

On January 8, 2016, the LTEMP DEIS was filed with Region 9 of the U.S. Environmental Protection Agency (EPA); a Notice of Availability and Notice of Public Meetings were published in the *Federal Register* (81 FR 963); and an email notification of the availability of the DEIS for download from the project website (www.ltempeis.gov) was sent to approximately 600 members of the public who had signed up for notification during the scoping period. Prior to this date, the DEIS was sent to each of the Governors, Senators, and Representatives from relevant congressional districts of the seven Colorado River Basin States (Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming).

In addition to making the DEIS available on the public website, 84 compact disc copies of the DEIS were mailed to individuals at their request; 46 copies were picked up at public meetings held for the DEIS; and copies were made available for public review after the DEIS was published at the following locations:

- J. Willard Marriott Library, University of Utah, 295 South 1500 East, Salt Lake City, Utah 84112.

- Cline Library, Northern Arizona University, 1001 S. Knoles Drive, Flagstaff, Arizona 86011-6022.

- Burton Barr Central Library, 1221 North Central Avenue, Phoenix, Arizona 85004.

- Page Public Library, 479 South Lake Powell Boulevard, Page, Arizona 86040.

- Grand County Library, Moab Branch, 257 East Center Street, Moab, Utah 84532.

- Sunrise Library, 5400 East Harris Avenue, Las Vegas, Nevada 89110.

- Denver Public Library, 10 West 14th Avenue Parkway, Denver, Colorado 80204.

- Natural Resources Library, U.S. Department of the Interior, 1849 C Street NW, Main Interior Building, Washington, D.C. 20240-0001.

The original 90-day public comment period was extended an additional 32 days (122-day total) to May 9, 2016, after several requests were received from the public and Cooperating Agencies. During the comment period, two in-person meetings and two Internet-based webinars were held to provide the public with information about the content and findings of the DEIS and to receive written comments on the DEIS. The meetings and webinars were held on the following dates:

- Webinar—Tuesday, February 16, 2016, at 6:30 p.m. Mountain Standard Time (MST);

- Meeting—Monday, February 22, 2016, at 6:00 p.m. MST, Flagstaff, Arizona;

- Meeting—Thursday, February 25, 2016, at 6:00 p.m. MST, Phoenix, Arizona; and

- Webinar—Tuesday, March 1, 2016, at 1:00 p.m. MST.

At these meetings, LTEMP staff were available to take comments and answer questions before and after presentations were made on the DEIS.

During the public comment period, the public was encouraged to submit comments electronically through the NPS Public, Environment, and Public Comment (PEPC) website. Comments were also received, however, through the mail or using a public comment form provided at the public meetings. More than 3,000 individual comment documents were received on the DEIS. Substantive comments within these documents were used to make changes to the DEIS when deemed appropriate and justified. Responses to comments are provided in Appendix Q of the EIS.

In addition to the public meetings described above, meetings were held with Cooperating Agencies, Tribes, and AMWG stakeholders after the comment review period ended to discuss potential revisions to the EIS.

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7 LIST OF PREPARERS

This chapter presents information on the preparers of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). The list of preparers is organized by agency or organization, and information is provided on education, experience, and contribution to the LTEMP EIS.

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Rick Clayton	B.S., Civil Engineering; B.S., Environmental Economics; 14 years experience in reservoir operations; 3 years experience in powerplant operations. Upper Colorado Region General Engineer.	Reclamation lead for power resource analysis; hydrology and reservoir modeling
Todd Gaston	M.S. Resource Economics; B.S. Environmental Science; 7 years experience in natural resources management and economics. Technical Service Center, Economics and Resource Planning Team.	Technical analyst and subject matter expert, socioeconomics, recreational economics
Katrina Grantz	Ph.D., Civil Engineering; 14 years experience in water resources research, hydrology, and decision support systems; 8 years experience in reservoir operations. Upper Colorado Region/Hydraulic Engineer.	Co-lead EIS project manager. Lead author of Section 4.2 (water resources) and Appendix D, technical lead for reservoir operations and hydrology; reservoir modeling
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Name	Education/Experience	Contribution
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Name	Education/Experience	Contribution
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U.S. Geological Survey		
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8 GLOSSARY

A

Abiotic: Absence of living organisms, includes chemical and physical environments and processes.

Aboriginal: The first or earliest known of its kind present in a region.

Above mean sea level (AMSL): Elevation or altitude of any object relative to the average sea level.

Acre-foot: Volume of water, 43,560 cubic feet (ft^3) (1,233 cubic meters [m^3], 325,851 gallons), that would cover 1 acre to a depth of 1 foot.

Active capacity: Reservoir capacity normally available to store and regulate reservoir inflows to meet established reservoir operating requirements. For Lake Powell, this reservoir storage capacity is nearly 21 million acre-feet (maf).

Active conservation capacity: Reservoir capacity assigned to regulate reservoir inflow for irrigation, power generation, municipal and industrial use, fish and wildlife, navigation, recreation water quality, and other purposes. Also referred to as active storage. For Lake Powell, this is the reservoir storage above the penstock openings at an elevation of 3,490 feet (ft) (1,064 meters [m]).

Active storage: See *active conservation capacity*.

Adaptive management: Method or system for examining alternative strategies for meeting measurable goals and objectives and then, if necessary and in response to new information and/or changing circumstances, adjusting actions according to what is learned.

Adaptive Management Work Group (AMWG): Federal advisory committee to the Secretary of the Interior. Incorporates those stakeholders with interest in the operation of Glen Canyon Dam and downstream resources and continues public involvement in the decision-making process.

Advection: The typically horizontal movement of a mass of fluid, such as water.

Adverse impact: Abnormal, harmful, or undesirable effect that results from taking a particular action.

Aeolian processes: Erosion, transport, and deposition of sediment by the wind. Commonly occurs in areas with sparse or nonexistent vegetation, a supply of fine sediment, and strong winds.

Aerate: To supply or impregnate with gas, usually air.

Affected environment: Existing biological, physical, social, and economic conditions of an area subject to change, both directly and indirectly, as the result of a proposed human action. Also, the chapter in an environmental impact statement (EIS) describing current environmental conditions. A description of the affected environment must include information necessary to assess or understand impacts, must contain enough detail to support the impact analyses, and must highlight environmentally sensitive resources.

Aggradation: Process of filling and raising the level of a streambed, floodplain, or sandbar by deposition of sediment. The opposite of degradation.

Aggregation: A consistent and disjunct group of fish that has no significant exchange of individuals with other aggregations, as indicated by recapture of tagged juveniles and adults and movement of radio-tagged adults.

Air quality: Measure of the condition, including health-related and visual characteristics, of the air. Often derived from quantitative measurements of the concentrations of specific injurious or contaminating substances (i.e., air pollutants).

Air Quality Control Region (AQCR): An interstate or intrastate area designated by the U.S. Environmental Protection Agency for the attainment and maintenance of National Ambient Air Quality Standards.

Albedo (effects): The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo; the albedo of soils ranges from high to low; vegetation-covered surfaces and oceans have a low albedo. The Earth's albedo varies mainly through varying cloudiness, snow, ice, leaf area, and land-cover changes.

Algae: Simple plants containing chlorophyll; most live submerged in water.

Algal bloom: Rapid and flourishing growth of algae.

Allocation, allotment: Refers to a distribution of water through which specific persons or legal entities are assigned individual rights to consume pro-rata shares of a specific quantity of water under legal entitlements. For example, a specific quantity of Colorado River water is distributed for use within each Lower Division state through an apportionment. Water available for consumptive use in that state is further distributed among water users in that state through the allocation. An allocation does not establish an entitlement; the entitlement is normally established by a written contract with the U.S. government.

Alluvial: Formed by the action of running water, such as that related to river and stream deposits.

Alluvium: Sedimentary material (e.g., clay, silt, sand, gravel, or other particulates) transported and deposited by the action of flowing water.

Alternatives: Courses of action that may meet the specific goals and objectives of a proposed action, often by different means and at varying levels of accomplishment, including the most likely future conditions without the project (i.e., no action).

Ambient: Surrounding environment or natural conditions in a given place and time.

American Indian: The indigenous peoples in North America within the boundaries of the present-day continental United States, Alaska, and the island state of Hawaii.

American Indian Tribe: Any extant or historical clan, Tribe, band, nation, or other group or community of indigenous peoples in the United States.

American Indian Religious Freedom Act (P.L. 95-341) (AIRFA): Act requiring federal agencies to consult with Tribal officials to ensure protection of religious cultural rights and practices.

Amphibian: Cold-blooded, smooth-skinned vertebrate animal that has a life stage in water (e.g., hatches as an aquatic larva with gills) and a life stage on land (e.g., transforms into an adult with air-breathing lungs). Includes salamanders, frogs, and toads.

Amphipod: An order of crustacean that is found in almost all aquatic environments.

AMSL: See *above mean sea level*.

AMWG: See *Adaptive Management Work Group*.

Anaerobic bacteria: Bacteria that survive and grow in environments with little or no oxygen.

Ancillary services: Those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system. See *regulation* and *spinning reserves*.

Anions: Ions that carry a negative charge (e.g., chloride, nitrate, sulfate, and phosphate).

Anoxic: Areas of water that are depleted of dissolved oxygen.

Antecedent: Prior or preceding event, condition, or cause.

Anthropogenic: Created, caused, or produced by humans.

Apportionment: Refers to the distribution of Colorado River water available to each Lower Division state in normal, surplus, or shortage condition years, as set forth, respectively, in Articles II(B)(1), II(B)(2), and II(B)(3) of the 1964 Supreme Court Decree in the case of Arizona v. California.

Appropriation: Amount of water legally set apart or assigned to a particular purpose or use.

Aquatic: Living or growing in or on the water.

Aquatic biota: Collective term describing the organisms living in or depending on the aquatic environment.

Aquatic habitat: Bodies of water that provide food, cover, and other elements critical to the completion of an organism's life cycle (e.g., streams, rivers, and lakes).

Aquifer: Permeable water-bearing underground rock formation that readily yields usable amounts of water to a well or spring. The formation could be sand, gravel, limestone, and/or sandstone.

Archaeological and Historic Preservation Act (AHPA): Legislation that amended the Reservoir Salvage Act of 1960, requiring federal agencies to provide for the preservation of historical and archeological data that might otherwise be lost or destroyed as the result of any federally licensed activity or program causing an alteration of terrain.

Archaeological resource: Any material remains or physical evidence of past human life or activities that are of archeological interest, including the record of the effects of human activities on the environment. An archeological resource is capable of revealing scientific or humanistic information through archeological research.

Archaeological Resources Protection Act of 1979 (ARPA): Legislation establishing requirements to protect archaeological resources and sites on public lands and Indian lands and to foster increased cooperation and exchange of information between governmental authorities, the professional archaeological community, and private individuals.

Archaeological site: A place (or group of physical sites) in which evidence of past activity is preserved (either prehistoric, historic, or contemporary); that has been, or may be, investigated using the discipline of archaeology; and that represents a part of the archaeological record.

Archaic: In American archeology, a cultural stage following the earliest known human occupation in the Americas (about 5500 BC to AD 100). This stage was characterized by a hunting and gathering lifestyle and seasonal movement to take advantage of a variety of resources.

Archaeology: Study of human cultures through the recovery and analysis of their material remains.

Arid: A region that receives too little water to support agriculture without irrigation. Less than 10 in. of rainfall a year in a region is typically considered arid.

Arroyo: Gully or channel cut by an ephemeral stream.

Arthropod: Any of the invertebrate animals (such as insects, spiders, or crustaceans) having an exoskeleton, a segmented body, and jointed limbs.

Artifact: Object produced or shaped by human beings and of archaeological or historical interest.

Aspect: The direction in which a feature faces.

Assemblage: A collection or community of plants or animals characteristically associated with a particular environment, which can be used as an indicator of that environment.

Attainment Area: An area considered to have air quality as good as or better than the National Ambient Air Quality Standards for a given pollutant. An area may be in attainment for one pollutant and in nonattainment for others.

Attenuation: Gradual loss of strength or intensity.

Authorization: Act by the Congress of the United States that sanctions the use of public funds to carry out a prescribed action.

Automatic generation control (AGC): Computerized power system regulation to maintain scheduled generation within a prescribed area in response to changes in transmission system operational characteristics.

Available hydropower (AHP): The monthly capacity and energy that is actually available based on prevailing water release conditions.

Average peak annual discharge: Found by generating a list of the single highest value of discharge from each year and calculating the mean.

B

Backwater: A relatively small, generally shallow area of a river with little or no current. See *return-current channel*.

Bald and Golden Eagle Protection Act: Law passed in 1940 that prohibits anyone without a permit issued by the Secretary of the Interior from taking bald or golden eagles, including their parts, nests, or eggs.

Bank storage: Water absorbed and stored in the banks of a stream, lake, or reservoir, and returned in whole or in part as the level of the water body surface falls.

Base flow: Portion of stream or river discharge that is derived from a natural storage source (i.e., groundwater recharge).

Baseline: Information identified or found at the beginning of a study or experiment that serves as a basis against which subsequent findings are measured or compared.

Baseload: Minimum load in a power system over a given period of time.

Baseload plant: Energy plant or powerplant normally operated to produce the minimum amount of power required to meet some or all of a given region's continuous energy demands. Consequently, it operates essentially at a constant load.

Basin: Area of land that drains to a particular stream, river, pond, or lake.

Basin States: In accordance with the Colorado River Compact of 1922, the Colorado River Basin is comprised of those parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming within and from which waters drain naturally into the Colorado River. These seven states are referred to as the Basin States. See *Colorado River Compact of 1922*.

Bathymetric: Pertains to the study of the underwater depth of a lake, ocean, or reservoir floor.

Beach: Sandbar that generally is considered to have recreational value. See *sandbar*.

Bed elevation: Height of streambed above a specified level. Change in bed elevation in pools of the Colorado River commonly is used as a measure of change in the amount of sediment stored on the riverbed.

Bedload: Sediment moving on or near the streambed and frequently in contact with it.

Bed material: Unconsolidated material of which a streambed is composed.

Bedrock: Native consolidated, solid rock foundation underlying the surface. Above it is usually an area of loose, broken, and weathered unconsolidated deposits of soil, sand, clay, or gravel.

Benthic: Living in or occurring at the bottom of a body of water.

Biodiversity: Number and kinds of organisms per unit area or volume; the composition of species in a given area at a given time.

Biological Assessment: Document prepared for the Endangered Species Act of 1973 (ESA) Section 7 process to determine whether a proposed major construction activity under the authority of a federal action agency is likely to adversely affect listed species, proposed species, or designated critical habitat.

Biological control: The use of living organisms, such as predators, parasitoids, and pathogens, to control pest insects, weeds, or diseases. Typically involves some human activity.

Biological Opinion (BO): Document stating opinion of the U.S. Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) as to whether a federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of critical habitat.

Biological response: Reactions or changes in cells, tissues, organs, and/or entire organisms resulting from chemical, physical, or environmental agents and stressors.

Biomass: Total amount of combustible solid, liquid, or gas derived from biological processes (e.g., living organisms) in a particular area or environment.

Biota: Living organisms (e.g., plants and animals) in a given region.

Blue-ribbon fishery: Designation made by the U.S. government and other authorities to identify recreational fisheries of extremely high quality. The designation is typically based on water quality, quantity, and accessibility; natural reproduction capacity; angling pressure; and the specific species present.

Bryophytes: Group of non-vascular, seedless plants including mosses, liverworts, and hornworts.

Bypass tube: Conduits that are used to release water in addition to the releases made through the powerplant. See *jet tube*.

C

Campable area: Areas suitable for recreational camping.

Candidate species: Plant or animal species about which sufficient information on biological status and threats is known to propose them as endangered or threatened. Undergoing status review by the FWS, but not yet officially listed as threatened or endangered under the ESA.

Capacity: In power terminology, the load for which a generator, transmission line, or system is rated; expressed in kilowatts. In this document, also refers to powerplant generation capability under specific operating conditions and the amount of marketable resource under such conditions.

Carbon dioxide (CO_2): A colorless, odorless, nonpoisonous gas that is a normal part of the Earth's atmosphere. Carbon dioxide is a product of fossil fuel combustion, but is also exhaled by humans and animals and absorbed by green growing things and by the sea. It is the most prominent greenhouse gas that traps heat radiated into the atmosphere.

Carbon monoxide (CO): Colorless, odorless gas that is toxic if breathed in high concentrations over an extended period. Listed as a criteria air pollutant under Title I of the Clean Air Act (CAA).

Carnivore: Any flesh-eating or predatory organism.

Carrying capacity: Maximum density of wildlife or population of a specific species that a particular region can sustain without deterioration of the habitat or hindering future generations' ability to maintain the same population.

Catch and release: Practice within recreational fishing intended as a conservation measure in which captured fish are unhooked and returned to the water before experiencing serious exhaustion or injury.

Cations: Ions that carry a positive charge (e.g., sodium, magnesium, calcium, iron, and aluminum).

Cenozoic age: Era extending from about 65 million years ago to the present.

Census block group: Geographic entities consisting of groups of individual census blocks. Census blocks are grouped together so that they contain between 250 and 550 housing units.

Channel: Natural or artificial watercourse with a definite bed and banks to confine and conduct continuously or periodically flowing water.

Channel margin bar: Narrow sand deposits that continuously or discontinuously line the riverbank.

Chemocline: Boundary or gradient between water masses of different chemical composition (e.g., salinity).

Chironomid: Group of two-winged flying insects that live their larval stage underwater and emerge to fly about as adults.

Cladocera: An order of small crustaceans commonly called water fleas.

Cladophora: Filamentous green alga that is very important to the food chain in the Colorado River below Glen Canyon Dam.

Class I scenic resource: Classification of areas within Glen Canyon that have outstanding scenic quality such as intricately carved landscapes, unique canyons, and unique geological features.

Class II scenic resource: Classification of an area within Glen Canyon that has superior quality or a diversity of form and color.

Clay: Fine-grained soil, rock, or mineral fragment that has a diameter of less than 0.002 millimeters (mm). Clay is often made up of one or more minerals (e.g., hydrous aluminum phyllosilicates, sometimes with iron, magnesium, alkali metals, alkaline earths, and other cations) with traces of metal oxides and organic matter.

Clean Air Act (CAA): Comprehensive federal law that regulates air emissions. This act establishes national ambient air quality standards (NAAQS) that protect public health and the environment. Under this act, construction and operating permits, as well as reviews of new stationary emissions sources and major modifications to existing sources, are required. It further requires facilities to comply with emission limits or reduction limits stipulated in State Implementation Plans (SIPs) and prohibits the federal government from approving actions that do not conform to SIPs. Originally passed in 1963, the national air pollution control program is actually based on the 1970 version of the law. The 1990 CAA amendments, in large part, were intended to deal with previously unaddressed or under-addressed problems such as acid rain, ground level ozone, ozone depletion, and air toxics.

Clean Water Act (CWA): Establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. Under the CWA, the U.S. Environmental Protection Agency (EPA) has implemented several pollution control programs, such as setting wastewater standards for industry and requiring National Pollutant Discharge Elimination System (NPDES) permits for discharges of effluents to surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with amendments in 1972.

Climate change: Significant and lasting change in the statistical distribution of weather conditions and patterns over periods of years, ranging from decades to millions of years.

Clovis technological complex: A widespread, distinctive early Paleoindian culture defined by a distinct form of fluted stone projectile points named for Clovis, New Mexico, the city near which they were found. Clovis technology dates to around 13,500 years ago.

Cobble: Loose particles of rock or mineral (sediment) that range in size from 64 to 256 mm in diameter. Cobbles are larger than gravel, but smaller than boulders.

Code of Federal Regulations (CFR): Codification and compilation of the general and permanent rules published in the *Federal Register* by the departments and agencies of the United States Federal Government. It is divided into 50 subject matter titles that represent broad areas subject to federal regulation. Each title contains one or more individual volumes, which are updated once each calendar year, on a staggered basis.

Cohort: A group of fish that were generated in the same spawning season and are born at the same time.

Coldwater fish: Species of fish that require relatively cold water (50–60°F, or 10–15°C) to survive. Cold water can hold more dissolved oxygen than warm water, so these species generally inhabit deeper lakes and ponds in northern regions, spring-fed streams and lakes with a constant cold water supply, or lakes in high altitudes that are cold. Rainbow trout is an example of a coldwater species.

Colorado River Basin: All areas that drain to the Colorado River and its tributaries.

Colorado River Basin Project Act of 1968 (CRBPA): Act that authorized construction of a number of water development projects, including the Central Arizona Project (CAP), and required the Secretary of Interior to develop the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, or Long-Range Operating Criteria (LROC).

Colorado River Basin Salinity Control Act: Law enacted by Congress in 1974 that directed the Secretary of the Interior to proceed with a program to enhance and protect the quality of water available in the Colorado River for use in the United States and Republic of Mexico.

Colorado River Compact of 1922: Provides for the equitable division and apportionment of the use of the waters of the Colorado River System between the Upper Basin and Lower Basin states.

Colorado River Ecosystem: Community of aquatic, riparian, and terrestrial fauna and flora of the Colorado River mainstream corridor and its tributaries, along with that system's processes and environments. In general, the CRE encompasses the Colorado River primarily from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park and includes the area where the Glen Canyon Dam operations impact physical, biological, recreational, cultural, and other resources.

Colorado River Simulation System (CRSS): Operational model of the Colorado River Basin based on a monthly time step.

Colorado River Storage Project Act (CRSPA) of 1956: Authorized comprehensive development of the water resources of the Upper Basin states (Colorado, New Mexico, Utah, and Wyoming) by providing for long-term regulatory storage of water, including construction of Glen Canyon Dam, to meet the entitlements of the Lower Basin states (Arizona, California, and Nevada).

Commercial river trip: Trip organized by a boating company that conducts tours and recreational outings for paying passengers.

Community: All members of a specified group of species present in a specific area at a specific time; a group of people who see themselves as a unit.

Compact: Agreement between states apportioning the water of a river basin to each of the signatory states.

Compact point: Lee Ferry, Arizona, the reference point designated by the Colorado River Compact dividing the Colorado River into two sub-basins, the Upper Basin and the Lower Basin.

Concentration: Amount of a chemical in a particular volume or weight of air, water, soil, or other medium.

Concrete-arch dam: Dam design often used in a narrow, steep-sided rock canyon with curvatures in both horizontal and vertical directions. The safety of an arch dam is dependent on the strength of the side wall abutments and the strength and elasticity of the concrete used in its construction.

Conductivity: Measure of the ability of water to pass an electrical current. Conductivity is an indicator of the amount of dissolved salts in a stream, and is often used to estimate the amount of total dissolved solids (TDS) rather than measuring each dissolved constituent separately. Conductivity in water is also affected by temperature.

Confluence: Meeting point of two or more rivers.

Consolidated Decree: Entered by the United States Supreme Court on March 27, 2006, in the case of Arizona v. California, 547 U.S. 150 (2006). In 1963, the Supreme Court reached a Decision in the case of Arizona v. California. The 1964 Supreme Court Decree in the case of Arizona v. California implemented the 1963 Decision. This 1964 Supreme Court Decree was supplemented over time after its adoption and the Supreme Court entered a Consolidated Decree in 2006 incorporating all applicable provisions of the earlier-issued Decisions and Decrees.

Consumptive water use: Total amount of water used by vegetation, human activities, and natural cycling processes (e.g., evaporation, transpiration, incorporation) that is not available for other uses within the system.

Continental climate: A climate lacking marine influence and characterized by more extreme temperatures than marine climates; therefore, it has a relatively high annual temperature range for its latitude.

Continental Divide: Drainage divide that separates the Atlantic and Pacific watersheds of North America.

Contingent valuation: Survey method asking for the maximum values that users would pay for access to a particular activity.

Control area: Part of a power system, or a combination of systems, to which a common electrical generation control scheme is applied.

Convection: Motions in a fluid that result in the transport and mixing of the fluid's properties.

Cooperating Agency: With respect to the National Environmental Policy Act of 1969, as amended (NEPA), process, an agency that has jurisdiction by law or special expertise concerning an aspect of a proposed federal action, and that is requested by the lead agency to participate in the preparation of an Environmental Impact Statement.

Coordinated operation: Generally, the operation of two or more interconnected electrical systems to achieve greater reliability and economy. As applied to hydropower resources, the operation of a group of hydropower plants to obtain optimal power benefits with due consideration for all other uses.

Copepods: Small crustaceans that live in virtually all marine and freshwater habitats.

Cosmology: Set of beliefs regarding the origin and structure of the universe.

Council on Environmental Quality (CEQ): Established by NEPA, CEQ regulations (40 CFR Parts 1500–1508) describe the process for implementing NEPA, including preparation of Environmental Assessments and EISs, and the timing and extent of public participation.

Cover: Vegetation, rocks, or other materials used by wildlife for protection from predators or weather.

Creel census: Angler survey to collect data on the harvest, size, and distribution of various species of fish.

Criteria air pollutants: Six common air pollutants for which NAAQS have been established by the EPA under Title I of the CAA. Included are sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), and lead (Pb). Standards were developed for these pollutants on the basis of scientific knowledge about their health effects.

Critical habitat: Specific areas within the geographical area occupied by the species that have physical or biological features essential to the conservation of a listed endangered or threatened species and may require special management considerations or protection. These areas are legally designated via *Federal Register* notices.

Cross-sectional area: Area of a stream, channel, or waterway, usually measured perpendicular to the flow.

Crustacean: Aquatic animals with hard external skeletons and segmented limbs, belonging to the class Crustacea; includes cladocerans, shrimp, crayfish, fairy shrimp, isopods, amphipods, lobsters, and crabs.

Cubic foot per second (cfs): As a rate of streamflow, a cubic foot of water passing a reference section in 1 second. A measure of a moving volume of water (1 cfs = 0.0283 m^3/s).

Cultural modification: Any human-caused change in the land form, water form, or vegetation, or the addition of a structure that creates a visual contrast in the basic elements (e.g., form, line, color, or texture) of the naturalistic character of a landscape.

Cultural property: The tangible evidence or expression of cultural heritage such as works of art, buildings, or their ruins.

Cultural resource: Any sites, districts, buildings, structures, objects, or features significant in history, architecture, archeology, culture, or science. Also, Native American sacred sites or special use areas that provide evidence of the prehistory and history of a community.

Cumulative impact: Impact assessed in an EIS that results from the incremental impacts of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or nonfederal), private industry, or individual undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

Cyanobacteria: Blue-green algae, prokaryotic, photosynthetic organisms that generally have a blue-green tint and lack chloroplasts.

Cyprinids: Largest family of freshwater fish, commonly called the carp family or minnow family.

D

Daily fluctuation: Difference between daily maximum and minimum releases from the dam. These scheduled fluctuations are used to maximize efficiency of power generation.

Dead capacity: Reservoir capacity from which stored water cannot be evacuated by gravity. At Glen Canyon Dam, this is the Lake Powell storage below the river outlet works openings at an elevation of 3,374 ft (1,028 m).

Debris fan: Sloping mass of water and debris, including boulders, cobbles, gravel, sand, silt, clay, and organic material (e.g., tree limbs), formed by debris flows at the mouth of a tributary.

Debris flow: Mixture of rocks, sediment, and organic material containing less than 40% water by volume that flows downslope under the force of gravity (e.g., flash flood).

Defoliation: Process by which a plant, shrub, or tree loses its leaves. Possible causes include insect activity, disease, chemicals, or the coming of autumn.

Degradation: Process wherein elevation of streambeds, floodplains, and sandbars is lowered by erosion. The opposite of aggradation.

Delivery: The amount of water delivered to the point of use.

Delta: Flat alluvial area formed at the mouth of some rivers and streams (e.g., Colorado River) where the mainstream flows into a body of standing water, such as a sea or lake (e.g., Lake Powell or Lake Mead), and deposits large quantities of sediment.

Depletion: Loss of water from a stream, river, or basin resulting from consumptive use.

Deposition: Settlement of material out of the water column and on to the streambed or flooded areas. Occurs when the energy of flowing water is unable to support the load of suspended sediment.

Desiccation: Process of drying out.

Desired future condition (DFC): Measurable target or value, established for any resource area that is of interest to managers; provides a reference point for evaluating treatment effectiveness and the need to implement additional treatments or management actions.

Detritivore: An organism that feeds on dead and decomposing matter.

Detritus: Loose natural materials, such as rock fragments or organic particles, that result directly from disintegration of rocks or organisms.

Diatom: Microscopic, single-celled, or colonial algae having cell walls of silica.

Diel fluctuations: Changes or fluctuations that occur in a 24-hour period that usually includes a day and the adjoining night.

Diptera: Order of insects that includes all true flies.

Direct effect (impact): Effect on the environment caused by an action; occurs at the same time and place as the initial action.

Direct impact: See *direct effect*.

Discharge (flow): Volume of water that is released from the dam at any given time or that passes a given point within a given period of time. Usually expressed in cubic feet per second (cfs).

Dispatch: The operating control of an integrated electric system whose job it is to (1) assign generation to specific generating plants and other sources of electric supply to effect the most reliable and economical supply as the total of the significant area loads rises or falls; (2) control operations and maintenance of high-voltage lines, substations, and equipment, including administration of safety procedures; (3) operate the interconnection; and (4) schedule energy transactions with other interconnected electric utilities.

Dissolved oxygen (DO): Amount of free oxygen found in water expressed as a concentration, milligrams per liter (mg/L), or as percent saturation (the amount of oxygen the water holds compared to the maximum amount it could absorb at that temperature). Low DO levels adversely affect fish and other aquatic life. The ideal dissolved oxygen for fish life is between 7 and 9 mg/L; most fish cannot survive when DO falls below 3 mg/L.

Dissolved solids: See *total dissolved solids (TDS)*.

Divert: To direct a flow away from its natural course.

Downstream: Situated or moving in the direction of a stream or river's current.

Drainage: Process of removing surface or subsurface water from a soil or area.

Drawdown: Lowering of a reservoir's water level; process of depleting reservoir or groundwater storage.

Drift: Food organisms dislodged and moved by river current. Can include algae, plankton, invertebrates, and larval fish.

Driftwood: Remains of trees that have been washed onto a shoreline by the action of winds, tides, or waves.

Drought: Period of unusually persistent dry weather that persists long enough to cause serious problems such as crop damage and/or water supply shortages.

Dune: Wind-deposited sand body, usually a rounded hill, ridge, or mound.

E

Ecological resource: Animals, plants, and the habitats in which they live, which may be land, air, or water.

Ecological restoration: Process of assisting in the recovery of an ecosystem that has been degraded, damaged, or destroyed.

Ecology: The relationship between living organisms and their environments.

Ecoregion: A geographically distinct area of land that is characterized by a distinctive climate, ecological features, and plant and animal communities.

Ecosystem: Complex system composed of a community of fauna and flora and that system's chemical and physical processes and environment.

Ecosystem management: Approach to natural resource management that seeks an understanding of the interrelationships among important physical, chemical, biological, cultural, political, and social processes in order to conserve resources and sustain ecosystems to meet both ecological and human needs of current and future generations.

Ectoparasitic: Living on the exterior of another organism, the host, obtaining nourishment from the latter.

Eddy: Current of water moving against the main current in a circular pattern. See *recirculation zone*.

Effect: Environmental consequences (the scientific and analytical basis for comparison of alternatives) that occur as a result of a proposed action. See *direct effect* and *indirect effect*.

Efficiency: Ratio of useful energy output to total energy input, usually expressed as a percentage.

Electric power system: Physically connected electric power generating, transmission, and distribution facilities operated as a unit under one control.

Electrical demand: Energy requirement placed upon a utility's generation at a given instant or averaged over any designated period of time.

Electrofishing: Application of a direct electric current to attract and temporarily immobilize fish for easy capture. See *mechanical removal*.

Embayment: a recess or an indentation in a shore line that forms an area with low flow.

Emergent marsh plants: Plants that are rooted in soil with basal portions that typically grow beneath the surface of the water but whose leaves, stems, and reproductive organs are above the water.

Emissions: Substances that are discharged into the air from industrial processes, vehicles, and living organisms.

Empirical: Based on experimental data rather than theory.

Encroachment: Act of advancing, intruding, or extending beyond established, usual, or proper limits.

Endangered species: Species or subspecies (plant or animal) whose survival is at risk of extinction throughout all or a significant portion of its range because it is either few in numbers or threatened by changing environmental or predation parameters. Requirements for declaring a species endangered are found in the ESA.

Endangered Species Act of 1973 (ESA): Provides a federal program for the conservation of threatened and endangered plants and animals and the habitats in which they are found. Requires consultation with the FWS and/or the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service to determine whether endangered or threatened species or their habitats will be affected by a proposed activity and what, if any, mitigation measures are needed to address the impacts.

Endemic: Native to and restricted to a particular geographic region.

Energy: Electric capacity generated and/or delivered over time; usually measured in kilowatt-hours.

Environmental Assessment (EA): Concise public document that a federal agency prepares under NEPA to provide sufficient evidence and analysis to determine whether a proposed action, or its alternatives, may have significant environmental effects on the human environment. In general, an EA must include brief discussions on the need for the proposal, the alternatives, the environmental impacts of the proposed action and alternatives, and a list of agencies and persons consulted. If significant effects may occur, an EIS is prepared instead of an EA.

Environmental Impact Statement (EIS): Detailed document required of federal agencies under NEPA for major proposals or legislation that will or could significantly affect the environment. An EIS is prepared with public participation and must disclose significant issues and impacts on the human environment that may result from the proposed action or its alternatives. An EIS includes the following: the environmental impact of the proposed action; any adverse impacts that cannot be avoided by the proposed action; alternative courses of action; relationships between local short-term use of the human environment and the maintenance and enhancement of long-term productivity; and a description of the irreversible and irretrievable commitment of resources that would occur if the action were accomplished.

Environmental justice: Fair treatment of people of all races, cultures, incomes, and educational levels with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Ephemeral stream: Stream that flows briefly only in direct response to precipitation and whose channel is, at all times, above the water table.

Epilimnion: Top layer of a thermally stratified lake or reservoir that exhibits essentially uniform warmer temperature. See *stratification*.

Epiphyte: A plant that derives its moisture and nutrients from the air and rain and grows on another plant for support.

Equalization flow: Dam releases made to balance water storage between Lake Powell and Lake Mead. Pursuant to the Interim Guidelines, these flow events are carried out if (1) the end of the water year storage forecast for Lake Powell is greater than that of Lake Mead; and (2) the storage forecast for the end of the water year in the Upper Basin reservoirs is greater than the quantity of storage required by Section 602(a) of the CRBPA (602[a] storage) for that same date.

Equalization tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is above the elevation in the equalization table of the Interim Guidelines. The tier provides for Lake Powell releases of more than 8.23 maf during the water year until the content of the lakes equalizes or certain elevations are attained.

Erosion: Gradual destruction or wearing away of a material (e.g., rock or sand) or object (e.g., beach) by water, wind, or other natural agents.

Ethnobotany (ethnobotanical): The plant lore and agricultural customs of a people; the study of such lore and customs.

Ethnohistory: The use of both historical and ethnographic data such as maps, music, paintings, photography, folklore, and oral tradition to understand a culture on its own terms and according to its own cultural code.

Euphotic zone: The superficial layer of a water body within the range of effective light penetration for photosynthesis.

Eutrophication: Enrichment of a body of water as a result of high concentrations of minerals and organic nutrients (especially nitrogen and phosphorus) that stimulate and promote the proliferation of aquatic plant life, thus reducing the dissolved oxygen content of the water.

Evaporation: Water vapor losses to the atmosphere from land areas, bodies of water, and all other moist surfaces.

Evapotranspiration: Sum of water transpired or used by plants and evaporated from surfaces (e.g., water bodies and soils) in a specific time period; usually expressed in depth of water per unit area.

Exceedance: Measured level of an air pollutant that is higher than the national or state ambient air quality standards. Also applies to water volume, flow, or energy generation that is above a particular percentage (exceedance level).

Excess capacity: Power generation capacity available on a short-term basis in excess of the firm capacity available through long-term contracts.

Executive Order (EO): President's or governor's directive or declaration that implements or interprets a federal statute, a constitutional provision, or a treaty. It has the force of law and is usually based on existing statutory powers; requires no action by Congress or a state legislature.

Existence value: Value people place on simply knowing an area or feature continues to exist in a particular condition.

Exotic species: Nonnative plant or animal deliberately or accidentally introduced into a new habitat where it is able to reproduce and survive.

Experimental flow: Investigational releases (e.g., high-flow experiments) that are designed to explore, test, and assess the relationships between dam operations and downstream resources in and along the Colorado River within the Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA).

Experimental population: Specific reintroduced populations of listed species under the ESA. The FWS determines whether an experimental population is "essential" or "nonessential" to the continued existence of the species.

Exposure: Contact of an organism with a chemical, radiological, or physical agent.

Extinct species: Species having no living members, such that it is no longer in existence.

Extirpated species: Species that no longer exists in a given region or area.

Extirpation: Elimination of a species or subspecies from a particular area, but not from its entire range.

F

Fan-eddy complex: An assemblage of geomorphic features created by a debris fan that projects into a stream or river and creates an area of recirculation (eddy) just downstream of the debris fan.

Fauna: Animals in a specific region or habitat, considered as a group.

Feature: Large, complex artifact, or part of a site, such as a hearth, cairn, housepit, rock alignment, or activity area.

Fecal coliform bacteria: Group of organisms common to the intestinal tracts of humans and animals. The presence of fecal coliform bacteria in water is an indicator of pollution and of potentially dangerous bacterial contamination.

Fecundity: Number of produced eggs or offspring; reproductive capability.

Federal Register: Official daily publication for rules, proposed rules, and notices of federal agencies and organizations, as well as executive orders and other presidential documents; published by the Office of the Federal Register, National Archives and Records Administration (NARA).

Filamentous algae: Plant that forms a greenish mat on the water surface.

Finding of No Significant Impact (FONSI): NEPA document issued by a federal agency briefly presenting the reasons why an action, not otherwise excluded, will not have a significant effect on the human environment if implemented. This finding is based on the results of an EA and other factors in the public planning record for a proposed action.

Fine sediment: Soil particles, typically defined as less than 1–2 mm in diameter (e.g., clay and silt), that are naturally filtered from coarser fractions and carried by water.

Firm energy or power: Uninterruptible energy and power guaranteed by the supplier to be available at all times except for reasons of uncontrollable forces or continuity of service provisions.

Fishery: Specified waters or area where fish or other aquatic animals are reared and caught.

Flash flood: Sudden high-flow event through a valley, canyon, or wash, following a short-duration, high-intensity rainfall.

Flatwater boating: Form of low-speed boating (e.g., canoeing or kayaking) that relies on flat waters (e.g., lakes, gorges, or slow-moving rivers), as opposed to rapids or white water.

Flood: Relatively high flow or inundation of water, as measured by either gage height or discharge quantity, that overtops the natural or artificial banks in any reach of a river and threatens or causes damage.

Flood Control Act of 1944: Act authorizing the construction of certain public works on rivers and harbors for flood control and other purposes.

Flood control capacity: Reservoir capacity assigned for the sole purpose of regulating flood inflows to reduce flood damage downstream.

Flood control pool: Reservoir volume above the active conservation and joint-use pool that is reserved for flood runoff and then evacuated as soon as possible to keep that space in readiness for the next flood. See *reservoir capacity*.

Flood flows: In this report, water releases from Glen Canyon Dam in excess of powerplant capacity (i.e., 31,500 cfs).

Floodplain: Mostly level, low-lying land adjacent to a water body that is subjected to inundation and submersion during high flow or rainfall events. The relative elevations of floodplain areas determine their frequency of flooding, which ranges from rare, severe, storm events to flows experienced several times a year.

Flora: Community of plants in a specific region or habitat, considered as a group.

Flow: Volume of water passing a given point per unit of time. See *instream flow requirements*, *minimum flow*, *peak flow*, *ponding flow*, *spike flow*, and *steady flow*.

Flow regime: Flow variation through time resulting from operations of the Glen Canyon Dam.

Fluctuating flows: Water released from Glen Canyon Dam that varies in volume, usually within a given range (e.g., 1,000 to 31,500 cfs), over a 24-hour period.

Fluctuation zone: Area of a sandbar or vegetation zone that is within the range of fluctuating flow.

Fluvial: Pertaining to a river or stream; indicates the presence or interaction of a river within an area or landform.

Fluvial geomorphology: Study and examination of stream and river channels, both in their natural setting and their response to human-induced changes in a watershed. Includes the processes that operate in river systems and the landforms they create or have created.

Folsom technological complex: A widespread, distinctive early Paleoindian culture defined by a distinct form of fluted stone projectile points named for Folsom, New Mexico, the city near which they were found. Folsom technology dates to between 11,500 and 10,000 years ago.

FONSI: See *Finding of No Significant Impact*.

Food chain: Succession of organisms in a community in which food energy is transferred from one organism to another as each consumes a lower member and in turn is consumed by a higher member.

Food web: Complex system or network of interrelated and interdependent food chains that describes how food energy is passed throughout an ecological community.

Food base: Substances or materials that provide living things with the nutrients they need to provide energy, grow, and sustain overall life.

Forage fish: Generally, small fish that produce prolifically and are consumed by predators.

Forced outage: Nonscheduled shutting down of a generating unit or other facility for emergency or other unforeseen reasons.

Forebay: Impoundment immediately above a dam or hydroelectric powerplant intake structure.

Fossil fuel: An energy source formed in the Earth's crust from decayed organic material. Common fossil fuels are petroleum, coal, and natural gas.

Fragmentation: Process by which habitats are increasingly subdivided into smaller units, resulting in their increased insularity as well as losses of total habitat area.

Fry: Life stage of fish between the egg and fingerling stages.

Fugitive dust: The dust released from any source other than a definable point source such as a stack, chimney, or vent. Sources include construction activities, storage piles, and roadways.

Full pool: Volume of water in a reservoir at maximum design elevation. At Lake Powell this is at an elevation of 3,700 ft (1,130 m). Total volume is 27 maf; this volume is decreasing as the lake fills with sediment.

G

Gage: Device or instrument used for measuring or testing.

Gated spillway: Overflow section of dam restricted by use of gates that can be operated to control releases from the reservoir to ensure the safety of the dam.

Gaging station: Specific location on a river or stream where systematic observations and measurements of hydrologic data are obtained through mechanical or electrical means.

Generation (power): Process of producing electrical energy by transforming other forms of energy. Also, the amount of electric energy produced.

Generator: Machine that converts mechanical energy into electrical energy.

Geology: Science that deals with the study of the materials, processes, environments, and history of the Earth, including rocks and their formation and structure.

Geomorphology: Geological study of the configuration and evolution of landforms and earth features.

Gigawatt-hour (GWh): One billion watt-hours of electrical energy.

Glen Canyon Dam: Second highest concrete arch dam in the United States. Constructed to harness the power of the Colorado River to provide for the water and power needs for people in the western United States.

Glen Canyon Dam Adaptive Management Program (GCDAMP): Provides an organization and process for cooperative integration of dam operations, downstream resource protection and management, and monitoring and research information, as well as to improve the values for which the GCNP and GCNRA were established.

Glen Canyon Environmental Studies (GCES): Program started by the Bureau of Reclamation in 1982 to collect scientific evidence on the positive and negative impacts on downstream environmental and cultural resources as a result of daily fluctuating releases from the dam.

Glen Canyon National Recreation Area (GCNRA): Area that encompasses hundreds of square miles from Lees Ferry in Arizona to the Orange Cliffs of southern Utah for water-based and backcountry recreation.

Global warming: Increase in the near-surface temperature of the Earth. Global warming has occurred in the distant past as the result of natural influences, but the term is today most often used to refer to the warming that many scientists predict will occur as a result of increased anthropogenic emissions of greenhouse gases.

Gradient: See *slope*.

Grand Canyon Monitoring and Research Center (GCMRC): Science provider for the GCDAMP. Operated by the U.S. Geological Survey, the GCMRC provides relevant scientific information about the status and trends of natural, cultural, and recreational resources found in those portions of the GCNP and GCNRA affected by Glen Canyon Dam operations.

Grand Canyon National Park (GCNP): A National Park since 1919, the area contains unique combinations of erosional forms. It is 277 river miles long and up to 18 miles wide. The area encompasses 1,218,375 acres and lies on the Colorado Plateau in northwestern Arizona, with land that is semiarid and consists of raised plateaus and structural basins.

Grand Canyon National Park Enlargement Act: An act of Congress enacted in 1975 to further protect the Grand Canyon by enlarging the park in the state of Arizona.

Grand Canyon Protection Act of 1992 (GCPA): Directs the operation of Glen Canyon Dam in compliance with existing law to protect, mitigate adverse impacts on, and improve the values for which the GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use.

Green algae: Members of the plant phylum Chlorophyta, which possess the green pigment chlorophyll that they use to capture light energy to fuel the manufacture of sugars. This diverse group of algae consists primarily of freshwater eukaryotic organisms, which serve as food and oxygen sources for other aquatic organisms.

Greenhouse effect: Increasing mean global surface temperature of the Earth caused by gases in the atmosphere (including carbon dioxide, methane, nitrous oxide, ozone, and chlorofluorocarbon). The greenhouse effect allows solar radiation to penetrate, but also absorbs infrared radiation returning to space.

Greenhouse gases (GHGs): Heat-trapping gases in the atmosphere that contribute to global warming and temperature gain near the Earth's surface. Natural and human-made GHGs include water vapor, carbon dioxide, methane, nitrogen oxides, ozone, and fluorinated gases (e.g., chlorofluorocarbons).

Gross generation: Total amount of electrical energy produced by a generating station or stations, measured at generator terminals.

Groundwater: Supply of water found beneath the Earth's surface, usually in porous rock formations (i.e., aquifers), which may supply wells and springs.

Gully: Landform that erodes sharply into soil, typically on a hillside; caused by running water. Gullies are similar to ditches or small valleys, but they are typically only 3 to 30 ft (0.9 to 9 m) wide and deep.

H

Habitat: Area or place, including physical and biotic conditions, where a plant or animal lives.

Hanging garden: Unique biological feature formed when spring water flows through cracks in the sandstone and seeps out through the canyon walls, allowing plants to grow vertically.

Harvest: In a recreational fishery, refers to numbers of fish that are caught and kept.

Head: Height of water above a specified point.

Headwater: Source and upper part of a stream or lake inflow.

Heavy metal: Metallic elements with high atomic weights (e.g., lead, mercury, cadmium, chromium, and arsenic) that are generally toxic in relatively low concentrations to plant and animal life.

Herbaceous: The plant strata that contain soft, not woody, stemmed plants that die to the ground in winter.

Herbivore: Animal that feeds on plants.

Herpetofauna: General grouping for reptiles and amphibians.

High flow: Pulses or temporary influxes of water that typically occur after periods of precipitation and are contained within the natural banks of the river (i.e., do not cause flooding). In a river, these events can lead to a temporary reduction in downstream temperature and increases in salinity, dissolved oxygen, and turbidity. High flows suspend and deliver large amounts of sediment and organic matter downstream, which can redeposit on sandbars and beaches. They can also restore and enhance riparian vegetation and can prevent undesirable vegetation from invading river channels. In addition, high-flow events can work to reshape and maintain native fish habitats, stimulate food base production, and suppress numbers of nonnative fish.

High-flow experiment (HFE): High-volume test releases (31,500 to 45,000 cfs) from the Glen Canyon Dam that are performed under sediment-enriched conditions. HFEs are specifically designed to benefit downstream resources; this includes maintaining and rebuilding sandbars and beaches in downstream reaches. Also referred to as a high-flow test.

High-flow test: See *high-flow experiment*.

Historic: The time period after the appearance of written records. In the New World, this generally refers to the time period after the beginning of European settlement at approximately 1600 AD.

Historic property: Any prehistoric or historic district, site, building, structure, or object included in, or eligible for inclusion in, the *National Register of Historic Places* maintained by the Secretary of the Interior. They include artifacts, records, and remains that are related to and located within such properties.

Historic resource: In the United States, material remains and the landscape alterations that have occurred since the arrival of Europeans.

Human environment: Natural and physical environment and the relationship of people with that environment including all combinations of physical, biological, cultural, social, and economic factors in a given area.

Hydraulic: Powered by water.

Hydroelectric plant: Electric powerplant using falling water as its motive force.

Hydroelectric power: Electricity produced by water.

Hydrogen sulfide (H_2S): A colorless, flammable, and extremely hazardous gas that occurs naturally in crude petroleum, natural gas, and hot springs.

Hydrograph: Graph showing, for a given point in a stream, the discharge, stage, velocity, or other property of water with respect to time.

Hydrologic budget: An accounting of the inflow to, outflow from, and storage change in a hydrologic unit such as an aquifer or drainage basin.

Hydrologic cycle: Continuous circulation of water in all of its phases (gas, liquid, solid) from the atmosphere to Earth by precipitation, and from Earth to the atmosphere by evaporation and transpiration. The land phase includes infiltration, runoff, and exchange between surface water and groundwater.

Hydrology: Science dealing with the occurrence, properties, distribution, circulation, and transport of water, including groundwater, surface water, rain, and snow.

Hydropower: See *hydroelectric power*.

Hypolimnetic: Pertaining to the lower, colder portion of a lake or reservoir, which is separated from the upper, warmer portion (epilimnion) by the thermocline.

Hypolimnion: Non-circulating bottom layer of a thermally stratified lake or reservoir that exhibits essentially uniform colder temperature and low dissolved oxygen.

Hypoxia: depressed levels of dissolved oxygen in water, usually resulting in decreased metabolism.

I

Igneous rock: A crystalline rock formed by the cooling and solidification of molten or partly molten material (magma). Igneous rock includes volcanic rock (rock solidified above the Earth's surface) and plutonic rock (rock solidified at considerable depth).

Impact: Effect, influence, alteration, or imprint caused by an action. See *adverse impact*, *cumulative impact*, *direct impact*, and *indirect impact*.

Impoundment: Body of water created by a dam, dike, floodgate, or other barrier.

Inactive capacity: Reservoir capacity that can be released from the dam but is normally not available (i.e., for power generation) because of operating agreements or physical restrictions. At Glen Canyon Dam, this is the reservoir storage above the river outlet works openings at elevation 3,374 ft (1,038 m) and below the penstock openings at elevation 3,490 ft (1,064 m), which is about 3.9 maf.

Indian trust assets: Lands, natural resources, or other assets held in trust or restricted against alienation by the United States for Native American Tribes or individual Native Americans.

Indian trust resource: Those natural resources, either on or off Indian lands, retained by or reserved by or for Indian Tribes through treaties, statutes, judicial decisions, and Executive Orders, which are protected by a fiduciary obligation on the part of the United States.

Indigenous: Native to an area.

Indirect effect (impact): Effect that occurs away from the place of action with effects that are related to, but removed from, a proposed action by an intermediate step or process. An example would be changes in surface-water quality resulting from soil erosion at construction sites.

Indirect impact: See *indirect effect*.

Inflow: Amount or rate of water flowing into a body of water. In this report, the water flowing into Lake Powell from the Colorado River and/or its tributaries; or water entering the Colorado River from tributaries between Glen Canyon Dam and Lake Mead; or water flowing into Lake Mead, mainly from the Colorado River.

Infrastructure: Basic facilities, utilities, services, and transportation framework needed to meet public and administrative needs for the functioning of an organization, system, or community.

In-situ: In its natural position or place; unmoved, unexcavated, remaining at the site or subsurface.

Insolation: Solar energy that is received on a given surface area during a given time.

Instream flow requirements: Amount of water flowing through a stream course needed to sustain instream values.

Intake: Structure in a dam, reservoir, or river through which water can be drawn into an outlet pipe or waterway.

Interconnected systems: System consisting of two or more individual power systems normally operating with connecting tie lines.

Interflow: Lateral movement of water in the upper layer of soil.

Interim shortage criteria/interim guidelines: Operational guidelines and coordinated reservoir management strategies (established in 2007) to address operations of Lake Powell and Lake Mead, particularly under drought and other low reservoir conditions. These criteria also provide a greater degree of certainty to U.S. Colorado River water users and managers of the Colorado River Basin by detailing information on when, and by how much, water deliveries will be reduced under specified reservoir conditions.

Intermittent stream: Stream that flows only at certain times of the year when the ground-water table is high; occasionally is dry or reduced to a pool stage when losses from evaporation or seepage exceed the amount of inflow.

Inundate: To cover with impounded waters or floodwaters.

Invasive species: Nonnative plant or animal, including noxious and exotic species, that is an aggressive colonizer and can out-compete other species. Their introduction causes or is likely to cause economic or environmental harm or harm to human health.

Invertebrate: Animal without a spinal cord, usually replaced by a hard exoskeleton or shell. Examples include insects, spiders, crayfish, snails, or clams.

Ion: Atom or molecule that carries either a positive or negative electrical charge.

Irretrievable commitments of resources: Those resources that are lost or lose value for a period of time and cannot be restored as a result of an action, such as temporary loss of power productivity due to of modified operations.

Irreversible commitments of resources: Those resources that cannot be regained, restored, or returned to their original condition within a reasonable time frame, such as the extinction of a species.

Irrigation district: A cooperative, self-governing public corporation set up as a subdivision of the state government, with definite geographic boundaries; organized and having taxing power to obtain and distribute water for irrigation of lands within the district; created under the authority of a state legislature with the consent of a designated fraction of the landowners or citizens.

J

Jeopardy opinion: FWS or NMFS opinion that an action is likely to jeopardize the continued existence of a listed species or result in the destruction or adverse modification of critical habitat.

Jet tube: A Glen Canyon Dam outlet that releases water below the level of penstocks. Four jet tubes with a combined release capacity of 15,000 cfs are not equipped with generation capability, but allow for a total release of about 45,000 cfs when used in combination with maximum releases from each of the eight penstocks.

Juvenile: Young organism older than 1 year but not having reached reproductive age.

K

Kaibab formation: The rock that makes the canyon rims and is the youngest of the Grand Canyon's geologic layers.

Kilovolt (kV): 1,000 volts (V).

Kilowatt (kW): Unit of electric power capacity equal to 1,000 watts (W), or about 1.34 horsepower (HP).

Kilowatt-hour (kWh): Basic unit of electric energy equaling an average of 1 kW of power applied over 1 hour.

L

Lake Mead National Recreation Area (LMNRA): American's first national recreation area; encompasses Lake Mead and Lake Mohave.

Lake Powell: Reservoir created by the completion of the Glen Canyon Dam on the Colorado River in 1963.

Landform: Any feature of the Earth's surface having a distinct shape and origin. Landforms include major features (such as continents, ocean basins, plains, plateaus, and mountain ranges) and minor features (such as hills, valleys, slopes, drumlins, and dunes).

Landmark (historic): Significant historic places designated by the Secretary of the Interior because they possess exceptional value or quality in illustrating or interpreting the heritage of the United States.

Landmark (visual): Type of reference point external to the observer. Usually a simply defined physical object that can be seen from many angles and distances over the tops of smaller elements and used as a radial reference.

Landscape: Traits, patterns, and structure of a specific geographic area including its biological composition, its physical environment, and its anthropogenic or social patterns.

Larva, larvae (pl.): The immature stage between the egg and pupa of insects having complete metamorphosis where the immature differs radically from the adult (e.g., caterpillars, grubs).

Larval fish: First life stage of fish after hatching. Larvae are not able to feed themselves, and carry a yolk-sac that provides their nutrition.

Latitude: Angular distance north or south of the equator, measured in degrees.

Law of the River: As applied to the Colorado River, the collective set of documents that apportions the Colorado River waters and regulates the use and management of the Colorado River among the seven Basin States and Mexico. It is comprised of numerous operating criteria, regulations, and administrative decisions included in federal and state statutes, interstate compacts, court decisions and decrees, an international treaty, and contracts with the Secretary of the Interior.

Lead (Pb): A gray-white metal that is listed as a criteria air pollutant. Health effects from exposure to lead include brain and kidney damage and learning disabilities. Sources include leaded gasoline and metal refineries.

Lead agency (or agencies): Federal agency (or agencies) either preparing or taking primary responsibility for preparing the NEPA compliance documents.

Lee Ferry: Reference point marking division between the Upper and Lower Colorado River basins. The point is located in the mainstream of the Colorado River 1 mi below the mouth of the Paria River in Arizona.

Lees Ferry: The historic location of Colorado River ferry crossings (1873 to 1928) and the current site of the U.S. Geological Survey stream gage above the Paria River confluence.

Limnology: Scientific study of the physical, chemical, meteorological, and biological aspects of freshwater bodies.

Listed species: Species, subspecies, or distinct population segments that have been added to the federal list of endangered and threatened wildlife and plants and receive legal protection under the ESA.

Load: Amount of electrical power or energy delivered or required at a given point.

Load-following: A pattern of hydropower generation that reacts instantaneously to change in demand for power.

Loam: Soil consisting of an easily crumbled mixture of clay, silt, and sand.

Low flow: Flow releases from the dam at a rate of 8,000 cfs or less.

Lower Basin: Those parts of the states of Arizona, California, Nevada, New Mexico, and Utah, within and from which waters drain naturally into the Colorado River below Lee Ferry, Arizona; defined by the Colorado River Compact of 1922.

Lower Colorado River Multi-Species Conservation Plan (MSCP): 50-year multi-stakeholder federal and non-federal partnership set up to protect the lower Colorado River environment while ensuring the certainty of existing river water rights and power operations; address the needs of threatened and endangered native species and their habitats in compliance with state and federal endangered species laws; and reduce the likelihood of listing additional species along the lower Colorado River.

Lower Division: Division of the Colorado River system that includes the states of Arizona, Nevada, and California; area defined by Article II of the Colorado River Compact of 1922.

Lower-elevation balancing tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is below 3,525 ft (1,074 m) AMSL. The tier provides for attempting to balance the contents of Lake Mead and Lake Powell, if possible, within the constraint that the release from Lake Powell would be not more than 9.5 maf and no less than 7.0 maf.

M

Macroinvertebrate: Animal without vertebrae, usually with a hard exoskeleton or shell, of a size large enough to be seen by the unaided eye.

Macrophyte (aquatic): Aquatic plant that is large enough to be observed with the naked eye. Grows in or near water.

Main channel: Deepest or central part of the bed of a stream or river, containing the main current.

Mainstem: Main course of a stream or river.

Mainstream: Principal or largest stream or river of a given area or drainage basin; in this document, the Colorado River.

Major federal action: Proposed federal undertaking entirely or partly financed, assisted, conducted, regulated, or approved by federal agencies that has the potential for significant impacts on the human environment and is thus subject to federal control and responsibility.

Mammal: Air-breathing animal whose skin is more or less covered with hair or fur and has mammary glands. Young are born alive (except for the platypus and echidna) and are nourished with milk. Mammals include humans, dogs, cats, deer, mice, squirrels, raccoons, bats, opossums, whales, seals, and others.

Management action: Decision-making response carried out to achieve a specific purpose.

Meander: Bends and loops in a river channel as the river snakes through a flat land area.

Mechanical removal (fish): Use of electrofishing, nets, and other gear types to physically remove fish from an ecosystem. See *electrofishing*.

Median: Middle value in a distribution, above and below which lie an equal number of values.

Megawatt (MW): One million watts of electrical power.

Megawatt-hour (MWh): One million watt-hours of electrical energy.

Memorandum of Understanding (MOU): Document structuring the collaboration among federal agencies and other stakeholders (e.g., Tribes, local governments) and describing an intended common line of action.

Mesa: A broad, flat-topped elevation with one or more steeply sloping to vertical sides.

Mesozoic age: An era of geologic time between the Paleozoic and the Cenozoic eras, spanning the time between 251 and 65 million years ago. The word Mesozoic is from Greek and means "middle life."

Metalimnion: Middle layer of a thermally stratified lake or reservoir where there exists a rapid decrease in temperature with depth. Also called thermocline.

Meteorology: Study of the Earth's atmosphere, particularly its patterns of climate and weather.

Metric ton: Unit of mass equal to 1,000 kilograms.

Microclimate: The climate of a small area, particularly that of the living space of a certain species, group, or community.

Mid-elevation tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is below 3,575 ft (1,090 m) AMSL and at or above 3,525 ft (1,074 m) AMSL. The annual releases in this tier are either 7.48 maf or 8.23 maf, depending upon the projected elevation of Lake Mead being above or below 1,025 ft (312 m) AMSL, respectively.

Midge: A very small, non-biting, two-winged insect, related to deer flies, mosquitos, and craneflies.

Mill: Monetary cost and billing unit used by utilities; equal to 1/1,000 of a U.S. dollar (equivalent to 1/10 of one cent).

Milligram per liter: Equivalent to one part per million.

Million acre-feet (maf): Unit of volume; the volume of water that would cover 1 million acres to a depth of 1 foot.

Mineral: Naturally occurring inorganic element or compound having an orderly internal structure and characteristic chemical composition, crystal morphology, and physical properties such as density and hardness. Minerals are the fundamental units from which most rocks are made.

Minimum flow: The lowest flow that occurs during the day, month, or year.

Mitigation: Action implemented to eliminate, avoid, minimize, or reduce the severity of an adverse impact on a particular resource resulting from the proposed action or its alternatives. Mitigation can include one or more of the following: (1) avoiding impacts; (2) minimizing impacts by limiting the degree or magnitude of an action; (3) rectifying impacts by restoration, rehabilitation, or repair of the affected environment; (4) reducing or eliminating impacts over time; and (5) compensating for the impact by replacing or providing substitute resources or environments to offset the loss.

Modified low fluctuating flow (MLFF): Current operating flow regime for the Glen Canyon Dam. The MLFF regime was established as the preferred alternative in the 1995 EIS and subsequent 1996 Record of Decision (ROD). In general, MLFF combines reduced daily flow fluctuations below the historic pattern of releases with high steady releases of short duration, intended to protect or enhance downstream resources while allowing limited flexibility for power operations. Established flows included minimum flows of no less than 8,000 cfs between 7 a.m. and 7 p.m., and 5,000 cfs at night; maximum rate of release limited to 25,000 cfs during fluctuating hourly releases; and releases of greater than 25,000 cfs (other than for emergencies) made steady on a daily basis in response to high inflow and storage conditions.

Monoculture: the cultivation or growth of a single crop or organism, especially on agricultural or forest land.

Monsoon: Rain event caused by a change in atmospheric circulation (e.g., wind direction) that results in stormy conditions, including excessive rainfall.

Morphology: Form and structure of an object (e.g., biological organism or rock formation) or any of its parts.

Mortality: Relative incidence or prevalence of death in a population.

Mouth (river): Natural opening, as the part of a stream or river, that empties into a larger body of water (e.g., another river, lake, bay, or ocean).

Myxozoa: Group of small parasitic animals that live in aquatic environments; one species in this group, *Myxobolus cerebralis*, is the parasite that causes whirling disease in rainbow trout.

N

National Ambient Air Quality Standards (NAAQS): Air quality standards established by the CAA, as amended. The primary NAAQS specify maximum outdoor air concentrations of criteria pollutants that would protect the public health within an adequate margin of safety. The secondary NAAQS specify maximum concentrations that would protect the public welfare from any known or anticipated adverse effects of a pollutant.

National Environmental Policy Act of 1969 (NEPA): Act passed by Congress in 1969 that sets national policy, procedures, tools, and compliance measures to support environmental protection, including encouraging productive harmony between people and their environment; promoting efforts that will prevent or eliminate damage to the environment and the biosphere and simulate the health and welfare of people; enriching the understanding of the ecological systems and natural resources important to the nation; and establishing a Council on Environmental Quality. It requires federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies prepare one of the following: a categorical exclusion, an EA, or an EIS.

National Historic Preservation Act (NHPA): Federal law providing that property resources with significant national historic value be placed on the *National Register of Historic Places*. It does not require permits; rather, it mandates consultation with the proper agencies whenever it is determined that a proposed action might affect a historic property.

National Register of Historic Places (NRHP): Official list of the nation's cultural resources worthy of preservation. Authorized under the NHPA, the NRHP is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect historic and archeological resources. Properties listed in the NRHP include districts, sites, buildings, structures, and objects that are significant in American history, architecture, archeology, engineering, and culture.

Native: Species of plants or wildlife that originated in the particular area or region in which they are growing or living.

Native American: See *American Indian*.

Native American Graves Protection and Repatriation Act (NAGPRA): Act that established the priority for ownership or control of Native American cultural items excavated or discovered on federal or Tribal land after 1990 and the procedures for repatriation of items in federal possession. The act allows for the intentional removal or excavation of Native American cultural items from federal or Tribal lands only with a permit or upon consultation with the appropriate Tribe.

Natural condition: State or status of resources that would occur (to the extent practicable) in the absence of human activities and/or dominance over the landscape.

Natural flow: The flow of any stream or river as it would be if unaltered by upstream diversion, storage, import, export, or change in upstream consumptive use caused by human activities.

Natural resource: Features and values that are inherently supplied by nature and considered to have value, including plants and animals, water, air, soils, topographic features, geologic features, and paleontological resources.

Natural Zone: An area managed for the conservation of natural resources and ecological processes while providing for their use by the public, as established by the National Park Service.

Nearshore: Area located between the boundary of the mainstem current and the shoreline. These regions are typically characterized by low water velocities (compared to the mainstem) and reduced turbulent mixing.

Nematode: An elongated, cylindrical worm parasitic in animals, insects, or plants, or free-living in soil or water.

Neotropical migratory bird: Bird that breeds in North America (i.e., Canada and the United States) during the spring and summer months and spends the winter months in Mexico, Central America, South America, or the Caribbean islands.

New High Water Zone (NHWZ): The area located next to the river, corresponding to river flows of 25,000 to 40,500 cfs, colonized with vegetation since the construction of Glen Canyon Dam; typically composed of riparian species, both native and nonnative.

Nitrate (NO_3): Naturally occurring plant nutrient that is essential to all life. It commonly enters water supply sources from decaying plants, manures, fertilizers, or other organic residues.

Nitrogen dioxide (NO_2): Toxic reddish brown gas that is a strong oxidizing agent, produced by combustion (as of fossil fuels). It is the most abundant of the oxides of nitrogen in the atmosphere and plays a major role in the formation of ozone. NO_2 is one of the six criteria air pollutants specified under Title I of the CAA. See *nitrogen oxides*.

Nitrogen oxides (NO_x): Includes various nitrogen compounds, primarily nitrogen dioxide and nitric oxide. They form when fossil fuels are burned at high temperatures and react with volatile organic compounds to form ozone, the main component of urban smog. They are also precursor pollutants that contribute to the formation of acid rain.

No action alternative: An alternative required by CEQ to be included in all EAs and EISs, representing conditions that would occur if the agency did not take the proposed action being considered. The environmental effects resulting from taking no action are compared to the effects of permitting the proposed action or any other action alternative to go forward.

Nonattainment area: The EPA's designation for an air quality control region (or portion thereof) in which ambient air concentrations of one or more criteria pollutants exceed NAAQS.

Non-firm power: Power that is not available continuously and may be interruptible; may be marketed on a short-term basis.

Nonnative: Species of plants or wildlife that did not originate in the particular area in which they are growing or living and that often interfere with natural biological systems.

Non-use valuation: The process of assigning a non-use value to a resource.

Non-use value: The economic benefit that arises from the knowledge that a resource exists (existence value), has been preserved for potential use in the future (option value), and will be available for use by one's heirs (bequest value). Non-use value is theoretically and conceptually distinct from use value. Contingent valuation is the only technique currently available for estimating non-use value.

Normal condition: As it relates to the Colorado River, when the Secretary of the Interior has determined that there is available water for annual releases totaling 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(1) of the Consolidated Decree.

Notice of Intent (NOI): Announcement published in the *Federal Register* that an EIS will be prepared and considered. Includes description of the proposed action and alternatives; provides time, place, and descriptive details of the proposed scoping process; and identifies the lead agency (or agencies) contact person.

NPS-28, Cultural Resource Management Guidelines: National Park Service guidelines that elaborate on policies and standards and offer guidance in applying them to establish, maintain, and refine park cultural resource programs.

Nutrients: Chemical elements or compounds that are essential to plant and animal growth and development, such as nitrogen and phosphorus. Nutrients are measured in milligrams per liter (mg/L).

O

Obligate species: Restricted to a particular condition of life; for example, dependent on a particular habitat to be able to breed.

Off-peak energy: Electric energy supplied during periods of relatively low system demand.

Old High Water Zone (OHWZ): Area of vegetation above the level corresponding to flood flows of about 120,000 to 125,000 cfs; typically composed of native tree species.

On-peak energy: Electric energy supplied during periods of relatively high system demand.

Operating tier: Pursuant to the Interim Guidelines established in 2007, coordinated operations of Lake Powell and Lake Mead defined four operation tiers: (1) Equalization Tier, (2) Upper Elevation Balancing Tier, (3) Mid-Elevation Tier, and (4) Lower Elevation Balancing Tier. See specific tiers for additional information.

Organic matter: Material derived from living plant or animal organisms.

Organochlorine pesticide: Pesticide containing a compound of carbon, chlorine, and hydrogen that does not break down easily and is stored in fatty tissues of any animal ingesting it. Accumulates in animals in higher trophic levels.

Oscillatoria: Genus of benthic (bottom-dwelling) cyanobacteria or plankton (blue-green algae) occurring in blooms in fresh water.

Ostracod: Group of small crustaceans with a bivalved carapace that can be closed to completely cover the body; important planktonic fish food.

Outage (power): Period during which a generating unit, transmission line, or other facility is out of service and power is not available.

Outflow (hydrology): Amount or rate of water flowing out of or from a body of water. In this report it refers to water leaving Lake Powell by way of Glen Canyon Dam.

Outlet works: Device, usually consisting of one or more bypass pipes or tunnels through the embankment of the dam, used to release and regulate water flow from a dam. These structures are similar in purpose to spillways, but outlet works can provide a lower volume and more controlled release. See *jet tube*.

Ozone (O_3): Strong-smelling, reactive, toxic gas consisting of three oxygen atoms chemically attached to each other. Ozone is formed in the atmosphere by chemical reactions involving NO_X and volatile organic compounds (VOCs) in the presence of sunlight. Ozone is one of the six criteria air pollutants under the CAA and is a major constituent of smog.

P

Paleoclimate: a climate prevalent at a particular time in the geologic past.

Paleoindian period: A late Pleistocene stage of cultural evolution in the Americas at the end of the last ice age, when the first traces of human activity begin to appear in the archaeological record characterized by big-game hunting and the use of fluted projectile points.

Paleozoic: An era of geologic time, from the end of the Precambrian to the beginning of the Mesozoic, or from about 542 to 251 million years ago; also, the rocks deposited during this time.

Parasite: Organism that lives on or in an organism of another species (i.e., host) in a way that harms or is of no advantage to the host. Parasites rarely kill their hosts, instead, they obtain nutriment from the host body to live, grow, and multiply.

Particulate matter (PM): Fine solid or liquid particles such as dust, smoke, mist, fumes, or smog, found in air or emissions that stick to lung tissue when inhaled. The size of the particulates is measured in micrometers (μm), which is 1 millionth of a meter (0.000039 in.). Particle size is important because the EPA has set standards for $PM_{2.5}$ and PM_{10} particulates, both of which are criteria air pollutants under the CAA. See *$PM_{2.5}$* and *PM_{10}*.

Pathogen: Bacterium, virus, or other microorganism that can cause disease in other living microorganisms or in humans, animals, and plants.

Peak demand: See *peak load*.

Peak flow: Maximum instantaneous flow in a specified period of time.

Peak load: Maximum electrical demand in a stated period of time.

Peak load plant: Powerplant that normally is operated to provide power during maximum load periods.

Peaking power: Powerplant capacity typically used to meet the highest levels of demand in a utility's load or demand profile.

Penstock: Conduit pipe used to convey water under pressure from a storage reservoir to the turbines of a hydroelectric powerplant.

Per capita income: The average income per person in a given group.

Perennial stream: Stream that flows continuously throughout the year because it lies at or below the groundwater table, which constantly replenishes it.

Periphyton: Complex mixture of algae, cyanobacteria, other microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems. It serves as an important food source for invertebrates, tadpoles, and some fish.

pH: A measure of the relative acidity or alkalinity of a solution, expressed in a scale of 0 to 14, with a neutral point at 7. Acid solutions have pH values lower than 7, and basic (i.e., alkaline) solutions have pH values higher than 7.

Phantom Ranch: Constructed in 1922, the Phantom Ranch is the only accommodation for hikers in the inner Grand Canyon. It consists of a cluster of guest houses and a canteen lying between Bright Angel Creek and the Colorado River in GCNP.

Phosphorous: Essential chemical food element that can contribute to the eutrophication of lakes and other water bodies. Increased phosphorus levels result from discharge of phosphorus-containing materials into surface waters.

Photosynthesis: Process in which chlorophyll-containing cells convert light into chemical energy, forming organic compounds from inorganic compounds.

Phreatophyte: Any plant, typically living in the desert, that obtains its water from long taproots that reach the water table.

Physiography: The physical geography of an area or the description of its physical features.

Phytoplankton: Microscopic, single-celled photosynthetic organisms that live suspended in water.

Piscivorous: Habitually feeding on fish.

Plankton: Tiny plant (phytoplankton) and animal (zooplankton) organisms with limited powers of locomotion usually living free in the water away from substrates.

Plano technological complex: Distinctive early Paleoindian culture defined by a range of unfluted stone projectile points. Plano technology dates to 11,000 to 8,000 years ago.

PM_{10}: Particulate matter with a mean aerodynamic diameter of 10 μm (0.0004 in.) or less. Particles with diameters smaller than this can be inhaled and accumulate in the respiratory system. PM_{10} is one of the six criteria pollutants specified under Title I of the CAA.

$PM_{2.5}$: Particulate matter with a mean aerodynamic diameter of 2.5 μm (0.0001 in.) or less. Particles with diameters smaller than this can lodge deeply in the lungs. $PM_{2.5}$ is one of the six criteria pollutants specified under Title I of the CAA.

Pollinator: Agent, such as an insect or bird, that moves pollen from the male anthers of a flower to the female stigma of a flower to accomplish fertilization.

Pollutant: Any material entering the environment that has undesired effects.

Ponding flow: Relatively high flows that produce warm low-velocity slackwater areas at tributary mouths that provide thermal refuges for drifting larvae and young warmwater fish (e.g., humpback chub).

Pool: Deep area of a stream or river between rapids or where the current is slow.

Post-dam: Period of time after the completion of Glen Canyon Dam in 1963.

Power demand: Rate at which electric energy is required and delivered to or by a system over any designated period of time.

Power marketing: Process by which Western Area Power Administration sells power generated at Glen Canyon Dam and other Colorado River Storage Project facilities. Subject to a number of requirements established under statutory criteria.

Power operations: Physical operations of a large electrical power system, including hydropower generation, control (operational flexibility, scheduling, load following, and reserves), and transmission.

Power pool: Two or more interconnected electric systems that operate on a coordinated basis to achieve economy and reliability in supplying their combined loads.

Powerplant: Structure that houses turbines, generators, and associated control equipment related to the generation of electrical power.

Powerplant capacity: For Glen Canyon Dam, maximum flow that can pass through the turbines when Lake Powell is full (33,200 cfs). Also refers to the electrical capacity of the generators; total nameplate generating capacity for the powerplant is 1,021,248 kilowatts.

Pre-dam: Period of time before the completion of the Glen Canyon Dam in 1963.

Predation: Act of preying or plundering, specifically the interaction between species when one animal (predator) captures and eats another animal (prey).

Predatory: Relating to or characteristic of organisms that survive by preying on other organisms for food.

Preference customer: In accordance with congressional directives, publicly owned systems, and nonprofit cooperatives that have preference over investor-owned systems for purchase of power from federal projects.

Preferred alternative: Alternative the lead agency (or agencies) believes would fulfill its statutory mission and responsibilities under NEPA, giving consideration to economic, environmental, technical, and other factors.

Prescribed fires: Application of fire (by planned or unplanned ignitions) to fuels in either their natural or modified states, under specified conditions, to allow the fire to burn in a predetermined area while producing the fire behavior required to achieve certain management objectives.

Prevention of significant deterioration (PSD): A federal air pollution permitting program intended to ensure that air quality does not diminish in attainment areas that meet NAAQS.

Primitive: Belonging to or characteristic of an early age of development.

Productivity (ecology): Rate of biomass generation by an individual, population, or community within an ecosystem. Also, the fertility or capacity of a given habitat or area.

Programmatic Agreement (PA): Document that records the terms and conditions agreed upon to resolve the potential adverse effects of a federal agency program, complex undertaking, or other situations in accordance with Section 800.14(b), "Programmatic Agreements," of 36 CFR Part 800, "Protection of Historic Properties."

Project area: Area in which a proposed action would occur and directly affect the environment. The project area for the LTEMP EIS is Lake Powell, Lake Mead, and the Colorado River and its corridor in between.

Proliferation: Rapid growth or increase in production of new parts or offspring.

Proposed action: An action proposed by an agency, subject to a NEPA analysis.

Proterozoic era: Final era of the Precambrian, spanning the time between 2.5 billion and 544 million years ago. Fossils of both primitive single-celled and more advanced multicellular organisms begin to appear in abundance in rocks from this era. Its name means "early life."

Protohistoric: Period between prehistory and history, during which a culture or civilization has not yet developed writing but other cultures have already noted its existence in their own writings. The protohistoric culture may also be in the process of developing its own writing techniques and creating its own written record.

Public involvement: Process of obtaining public input into each stage of development of planning documents. Required as a major input into any EIS.

R

Radionuclide: Unstable nuclide that undergoes radioactive decay.

Ramp rate: Rate of change (cfs/hr) in instantaneous dam releases. The ramp rate is established to prevent undesirable effects due to rapid changes in loading or, in the case of hydroelectric powerplants, discharge.

Range: Geographic region in which a given plant or animal normally lives or grows.

Rapid: Turbulent section of a river. Fast-flowing current typically is caused by a relatively steep descent in the riverbed or a constriction of the main channel.

Reach: Any specified length of a stream or river.

Rearing: Bringing up from the early stages of life, through maturity, until fully grown.

Reattachment bar: Sandbar located where downstream flow meets the riverbank at the downstream end of a recirculation zone. An element of a fan-eddy complex.

Recirculation zone: Area of flow composed of one or more eddies immediately downstream from a constriction in the channel, such as a debris fan or rock outcrop. An element of a fan-eddy complex.

Reclamation Project Act of 1939: This act provides a comprehensive plan for the variable payment of construction charges on U.S. reclamation projects.

Record of Decision (ROD): Document separate from but associated with an EIS that publicly and officially discloses the responsible agency's decision on the EIS alternative to be implemented.

Recovery: Return to or regaining of any former and better state or condition. As it relates to ESA, recovery is the process by which the decline of an endangered or threatened species is arrested or reversed, and threats to its survival (including the ecosystem upon which they depend) are neutralized, so that its long-term survival in nature can be ensured.

Recruitment: Survival of young plants and animals from birth to reproductive age or a life stage less vulnerable to environmental change.

Redd: Depression, or spawning nest, dug by fish (especially trout or salmon) in river- or lakebed for the deposition of eggs.

Redeposition: Formation into a new accumulation, such as the settlement of sedimentary material that has been picked up and moved (reworked) from the place of its original deposition.

Refuge: Protection or shelter, as from something dangerous, threatening, harmful, or unpleasant.

Refugia: Locations or areas where conditions remain suitable to allow a species or a community of species to survive following extinction in surrounding areas. Plural of refugium.

Region of influence (ROI): Area occupied by affected resources and the distances at which impacts associated with a proposed action may occur.

Regulation: Capacity devoted to providing the minute-by-minute change in generation above and below a generator's operating set point. It is needed to maintain a constant voltage within a power control area given variation in generator units. Regulation results in instantaneous deviations above and below the mean hourly flow within each hour that do not affect the mean hourly flow over a full hour. In the United States, regulating capacity is controlled by computers (via automatic generation control).

Reptile: Cold-blooded vertebrate of the class Reptilia whose skin is usually covered in scales or scutes. Reptiles include snakes, lizards, turtles, crocodiles, and alligators.

Reserve generating capacity: Extra generating capacity available to meet unanticipated capacity demand for power in the event of generation loss due to scheduled or unscheduled outages of regularly used generating capacity.

Reservoir: Natural or artificially impounded body of water, commonly created by the building of a dam, that is used for the storage, regulation, and control of water.

Reservoir capacity: Total or gross storage capacity of the reservoir at full supply level.

Restoration: Manipulation of the physical, chemical, or biological characteristics of a resource or site with the goal of improving or returning its natural/historic functions to any former and better state or condition.

Return-current channel: Channel excavated by upstream eddy flow that forms behind a reattachment bar. See *backwater*.

Riffle: Stretch of choppy water caused by an underlying rock shoal or sandbar.

Riparian: Along a river, pond, lake, or tidewater.

Riparian zone: Area encompassing the alluvial sediment deposits where river and alluvial groundwater supplement that available from local precipitation.

Risk: Likelihood of suffering a detrimental effect as a result of exposure to a hazard.

River basin: Land area surrounding one river from its headwaters to its mouth. The area drained by a river and its tributaries.

River corridor: River and the area of land adjacent to it, including the talus slopes at the bases of cliffs, but not the cliffs themselves.

River mile (RM): Unit of measurement (in miles) that quantifies distance (or length) in miles along a river from its mouth or other reference point. On the Colorado River, River Mile 0 is located at the U.S. Geological Survey gage at Lees Ferry, Arizona; points downstream are positive values while those upstream are negative.

River runner: Individual who recreationally navigates a moving body of water, typically a whitewater river, using a raft, kayak, or other type of boat. See *whitewater rafting*.

River stage: Water surface elevation of a river above a reference datum.

Riverine: Of, resembling, relating to, or situated on a river or riverbank.

RiverWare: Commercial river system simulation computer program that was configured to simulate operation of the Colorado River for this EIS.

Rotifer: Microscopic, multicellular invertebrates from the class Rotifera; common in freshwater.

Runoff: Portion of the precipitation, melted snow, or irrigation water that flows across ground surface and eventually is returned to surface water sources. Runoff can pick up pollutants from the air or land and carry them to the receiving waters.

S

Sacred landscape: Natural places recognized by a cultural group as having spiritual or religious significance.

Sacred site: Any specific, discrete, narrowly delineated location on federal land that is identified by an Indian Tribe, or Indian individual determined to be an appropriately authoritative representative of an Indian religion, as sacred by virtue of its established religious significance to, or ceremonial use by, an Indian religion; provided that the Tribe or appropriate authoritative representative of an Indian religion has informed the agency of the existence of such a site.

Salinity: Degree of dissolved minerals (e.g., salts) in water. Also commonly referred to as total dissolved solids (TDS). See *total dissolved solids*.

Salmonid: Of, belonging to, or characteristic of fish belonging to the Salmonidae family, which includes salmon, trout, and whitefish.

Salt Lake City Area Integrated Projects (SLCA/IP): Part of an interconnected generation and transmission system that includes federal, public, and private power-generating facilities.

Sand: Rock or mineral fragment of any composition that has a diameter ranging from 0.5 to 2.0 mm. Sand has a gritty feel.

Sand budget: Management tool used to analyze and describe the various sand and sediment inputs (sources) and outputs (sinks) within a defined system; can be used to predict morphological change over time.

Sand load: See *sediment load*.

Sand mass balance: Difference between the mass of sand being transported into an area and the mass of sand being transported out of the area. A positive sand mass balance indicates that sand is accumulating in the area, whereas a negative sand mass balance indicates that the mass of sand is decreasing in the area.

Sandbar: Any of the fine-grained alluvial deposits that intermittently form the riverbank. These fine-grained deposits are in contrast to the rocky surfaces predominately found throughout the Grand Canyon. See *beach*.

Sandstone: Sedimentary rock composed primarily of sand-sized (0.0025 to 0.08 in.) grains.

Scheduled outage: Shutdown of a generating unit or other facility for inspection or maintenance, in accordance with an advance schedule.

Scheduling: Matching of daily system energy and capacity needs with available generation.

Schist: Metamorphic rock formed from many types of rocks. Minerals in the rocks include micas, chlorite, talc, hornblende, and garnets. The minerals are characteristically platey and foliated (layered), indicating they were subjected to intense compression.

Scope: Range of actions, alternatives (including no action), and impacts to be considered in an EIS.

Scoping: Process required by NEPA to solicit input, issues, and information from within the agency, other agencies, and the public related to the proposed action prior to preparation of an EIS. Scoping assists the preparers of an EIS in defining the proposed action, identifying alternatives, and developing preliminary issues to be addressed in an EIS.

Scour: Erosion in or along a stream bed caused by high flow velocities.

Secretary: Secretary of the Department of the Interior (DOI) and duly appointed successors, representatives, and others with properly delegated authority.

Sediment: Unconsolidated solid material that is washed from land (e.g., from weathering of rock) and is carried by, suspended in, or deposited by water or wind. Sediment varies in size and includes clay, silt, sand, gravel, and cobble.

Sediment augmentation: Adding sand-, silt-, or clay-size sediments to the Colorado River to increase turbidity or sediment supply.

Sediment load: Mass of sediment passing through a stream cross-section in a specified period of time.

Sediment transport: Movement of sediment in a downstream direction caused by flowing water.

Sedimentary rock: Rock formed at or near the Earth's surface from the consolidation of loose sediment that has accumulated in layers through deposition by water, wind, or ice, or organisms. Examples are sandstone and limestone.

Sedimentation: Removal, transport, and deposition of sediment particles by wind or water.

Seep: Moist or wet place where groundwater slowly exits through soil or rock.

Seepage: Relatively slow movement of water through a medium such as sand.

Semi-arid: Moderately dry region or climate where moisture is normally greater than under arid conditions but still limits the production of vegetation.

Sensitive species: Plant or animal species listed by the state or federal government as threatened, endangered, or a species of special concern. The list of sensitive species typically varies from state to state, and the same species can be considered sensitive in one state but not in another. Also, a species that is adversely affected by disturbance or altered environmental conditions. See also *special status species*.

Separation bar: Sandbar located at the upstream end of a recirculation zone, where downstream flow becomes separated from the riverbank, creating an eddy.

Shoal: Shallow area in a body of water.

Shortage condition: When the Secretary has determined that there is available for annual release less than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(3) of the Consolidated Decree.

Silt: Fine rock fragments or mineral particles of any composition between sand and clay in size that have diameters ranging from 0.002 to 0.05 mm.

Simulid: Group of two-winged flying insects who live their larval stage underwater and emerge to fly about as adults.

Sinuous: Ratio of the length of a river's thalweg to the length of the valley proper. A measure of a river's meandering.

Site: In archeology, any location of past human activity.

Slope: Change in elevation per unit of horizontal distance.

Socioeconomic: Social and economic conditions in the study area.

Solar radiation: Electromagnetic radiation emitted by the sun.

Soundscapes: Sound or combination of sounds that forms or arises from an immersive environment.

Spawn: To lay eggs, especially fish.

Spawning beds: Places where eggs of aquatic animals lodge or are placed during or after fertilization.

Special status species: Any plant or animal species that is listed or proposed for listing as threatened or endangered by the FWS or NMFS under the provisions of the ESA. Also any species designated by the FWS as "candidate," "sensitive," or a "species of concern"; or a species listed by a state in a category implying potential endangerment or extinction (e.g., sensitive or rare).

Species of special concern: Species that may have a declining population, a limited occurrence, or low numbers for any of a variety of reasons.

Spike flow: Natural or experimental increase in the flow of water for a short duration.

Spills: Water releases from Glen Canyon Dam that do not pass through the turbines for the generation of electricity.

Spillway: Overflow channel of a dam to provide a controlled release.

Spinning reserves: Extra generating capacity that is available for immediate use in response to system problems or sudden load changes by increasing the power output of generators that are already connected to the power system. Within minutes or less, reserves allow for increases in the water release rates at Glen Canyon Dam to increase power generation, up to a limit known as the spinning reserve requirement, to compensate for the loss in generation elsewhere in the grid.

Spring: Point at which groundwater meets the Earth's surface, causing water to flow from the ground.

Stage: See *water-surface elevation*.

Stakeholder: Person, group, or organization that has direct or indirect investment, share, or interest in an organization or project because it can affect or be affected by related actions, objectives, and/or policies.

State Historic Preservation Office(r) (SHPO): The state officer charged with the identification and protection of prehistoric and historic resources in accordance with the NHPA.

Steady flow: Flow released from the dam at any volume that does not vary beyond a small percentage over a 24-hour period.

Stewardship: Conducting, supervising, managing, or protecting something considered of value or worth caring for and preserving. The concept of stewardship has been applied in diverse areas, including the environment, economics, health, property, information, and religion.

Strata: Single, distinct layers of sediment or sedimentary rock.

Stratification: Thermal layering of water in lakes and streams. Lakes usually have three zones of varying temperature: epilimnion—top layer with essentially uniform warmer temperature; metalimnion—middle layer of rapid temperature decrease with depth; and hypolimnion—bottom layer with essentially uniform colder temperatures.

Stratigraphy: Layers of sediments and rocks that reflect the geologic history of an area. With respect to cultural resources and archaeological sites, the relative stratigraphic locations of human artifacts help determine the sequence in which past human activities took place.

Stream: Natural water course. See *ephemeral stream*, *intermittent stream*, and *perennial stream*.

Stream flow: Volume or rate, expressed in cubic feet per second (cfs), of water moving in a stream or river, at any given time.

Stream gage: Active, continuously functioning field measuring device for which stream flow is computed or estimated.

Subadult: Fish that are less than 3 years of age.

Subsistence: The practices by which a group or individual acquires food, such as through hunting and gathering, fishing, and agriculture.

Substrate: Surface on which a plant or animal grows or is attached.

Sulfur dioxide (SO_2): Colorless gas released from many sources, especially burning fossil fuels. Sulfur dioxide is one of the six criteria air pollutants specified under Title I of the CAA.

Sulfur oxides (SO_x): Compounds containing sulfur and oxygen, such as sulfur dioxide (SO_2) and sulfur trioxide (SO_3). Pungent, colorless gases that are formed primarily by fossil fuel combustion, notably from coal-fired powerplants. Sulfur oxides may damage the respiratory tract, as well as plants and trees.

Surface water: Water on the Earth's surface that is directly exposed to the atmosphere, as distinguished from water in the ground (groundwater).

Surplus condition: When the Secretary has determined that there is available for annual release more than 7.5 maf to satisfy consumptive use in the Lower Division states pursuant to Article II(B)(2) of the Consolidated Decree.

Surplus energy: Energy greater than that of contracted firm load that may be available for a short-term period to serve additional load; usually attributed to favorable, but unanticipated, hydrologic conditions.

Suspended solids: Small particles of sand, silt, clay, and organic material moving with the water or along the bed of the stream that are not in true solution (i.e., can be removed by filtration or settling).

Suspension: Heterogeneous mixture of fine solid particles in a liquid or gas, such as sand in water. The suspended particles will settle over time, if left undisturbed, or can be removable by filtration.

Sustainable hydropower (SHP): Fixed level of long-term capacity and energy available from SLCA/IP facilities during summer and winter seasons; this amount is the minimum commitment level for capacity that Western will provide to all SLCA/IP customers.

Sweat lodge: In Native American culture, a ceremonial event of traditional prayers and songs that are held in a lodge constructed of a wood frame covered with blankets, with hot stones that release steam when water is poured on them.

T

Tailwater: Reach of river immediately downstream of a dam, where the water is more similar to that in the reservoir than farther downstream.

Talus: Sloping accumulation of rock debris; also, rock fragments at the base of a cliff as the result of sliding or falling.

Taxa: Taxonomic unit or category within the biological system of classification to which organisms are assigned, including species, genus, family, order, class, and phylum.

Technical Work Group (TWG): Subcommittee comprised of technical representatives of the Adaptive Management Work Group (AMWG) to develop criteria and standards for monitoring and research programs.

Temperate: Moderate climate that lacks extremes in temperature.

Temperature control device (TCD): Apparatus used to modify the dam's penstocks to allow for selective withdrawal from the reservoir, as to influence the temperature of the release water (e.g., warm surface water versus cold deep water).

Temporal: Of, relating to, or limited by time.

Temporary structure: Any structure that can be readily and completely dismantled and removed from the site between periods of actual use. It may or may not be authorized at the same site from season to season or from year to year.

Terrace: Surface form of a high sediment deposit having a relatively flat surface and steep slope facing the river.

Terrain: Topographic layout and features of a tract of land or ground.

Terrestrial: Pertaining to plants or animals living on land rather than in water.

Texture: Visual manifestations of light and shadow created by the variations in the surface of an object or landscape.

Thalweg: Line connecting the deepest points along the length of a valley or riverbed.

Thermal: Of, relating to, affected by, or producing heat.

Thermocline: Zone of maximum change in temperature in a water body, separating upper (epilimnetic) from lower (hypolimnetic) zones.

Threatened species: Any species or subspecies that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range. Requirements for declaring a species threatened are contained in the ESA of 1973.

Toe: Point at which the bottom of a slope or embankment intersects the natural ground, such as the upstream or downstream toe of the dam or the downstream toe of a landslide or debris fan.

Topography: Physical shape of the ground surface; the relative position and elevations of natural and human-made features of an area.

Total dissolved solids (TDS): Dissolved materials in the water including ions such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium. In many instances, the term TDS is used to reflect salinity, since these ions are typically in the form of salts. See *salinity*.

Toxicity: Harmful effects on an organism caused by exposure to a hazardous substance. Environmental exposures are primarily through inhalation, ingestion, or contact with the skin.

Trace (hydrology): Sequence of flows over a specified period of time.

Traditional Cultural Property (TCP): Site or resource that is eligible for inclusion in the NRHP because of its association with cultural practices or beliefs of a living community that are (1) rooted in that community's history, and (2) important in maintaining the continuing cultural identity of the community.

Traditional use area: Broad landscapes over which contemporary people and their ancestors have hunted, fished, and gathered.

Translocation: Intentional capture, movement, and release of individuals of a species from one location or area to another. This type of transfer is typically done to prevent harm to the individuals or to establish additional populations elsewhere.

Transmission line: Facility for transmitting electrical energy at high voltage from one point to another point.

Travertine: Sedimentary rock formed by the precipitation of carbonate minerals from solution in ground and surface waters, and/or geothermal hot springs.

Tribal land: In the NAGPRA, tribal land is defined as: (1) all lands within the exterior boundaries of any Indian reservation; (2) all dependent Indian communities; and (3) any lands administered for the benefit of Native Hawaiians pursuant to the Hawaiian Homes Commission Act, 1920, and section 4 of Public Law 86-3. In the NHPA, Tribal land is defined as (1) all lands within the exterior boundaries of any Indian reservation, and (2) all dependent Indian communities.

Tribe: Term used to designate a federally recognized group of American Indians and their governing body. Tribes may be comprised of more than one band.

Tributary: River or stream that flows into another stream, river, or lake.

Trigger: Condition-dependent or environmental cues that determine management actions.

Trophic: Of, relating to, or pertaining to nutrition, food, or feeding. For example, the feeding habits or food relationship of different organisms in a food chain.

Trout: Prized game fish native to the Northern Hemisphere, that has been widely introduced (i.e., it is nonnative) across the globe, including the Colorado River below Glen Canyon Dam (with exception of the native cutthroat trout). These fishes feature a streamlined, speckled body with small scales and soft fins, although their individual coloring and appearance can change depending on the specific surroundings and environment in which they live. Typically smaller than the related salmon, trout are usually found in cool (50–60°F, 10–16°C), clear freshwater streams and lakes. Trout are an important food source for humans and wildlife including brown bears, birds of prey (e.g., eagles), and other animals. However, their existence threatens many native fish species and their habitats owing to competition, displacement, and predation.

Trout management flow (TMF): Special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging young-of-the-year (YOY) trout.

Turbidity: Measure of the water clarity or the ability of light to pass through water. Affected by the amount of suspended particles, dissolved solids, and colloidal materials that are suspended in water.

Turbine: Device or machine for generating rotary mechanical power from the energy of a stream of fluid (such as water, steam, hot gas, or wind). Turbines convert the kinetic energy of fluids to mechanical energy through the principles of impulse and reaction, or a mixture of the two. Turbines are considered the most economical means of turning large electrical generators.

Turbulent: Marked or characterized by disturbances, changes, and unrest, such as unsteady motion and agitation of water.

U

Upper Basin: Those parts of the states of Arizona, Colorado, New Mexico, Utah, and Wyoming, within and from which waters drain naturally into the Colorado River above Lee Ferry, Arizona; defined by the Colorado River Compact of 1922.

Upper Colorado River Commission: Commission established by the Upper Colorado River Basin Compact with five appointed members, one from each of the Upper Division States (Colorado, New Mexico, Utah, Wyoming) and one representing the United States of America. Its purpose is to administer the Upper Colorado River Basin Compact.

Upper Division: Division of the Colorado River system that includes the states of Colorado, New Mexico, Utah, and Wyoming; area defined by Article II of the Colorado River Compact of 1922.

Upper-elevation balancing tier: Operation elevation that applies when Lake Powell's projected January 1 elevation is below the elevation in the equalization table of the Interim Guidelines, but above 3,575 ft (1,090 m) AMSL. The tier defines several different operations for attempting to balance the contents of Lake Mead and Lake Powell, if possible, that may occur based on the projected elevations of each lake, within the constraint that the release from Lake Powell would be not more than 9.0 maf and no less than 7.0 maf.

Upstream: Toward the source of a stream or river, against the normal direction of water flow.

Use value: Economic benefit associated with the physical use of a resource, usually measured by the consumer surplus or net economic value associated with such use. The contingent value method is one technique used to estimate use value.

V

Varial zone: Portion of the river bottom that is alternately flooded and dewatered.

Velocity: Rate of flow of water or water-sediment mixture.

Vertebrate: Animal species with a backbone. Includes fish, amphibians, reptiles, birds, and mammals.

Visibility degradation: Scattering and absorption of light by fine particles with a secondary contribution by gases; cumulative emissions of air pollutants from a myriad of sources.

Visitor day: Use of a site or area for 12 visitor hours, which may be aggregated by one or more persons for a single continuous or intermittent use (e.g., multiple visits).

Visitor use: Usage of recreation and wilderness resources by people for inspiration, stimulation, solitude, relaxation, education, pleasure, or satisfaction.

Visual contrast: Opposition or unlikeness of different forms, lines, colors, or textures in a landscape.

Visual impact: Any modification in land forms, water bodies, or vegetation, or any introduction of structures that negatively or positively affect the visual character or quality of a landscape through the introduction of visual contrasts in the basic elements of form, line, color, and texture.

Visual resource: Refers to all objects (manmade and natural, moving and stationary) and features such as landforms and water bodies that are visible on a landscape.

Volatile organic compound (VOC): Broad range of organic compounds that readily evaporate at normal temperatures and pressures. Sources include certain solvents (e.g., acetone), degreasers (e.g., benzene), and fuels (e.g., gasoline). VOCs also react with other substances (primarily nitrogen oxides) to form ozone. They contribute significantly to photochemical smog production and certain health problems.

W

Warmwater fish: Species of fish that grow best in water at least 80°F (27°). Warm water holds less DO than cool or cold water, so warmwater species, such as largemouth bass, catfish, and bluegill, require less oxygen to survive.

Wash: Normally dry streambed that occasionally conveys flowing water.

Water column: Hypothetical “cylinder” of water from the surface of a water body to the bottom, within which physical and chemical properties can be measured.

Water quality: Term used to describe the chemical, physical, and biological characteristics of water, usually with respect to its suitability for a particular purpose.

Water right: Legal entitlement of an individual or entity to extract water from a water source (surface water or groundwater) for a beneficial use (e.g., potable water supply, irrigation, mining, livestock).

Water table: Upper level of groundwater below which soil and rock are saturated with water.

Water year: Period of time beginning October 1 of one year and ending September 30 of the following year and designated by the calendar year in which it ends.

Waterfowl: Water birds, usually referring to ducks, geese, and swans.

Watershed: Region or area from which all water entering a particular water body drains. Also known as a basin.

Water-surface elevation (stage): Height, or elevation, of a water surface above or below an established reference level, such as sea level.

Weed: Plant considered undesirable, unattractive, or troublesome, usually introduced and growing without intentional cultivation.

Western Area Power Administration (WAPA): One of four power marketing administrations of the U.S. Department of Energy that markets and delivers reliable, renewable, cost-based hydroelectric power and related services within a 15-state region of the central and western United States.

Western Electricity Coordinating Council (WECC): Regional entity responsible for coordinating and promoting bulk electric system reliability in the Western Interconnection.

Wetlands: Federally protected areas that are saturated or flooded by surface or groundwater frequently enough or long enough to support plants, birds, and animals adapted to live in wet environments. Generally include swamps, marshes, bogs, estuaries, wet meadows, river overflows, mud flats, natural ponds, and other inland and coastal areas.

Wheeling: Occurs when two indirectly connected utilities agree to purchase or sell power to each other.

Whirling disease: Disease caused by a parasite; results in neurological damage to young fish, causing them to swim in a corkscrew pattern. Affected fish are unable to feed properly and are vulnerable to predators.

Whirlpool: Water moving rapidly in a circle so as to produce a depression.

Whitewater boating: See *whitewater rafting*.

Whitewater rafting: Recreational navigation of a moving body of water (e.g., river) characterized by fast-flowing rough water or rapids, using a raft, kayak, or other type of boat.

Wild and Scenic Rivers Act: Primary river conservation law enacted in 1968. The Act was specifically intended by Congress to balance the existing policy of building dams on rivers for water supply, power, and other benefits with a new policy of protecting the free-flowing character and outstanding values of other rivers.

Wilderness: Undeveloped land retaining its primeval character without permanent improvements or human habitation, and that generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable.

Wilderness Act of 1964: Legislation enacted in 1964 to designate wilderness areas, with Congressional approval, to ensure that these lands are preserved and protected in their natural condition.

Wilderness areas: Areas and lands designated by Congress and defined by the Wilderness Act of 1964 as places "where the earth and its community are untrammeled by man, where man himself is a visitor who does not remain." Designation is aimed at ensuring that these lands are preserved and protected in their natural condition.

Wilderness characteristics: Wilderness characteristics include (1) naturalness: the area generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) outstanding opportunities: the area has either outstanding opportunities for solitude, or outstanding opportunities for primitive and unconfined types of recreation; (3) size: the area is at least 5,000 acres (20 km^2) of land, or is of sufficient size to make practicable its preservation and use in an unimpaired condition; and (4) values: the area may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.

Willingness to pay: Method of estimating the value of activities, services, or other goods, where value is defined as the maximum amount a consumer would be willing to pay for the opportunity rather than do without. The total willingness to pay, minus the user's costs of participating in the opportunity, defines the consumer surplus and benefits.

Wind rose: Circular diagram, for a given locality or area, showing the frequency and strength of the wind from various directions over a specified period of record.

World Heritage Site: Area identified by the World Heritage Committee of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) as having outstanding universal value for cultural and natural heritage.

X

Xeric: Low in moisture. Dry environmental conditions. Habitats or sites characterized by their limited water availability.

Y

Young-of-year (YOY): Young (usually fish) produced in the current calendar year. Also referred to as age 0.

Z

Zooplankton: Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs. Zooplankton can be permanent (i.e., rotifers or cladocerans) or temporary, as with the early life stages (i.e., eggs, larvae, juveniles, and adults) of many fish and invertebrate species.

Glen Canyon Dam

Long-Term Experimental and Management Plan Environmental Impact Statement

FINAL

Volume 2—Appendices A–N

U.S. Department of the Interior
Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

October 2016













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GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN FINAL ENVIRONMENTAL IMPACT STATEMENT

Joint-Lead Agencies
Bureau of Reclamation
National Park Service

Cooperating Agencies
Department of the Interior
Bureau of Indian Affairs
U.S. Fish and Wildlife Service
U.S. Department of Energy
Western Area Power Administration
Arizona Game and Fish Department
Colorado River Board of California
Colorado River Commission of Nevada
Upper Colorado River Commission
Havasupai Tribe
Hopi Tribe
Hualapai Tribe
Kaibab Band of Paiute Indians
Navajo Nation
Pueblo of Zuni
Salt River Project
Utah Associated Municipal Power Systems

ABSTRACT

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation and National Park Service (NPS), proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, including those of importance to American Indian Tribes.

The Final Environmental Impact Statement (FEIS) was developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), and followed the implementing regulations developed by the President's Council on Environmental Quality in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46. The FEIS analysis draws on the scientific information that has been collected under the Glen Canyon Dam Adaptive Management Program over the last 20 years to identify the potential environmental effects associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. Seven alternatives were considered and analyzed for the LTEMP EIS—a no action alternative (Alternative A), a hydropower-focused alternative (Alternative B), three condition-dependent alternatives (Alternatives C, D, and E), and two steady flow alternatives (Alternatives F and G). These alternatives incorporated a broad range of operations and experimental actions that together allowed for a full evaluation of possible impacts of the

proposed action. Based on the impact analyses conducted, DOI has chosen Alternative D as both the preferred and the environmentally preferred alternative. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

For additional information, visit http://ltempeis.anl.gov or contact:

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CONTENTS

ABSTRACT iii

ACRONYMS AND ABBREVIATIONS lxiii

1 INTRODUCTION 1-1

1.1 Description of the Proposed Action 1-4
1.2 Purpose of and Need for Action 1-5
1.3 Lead and Cooperating Agencies and Consulting Tribes 1-9
1.3.1 Lead Agencies 1-9
1.3.2 Cooperating Agencies and Consulting Tribes 1-9
1.4 Objectives and Resource Goals of the LTEMP 1-10
1.5 Scope of the EIS 1-13
1.5.1 Affected Region and Resources 1-13
1.5.2 Impact Topics Selected for Detailed Analysis 1-14
1.5.3 Impact Topics Dismissed from Detailed Analysis 1-15
1.6 Role of Adaptive Management 1-16
1.6.1 History of the Existing Adaptive Management Program 1-16
1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations 1-17
1.7 Role of Decision Analysis in the EIS Process 1-17
1.8 History, Location, and Setting 1-18
1.8.1 History and Purpose of Glen Canyon Dam 1-18
1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area 1-19
1.8.3 Operation of the Glen Canyon Dam 1-20
1.8.4 History, Purpose, and Significance of the National Park System Units 1-22
1.8.4.1 Grand Canyon National Park 1-22
1.8.4.2 Glen Canyon National Recreation Area 1-24
1.8.4.3 Lake Mead National Recreation Area 1-24
1.8.5 Tribal Lands 1-25
1.8.5.1 Fort Mojave Tribe 1-26
1.8.5.2 Havasupai Tribe 1-26
1.8.5.3 Hopi Tribe 1-27
1.8.5.4 Hualapai Tribe 1-27
1.8.5.5 Navajo Nation 1-27
1.8.5.6 Pueblo of Zuni 1-28
1.8.5.7 Southern Paiute Tribes 1-28
1.9 Laws and Regulations Related to Operations of Glen Canyon Dam and Park Management 1-29
1.9.1 Environmental Laws and Executive Orders 1-29
1.9.2 Cultural/Historical Laws and Executive Orders 1-30

CONTENTS (Cont.)

1.9.3 American Indian and Tribal Consultation Laws and Executive Orders ... 1-31
1.9.4 Laws Establishing Criteria Related to Power Marketing ... 1-31
1.9.5 Law of the River ... 1-31
1.10 Related Actions ... 1-31
1.10.1 Biological Opinions ... 1-33
1.10.2 Environmental Impact Statements and Related Documents ... 1-33
1.10.3 Environmental Assessments and Related Documents ... 1-35
1.10.4 Other Actions, Programs, Plans, and Projects ... 1-36

2 DESCRIPTION OF ALTERNATIVES ... 2-1

2.1 Development of Alternatives ... 2-2
2.2 Descriptions of Alternatives Considered in Detail ... 2-4
2.2.1 Alternative A (No Action Alternative) ... 2-8
2.2.2 Alternative B ... 2-20
2.2.3 Alternative C ... 2-23
2.2.3.1 Base Operations under Alternative C ... 2-25
2.2.3.2 Implementation Process for Experiments under Alternative C ... 2-27
2.2.3.3 Sediment-Related Experiments To Be Evaluated under Alternative C ... 2-37
2.2.3.4 Aquatic Resource-Related Experiments To Be Evaluated under Alternative C ... 2-38
2.2.4 Alternative D (Preferred Alternative) ... 2-41
2.2.4.1 Base Operations under Alternative D ... 2-44
2.2.4.2 Operational Flexibility under Alternative D ... 2-46
2.2.4.3 Implementation Process for Experiments under Alternative D ... 2-48
2.2.4.4 Communication and Consultation Process for Alternative D ... 2-57
2.2.4.5 Sediment-Related Experiments To Be Evaluated under Alternative D ... 2-58
2.2.4.6 Aquatic Resource-Related Experiments To Be Evaluated under Alternative D ... 2-62
2.2.4.7 Conservation Measures under Alternative D ... 2-72
2.2.5 Alternative E ... 2-72
2.2.5.1 Base Operations under Alternative E ... 2-72
2.2.5.2 Experimental Framework for Alternative E ... 2-75
2.2.6 Alternative F ... 2-80
2.2.7 Alternative G ... 2-81
2.3 Alternatives Considered and Eliminated from Detailed Study ... 2-84
2.3.1 Modified Low Fluctuating Flows with Extended Protocols ... 2-84

CONTENTS (Cont.)

2.3.2 Naturally Patterned Flow Alternative 2-85
2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative 2-85
2.3.4 Grand Canyon First! Alternative 2-86
2.3.5 Species Community and Habitat-Based Alternative 2-86
2.3.6 Stewardship Alternative 2-86
2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives 2-87
2.3.8 Decommission Glen Canyon Dam Alternative 2-87
2.3.9 Fill Lake Mead First Alternative 2-88
2.3.10 Full-Powerplant Capacity Operations Alternative 2-88
2.3.11 Run-of-the-River Alternative 2-88
2.4 Alternative Elements Eliminated from Detailed Study 2-89
2.4.1 New Infrastructure 2-89
2.4.2 Flow and Non-Flow Actions 2-90
2.5 Summary Comparison of Alternatives 2-91

3 AFFECTED ENVIRONMENT 3-1

3.1 Project Area 3-1
3.1.1 Colorado River Setting 3-1
3.1.2 Geologic Setting 3-3
3.1.2.1 Tribal Perspectives on Geologic Setting 3-3
3.1.3 Climatic Setting 3-4
3.1.4 Glen Canyon Dam Releases and Flow 3-5
3.1.5 Colorado River Ecosystem Resource Linkages 3-6
3.2 Water Resources 3-6
3.2.1 Hydrology 3-7
3.2.1.1 Lake Powell Hydrology 3-8
3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam 3-11
3.2.1.3 Lake Mead Hydrology 3-13
3.2.1.4 Seeps and Springs 3-14
3.2.2 Water Quality 3-16
3.2.2.1 Lake Powell Water Quality 3-16
3.2.2.2 Colorado River Water Quality 3-19
3.2.2.3 Lake Mead Water Quality 3-27
3.2.3 Tribal Perspectives on Water Resources 3-29
3.2.4 Hydrology and Climate Change 3-32
3.2.4.1 Basis for Runoff Estimates 3-32
3.2.4.2 Water Variability and Availability 3-33
3.2.4.3 Seasonal Timing Shifts 3-34
3.2.4.4 Water Quality 3-35
3.3 Sediment Resources 3-35
3.3.1 Background: Geomorphology of the Colorado River 3-35

CONTENTS (Cont.)

3.3.1.1 Geomorphic Features of the Colorado River 3-37
3.3.1.2 Glen Canyon Geomorphology 3-40
3.3.1.3 Marble and Grand Canyon Geomorphology 3-41
3.3.2 Sediment Characteristics and Transport Mechanisms 3-43
3.3.2.1 Particle Size and Sediment Supply 3-45
3.3.2.2 Sediment Transport Capacity 3-46
3.3.2.3 River Stage 3-46
3.3.3 Sediment Sources 3-46
3.3.3.1 Gaged Tributaries 3-48
3.3.3.2 Ungaged Tributaries 3-48
3.3.4 Sediment Transport and Storage 3-50
3.3.4.1 Sediment Transport 3-50
3.3.4.2 Sediment Storage 3-51
3.3.4.3 High-Flow Experiments 3-51
3.3.4.4 Sediment Supply Limitation 3-53
3.3.4.5 Sandbar Deposition and Retention 3-53
3.3.5 Lake Deltas 3-56
3.4 Natural Processes 3-57
3.5 Aquatic Ecology 3-59
3.5.1 Aquatic Food Base 3-59
3.5.1.1 Periphyton and Rooted Aquatic Plants 3-61
3.5.1.2 Plankton 3-63
3.5.1.3 Macroinvertebrates 3-63
3.5.1.4 Nonnative Invasive Species 3-66
3.5.1.5 Food Web Dynamics 3-69
3.5.2 Native Fish 3-70
3.5.2.1 Special Status Fish Species 3-72
3.5.2.2 Other Native Species 3-86
3.5.3 Nonnative Fish 3-90
3.5.3.1 Coldwater Nonnative Species 3-94
3.5.3.2 Warmwater Nonnative Species 3-100
3.5.3.3 Interactions with Native Species 3-101
3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions 3-104
3.6 Vegetation 3-109
3.6.1 Historic and Remnant Riparian Plant Communities 3-110
3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam 3-111
3.6.2.1 Tribal Perspectives on Vegetation 3-119
3.6.3 Special Status Plant Species 3-121
3.7 Wildlife 3-124
3.7.1 Invertebrates 3-125
3.7.2 Amphibians and Reptiles 3-126
3.7.3 Birds 3-127

CONTENTS (Cont.)

3.7.4 Mammals ... 3-129
3.7.5 Special Status Wildlife Species ... 3-131
3.7.5.1 Invertebrates ... 3-132
3.7.5.2 Amphibians and Reptiles ... 3-136
3.7.5.3 Birds ... 3-136
3.7.5.4 Mammals ... 3-142
3.7.6 Tribal Perspectives on Wildlife ... 3-142
3.8 Cultural Resources ... 3-144
3.8.1 Area of Potential Effect ... 3-146
3.8.2 Description of Cultural Resources and Site Types ... 3-149
3.8.2.1 Archaeological Resources ... 3-149
3.8.2.2 Historic Resources ... 3-153
3.8.2.3 Cultural Landscapes ... 3-155
3.8.2.4 Traditional Cultural Properties and Ethnographic Resources ... 3-156
3.9 Tribal Resources ... 3-156
3.9.1 Fort Mojave Indian Tribe ... 3-157
3.9.2 Havasupai ... 3-158
3.9.3 Hopi ... 3-158
3.9.4 Hualapai ... 3-159
3.9.5 Navajo Nation ... 3-162
3.9.6 Pueblo of Zuni ... 3-164
3.9.7 Southern Paiute Tribes ... 3-167
3.9.8 Indian Trust Assets and Trust Responsibility ... 3-168
3.10 Recreation, Visitor Use, and Experience ... 3-168
3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area ... 3-169
3.10.1.1 Lees Ferry Recreational Fishery ... 3-169
3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach ... 3-174
3.10.2 The Colorado River in Grand Canyon National Park ... 3-178
3.10.2.1 Campsites in Grand Canyon National Park ... 3-179
3.10.2.2 River Flow and Fluctuation ... 3-183
3.10.2.3 Hualapai Tribe Recreation Program ... 3-186
3.10.3 Recreation Use on Lake Mead and Lake Powell ... 3-187
3.10.3.1 Lake Mead National Recreation Area ... 3-187
3.10.3.2 Lake Powell, Glen Canyon National Recreation Area ... 3-187
3.10.4 Park Operations and Management ... 3-187
3.11 Wilderness ... 3-188
3.11.1 Law and Policy ... 3-189
3.11.2 Defining Wilderness Character ... 3-190
3.12 Visual Resources ... 3-192
3.12.1 Glen Canyon National Recreation Area ... 3-193

CONTENTS (Cont.)

3.12.2 Grand Canyon and the Colorado River 3-195
3.12.3 Lake Mead National Recreation Area 3-198
3.13 Hydropower 3-198
3.13.1 Power Operations 3-199
3.13.1.1 Hydropower Generation 3-199
3.13.1.2 Basin Fund 3-200
3.13.1.3 Operational Flexibility 3-201
3.13.1.4 Scheduling 3-202
3.13.1.5 Load/Generation Following and Regulation 3-203
3.13.1.6 Capacity Reserves 3-205
3.13.1.7 Disturbances and Emergencies and Outage Assistance 3-205
3.13.1.8 Transmission System 3-206
3.13.2 Power Marketing 3-206
3.13.2.1 Wholesale Rates 3-209
3.13.2.2 Retail Rates 3-209
3.14 Socioeconomics and Environmental Justice 3-209
3.14.1 The Six-County Region of Influence 3-210
3.14.1.1 Population 3-210
3.14.1.2 Income 3-211
3.14.1.3 Employment 3-211
3.14.1.4 Unemployment 3-213
3.14.1.5 Environmental Justice 3-213
3.14.2 The Seven-State Region of Influence 3-221
3.14.2.1 Population 3-221
3.14.2.2 Income 3-222
3.14.2.3 Employment 3-224
3.14.2.4 Unemployment 3-226
3.14.2.5 Environmental Justice 3-226
3.14.3 Non-Use Value 3-228
3.15 Air Quality 3-229
3.15.1 Local Air Quality 3-229
3.15.2 Regional Air Quality 3-231
3.15.3 Regional Air Emissions 3-234
3.16 Climate Change 3-236

4 ENVIRONMENTAL CONSEQUENCES 4-1

4.1 Overall Analysis and Assessment Approach 4-1
4.2 Water Resources 4-9
4.2.1 Analysis Methods 4-10
4.2.1.1 Hydrology 4-10
4.2.1.2 Water Quality 4-13
4.2.2 Summary of Impacts 4-14

CONTENTS (Cont.)

4.2.2.1 Hydrology 4-14
4.2.2.2 Water Quality 4-37
4.2.3 Alternative-Specific Impacts 4-47
4.2.3.1 Alternative A (No Action Alternative) 4-48
4.2.3.2 Alternative B 4-49
4.2.3.3 Alternative C 4-53
4.2.3.4 Alternative D (Preferred Alternative) 4-55
4.2.3.5 Alternative E 4-58
4.2.3.6 Alternative F 4-60
4.2.3.7 Alternative G 4-62
4.3 Sediment Resources 4-65
4.3.1 Analysis Methods 4-66
4.3.2 Summary of Impacts 4-70
4.3.3 Alternative-Specific Impacts 4-72
4.3.3.1 Alternative A (No Action Alternative) 4-75
4.3.3.2 Alternative B 4-77
4.3.3.3 Alternative C 4-80
4.3.3.4 Alternative D (Preferred Alternative) 4-81
4.3.3.5 Alternative E 4-84
4.3.3.6 Alternative F 4-85
4.3.3.7 Alternative G 4-86
4.4 Natural Processes 4-87
4.4.1 Analysis Methods 4-88
4.4.2 Summary of Impacts 4-88
4.4.3 Alternative-Specific Impacts 4-97
4.4.3.1 Alternative A (No Action Alternative) 4-97
4.4.3.2 Alternative B 4-97
4.4.3.3 Alternative C 4-98
4.4.3.4 Alternative D (Preferred Alternative) 4-99
4.4.3.5 Alternative E 4-99
4.4.3.6 Alternative F 4-100
4.4.3.7 Alternative G 4-101
4.5 Aquatic Ecology 4-102
4.5.1 Analysis Methods 4-102
4.5.1.1 Aquatic Food Base 4-102
4.5.1.2 Nonnative Fish 4-103
4.5.1.3 Native Fish 4-106
4.5.1.4 Aquatic Parasites 4-107
4.5.2 Summary of Impacts 4-107
4.5.2.1 Aquatic Food Base 4-107
4.5.2.2 Nonnative Fish 4-119
4.5.2.3 Native Fish 4-127
4.5.2.4 Aquatic Parasites 4-135

CONTENTS (Cont.)

4.5.3 Alternative-Specific Impacts on Aquatic Resources 4-137
4.5.3.1 Alternative A (No Action Alternative)..... 4-137
4.5.3.2 Alternative B 4-140
4.5.3.3 Alternative C 4-143
4.5.3.4 Alternative D (Preferred Alternative)..... 4-148
4.5.3.5 Alternative E..... 4-154
4.5.3.6 Alternative F..... 4-157
4.5.3.7 Alternative G..... 4-160
4.6 Vegetation 4-163
4.6.1 Analysis Methods..... 4-164
4.6.2 Summary of Impacts..... 4-168
4.6.2.1 Impacts on Old High Water Zone Vegetation..... 4-177
4.6.2.2 Impacts on New High Water Zone..... 4-179
4.6.2.3 Wetlands..... 4-185
4.6.2.4 Special Status Plant Species..... 4-187
4.6.3 Alternative-Specific Impacts 4-190
4.6.3.1 Alternative A (No Action Alternative)..... 4-191
4.6.3.2 Alternative B 4-192
4.6.3.3 Alternative C 4-194
4.6.3.4 Alternative D (Preferred Alternative)..... 4-196
4.6.3.5 Alternative E..... 4-197
4.6.3.6 Alternative F..... 4-199
4.6.3.7 Alternative G..... 4-201
4.7 Wildlife..... 4-203
4.7.1 Analysis Methods..... 4-203
4.7.2 Summary of Impacts..... 4-204
4.7.2.1 Terrestrial Invertebrates 4-204
4.7.2.2 Amphibians and Reptiles..... 4-210
4.7.2.3 Birds 4-212
4.7.2.4 Mammals..... 4-214
4.7.2.5 Special Status Species 4-216
4.7.3 Alternative-Specific Impacts on Wildlife 4-227
4.7.3.1 Alternative A (No Action Alternative)..... 4-227
4.7.3.2 Alternative B 4-229
4.7.3.3 Alternative C 4-230
4.7.3.4 Alternative D (Preferred Alternative)..... 4-231
4.7.3.5 Alternative E..... 4-232
4.7.3.6 Alternative F..... 4-233
4.7.3.7 Alternative G..... 4-234
4.8 Cultural Resources 4-235
4.8.1 Compliance with Federal Regulations..... 4-235
4.8.2 Analysis Methods..... 4-235
4.8.3 Summary of Impacts..... 4-238

CONTENTS (Cont.)

4.8.4 Alternative-Specific Impacts 4-246
4.8.4.1 Alternative A (No Action Alternative)..... 4-246
4.8.4.2 Alternative B 4-246
4.8.4.3 Alternative C 4-247
4.8.4.4 Alternative D (Preferred Alternative)..... 4-248
4.8.4.5 Alternative E..... 4-248
4.8.4.6 Alternative F..... 4-249
4.8.4.7 Alternative G..... 4-250
4.9 Tribal Resources..... 4-251
4.9.1 Tribal Resource Goals..... 4-251
4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons 4-252
4.9.1.2 Protect and Preserve Sites of Cultural Importance..... 4-254
4.9.1.3 Preserve and Enhance Respect for Canyon Life 4-256
4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons..... 4-258
4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons..... 4-259
4.9.1.6 Economic Opportunity 4-259
4.9.1.7 Maintain Tribal Water Rights and Supply 4-260
4.9.1.8 LTEMP Process..... 4-261
4.9.2 Analysis Methods..... 4-261
4.9.3 Summary of Impacts..... 4-262
4.9.4 Alternative-Specific Impacts 4-268
4.9.4.1 Alternative A (No Action Alternative)..... 4-268
4.9.4.2 Alternative B 4-270
4.9.4.3 Alternative C 4-271
4.9.4.4 Alternative D (Preferred Alternative)..... 4-273
4.9.4.5 Alternative E..... 4-274
4.9.4.6 Alternative F..... 4-276
4.9.4.7 Alternative G..... 4-277
4.10 Recreation, Visitor Use, and Experience..... 4-279
4.10.1 Analysis Methods..... 4-279
4.10.2 Summary of Impacts..... 4-281
4.10.2.1 Glen Canyon Fishing..... 4-281
4.10.2.2 Glen Canyon Day Rafting 4-290
4.10.2.3 Glen Canyon Recreational Facilities..... 4-291
4.10.2.4 Whitewater Boating..... 4-291
4.10.2.5 Reservoir Activities and Facilities 4-292
4.10.2.6 Tribal Recreation Operations 4-293
4.10.2.7 Pearce Ferry..... 4-296
4.10.2.8 Park Operations and Management 4-296

CONTENTS (Cont.)

4.10.3 Alternative-Specific Impacts 4-297
4.10.3.1 Alternative A (No Action Alternative) 4-297
4.10.3.2 Alternative B 4-298
4.10.3.3 Alternative C 4-300
4.10.3.4 Alternative D (Preferred Alternative) 4-301
4.10.3.5 Alternative E 4-303
4.10.3.6 Alternative F 4-304
4.10.3.7 Alternative G 4-306
4.11 Wilderness 4-307
4.11.1 Analysis Methods 4-307
4.11.2 Summary of Impacts 4-308
4.11.3 Alternative-Specific Impacts 4-313
4.11.3.1 Alternative A (No Action Alternative) 4-314
4.11.3.2 Alternative B 4-314
4.11.3.3 Alternative C 4-315
4.11.3.4 Alternative D (Preferred Alternative) 4-316
4.11.3.5 Alternative E 4-317
4.11.3.6 Alternative F 4-317
4.11.3.7 Alternative G 4-318
4.12 Visual Resources 4-319
4.13 Hydropower 4-322
4.13.1 Analysis Methods 4-322
4.13.1.1 Hydropower Resource and Capacity Expansion Impacts 4-323
4.13.1.2 Wholesale Rate Impacts 4-330
4.13.1.3 Retail Rate Impacts 4-332
4.13.1.4 Hoover Dam Impacts 4-333
4.13.2 Summary of Hydropower Impacts 4-334
4.13.2.1 Monthly Water Release Impacts 4-334
4.13.2.2 Hydropower Power Generation and Capacity Impacts 4-340
4.13.2.3 Economic Impacts 4-343
4.13.2.4 Change in FES Wholesale Rates 4-349
4.13.2.5 Retail Rate and Bills Impacts 4-350
4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics 4-351
4.13.3 Alternative-Specific Impacts 4-353
4.13.3.1 Alternative A (No Action Alternative) 4-353
4.13.3.2 Alternative B 4-353
4.13.3.3 Alternative C 4-354
4.13.3.4 Alternative D (Preferred Alternative) 4-355
4.13.3.5 Alternative E 4-358
4.13.3.6 Alternative F 4-359
4.13.3.7 Alternative G 4-360

CONTENTS (Cont.)

4.14 Socioeconomics and Environmental Justice 4-362
4.14.1 Analysis Methods 4-362
4.14.1.1 Recreational Use and Environmental Non-Use Values 4-362
4.14.1.2 Recreational Economic Impacts 4-364
4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts 4-364
4.14.1.4 Environmental Justice 4-365
4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice 4-365
4.14.2.1 Recreational Use Values 4-365
4.14.2.2 Environmental Non-Use Values 4-378
4.14.2.3 Recreational Economic Impacts 4-379
4.14.2.4 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts 4-382
4.14.2.5 Environmental Justice Impacts 4-384
4.14.3 Alternative-Specific Impacts 4-390
4.14.3.1 Alternative A (No Action Alternative) 4-390
4.14.3.2 Alternative B 4-391
4.14.3.3 Alternative C 4-393
4.14.3.4 Alternative D (Preferred Alternative) 4-395
4.14.3.5 Alternative E 4-396
4.14.3.6 Alternative F 4-398
4.14.3.7 Alternative G 4-400
4.15 Air Quality 4-402
4.15.1 Analysis Methods 4-402
4.15.2 Summary of Impacts 4-403
4.15.3 Alternative-Specific Impacts 4-409
4.15.3.1 Alternative A (No Action Alternative) 4-409
4.15.3.2 Alternative B 4-409
4.15.3.3 Alternative C 4-410
4.15.3.4 Alternative D (Preferred Alternative) 4-410
4.15.3.5 Alternative E 4-410
4.15.3.6 Alternative F 4-411
4.15.3.7 Alternative G 4-411
4.16 Climate Change 4-411
4.16.1 Analysis Methods 4-412
4.16.1.1 Effects of LTEMP Alternatives on Climate Change 4-412
4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources 4-413
4.16.2 Summary of Impacts 4-414
4.16.2.1 Effects of LTEMP Alternatives on Climate Change 4-414
4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources 4-419

CONTENTS (Cont.)

4.16.3 Alternative-Specific Impacts 4-421
4.16.3.1 Alternative A (No Action Alternative)..... 4-421
4.16.3.2 Alternative B 4-424
4.16.3.3 Alternative C 4-424
4.16.3.4 Alternative D (Preferred Alternative)..... 4-424
4.16.3.5 Alternative E..... 4-425
4.16.3.6 Alternative F..... 4-425
4.16.3.7 Alternative G..... 4-426
4.17 Cumulative Impacts..... 4-426
4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts..... 4-426
4.17.1.1 Past and Present (Ongoing) Actions..... 4-427
4.17.1.2 Reasonably Foreseeable Future Actions 4-442
4.17.2 Climate-Related Changes..... 4-445
4.17.3 Cumulative Impacts Summary by Resource..... 4-446
4.17.3.1 Water Resources..... 4-446
4.17.3.2 Sediment Resources 4-457
4.17.3.3 Natural Processes 4-458
4.17.3.4 Aquatic Ecology..... 4-458
4.17.3.5 Vegetation 4-461
4.17.3.6 Wildlife..... 4-463
4.17.3.7 Cultural Resources 4-466
4.17.3.8 Tribal Resources..... 4-467
4.17.3.9 Recreation, Visitor Use, and Experience..... 4-468
4.17.3.10 Wilderness..... 4-469
4.17.3.11 Visual Resources..... 4-470
4.17.3.12 Hydropower..... 4-471
4.17.3.13 Socioeconomics and Environmental Justice 4-472
4.17.3.14 Air Quality and Climate Change..... 4-472
4.18 Unavoidable Adverse Impacts..... 4-474
4.19 Relationship between Short-Term Use and Long-Term Productivity..... 4-475
4.20 Irreversible and Irretrievable Commitments of Resources..... 4-475

5 CONSULTATION AND COORDINATION 5-1

5.1 Consultation and Coordination with Other Agencies and Programs 5-1
5.1.1 U.S. Department of the Interior 5-1
5.1.2 Cooperating Agencies..... 5-1
5.1.3 American Indian Tribes 5-2
5.1.4 Other Consultations 5-6
5.1.4.1 National Historic Preservation Act..... 5-6
5.1.4.2 State and Local Water and Power Agency Coordination..... 5-7
5.1.4.3 U.S. Fish and Wildlife Service..... 5-7

CONTENTS (Cont.)

5.2 Public Involvement 5-8
5.2.1 Public Scoping Process and Comments Received 5-8
5.2.2 Public Meetings on Alternatives 5-10
5.2.3 Glen Canyon Dam Adaptive Management Working Group 5-11
5.2.4 Public Involvement on the LTEMP DEIS 5-11

6 REFERENCES 6-1

7 LIST OF PREPARERS 7-1

8 GLOSSARY 8-1

APPENDIX A: Adaptive Management Working Group Desired Future Conditions A-1

A.1 Desired Future Conditions: Colorado River Ecosystem A-5
A.1.1 DFC Description A-5
A.1.2 DFC Background and Legislation A-6
A.1.3 Why the Colorado River Ecosystem DFCs Are Important A-6
A.1.4 Colorado River Ecosystem DFCs A-6
A.1.4.1 Sediment-Related Resources DFCs A-6
A.1.4.2 Water Quality DFCs A-7
A.1.4.3 Colorado River Ecosystem Aquatic Resource DFCs A-7
A.1.4.4 Colorado River Ecosystem Riparian Resource DFCs A-9
A.1.5 Colorado River Ecosystem DFCs Additional Information A-9
A.1.5.1 Colorado River Ecosystem Linkages A-9
A.1.5.2 Colorado River Ecosystem Metrics A-10
A.2 Power Desired Future Conditions A-10
A.2.1 Power DFC Description A-10
A.2.2 Power DFC Background and Legislation A-10
A.2.3 Why the Power DFC Is Important A-11
A.2.4 Power DFCs A-11
A.2.5 Power DFC Additional Information A-12
A.2.5.1 Power Linkages A-12
A.2.5.2 Power Metrics A-12
A.3 Cultural Resources Desired Future Conditions A-13
A.3.1 Cultural Resources DFC Description A-13
A.3.2 DFC Background and Legislation A-13
A.3.3 Why the Cultural Resources DFCs Are Important A-13
A.3.4 NRHP Eligible Historic Properties DFCs A-14
A.3.4.1 Prehistoric Archaeological Sites and Historic Sites A-14
A.3.4.2 Traditional Cultural Properties A-14
A.3.5 NRHP Eligible Historic Properties DFC Additional Information A-15
A.3.5.1 NRHP Eligible Historic Properties Linkages A-15

CONTENTS (Cont.)

A.3.5.2 NRHP Eligible Historic Properties Metrics A-16
A.3.6 Resources of Traditional Cultural Significance but Not NRHP Eligible A-16
A.3.7 Resources of Traditional Cultural Significance DFCs A-16
A.3.8 Resources of Traditional Cultural Significance Linkages A-17
A.3.9 Resources of Traditional Cultural Significance Metrics A-17
A.4 Recreation Desired Future Conditions A-17
A.4.1 Recreation DFC Description A-17
A.4.2 DFC Background and Legislation A-17
A.4.3 Why the Recreation DFC Is Important A-18
A.4.3.1 Grand Canyon National Park A-18
A.4.3.2 Glen Canyon National Recreation Area A-18
A.4.4 Recreation DFCs A-18
A.4.4.1 River Recreation in Grand Canyon National Park A-18
A.4.4.2 River Recreation in Glen Canyon National Recreation Area A-19
A.4.4.3 Blue Ribbon Trout Fishery in Glen Canyon National Recreation Area A-19
A.4.4.4 River Corridor Stewardship A-19
A.4.5 Recreation DFC Additional Information A-20
A.4.6 Recreation Linkages A-20
A.4.7 Recreation Metrics A-20
A.5 Reference A-21

APPENDIX B: Performance Metrics Used to Evaluate Alternatives B-1

B.1 Aquatic Ecology B-3
B.1.1 Humpback Chub B-3
B.1.2 Other Native Fish B-5
B.1.3 Trout Fishery B-5
B.1.4 Nonnative Aquatic Species B-6
B.2 Archaeological and Cultural Resources B-7
B.3 Hydropower and Energy B-9
B.4 Natural Processes B-10
B.5 Recreational Experience B-11
B.5.1 Grand Canyon Metrics B-11
B.5.2 Glen Canyon Metrics B-15
B.6 Riparian Vegetation B-16
B.7 Sediment B-18
B.8 Tribal Resources B-18
B.9 Water Delivery B-24
B.10 References B-25

CONTENTS (Cont.)

APPENDIX C: Decision Analysis to Support Development of the Glen Canyon Dam Long-Term Experimental and Management Plan C-1

APPENDIX D: Hydrology Technical Information and Analysis D-1

D.1 Analysis Methods D-3
D.1.1 Background D-3
D.1.2 Initial Conditions D-4
D.1.3 Reservoir Operations D-4
D.1.3.1 Upper Basin Reservoirs above Lake Powell D-4
D.1.3.2 Lake Powell and Lake Mead D-5
D.1.3.3 Lake Mohave and Lake Havasu D-9
D.1.4 Representation of the Different Alternatives in CRSS D-9
D.1.4.1 Experimental Components Modeled in CRSS D-22
D.1.5 Input Hydrology D-23
D.1.6 Input Demands D-26
D.1.7 Other Key Assumptions D-26
D.2 Supplemental Information on Impact Modeling D-27
D.2.1 Low Summer Flows D-27
D.2.2 Modeled Annual Releases Extending beyond the End of the Water Year D-28
D.2.3 Lake Elevation D-29
D.3 References D-36

APPENDIX E: Sediment Resources Technical Information and Analysis E-1

E.1 Introduction E-3
E.1.1 Analysis Period E-3
E.1.2 General Scope E-3
E.2 Methods E-4
E.2.1 Sand Budget Model E-4
E.2.1.1 Model Description E-4
E.2.1.2 Sand Budget Model Modifications E-5
E.2.1.3 Modified Sand Budget Model Inputs E-6
E.2.2 Sediment Metrics E-8
E.2.2.1 Sand Load Index E-9
E.2.2.2 Standard Deviation of High Flows E-9
E.2.2.3 Sand Mass Balance Index E-10
E.3 Results E-10
E.3.1 HFEs Determined by Alternative E-10
E.3.2 Metrics E-11
E.3.2.1 Sand Load Index E-12
E.3.2.2 Standard Deviation of High Flows E-12

CONTENTS (Cont.)

E.3.3 Sand Mass Balance Index E-12
E.3.4 Alternative Performance under Climate Change Scenarios E-13
E.3.5 Relative Impacts of Dam Operations and Hydrology on Performance E-13
E.4 Lake Deltas E-15
E.5 Limitations and Known Issues E-17
E.5.1 Geographic Scope E-17
E.5.2 Modeling Improvements E-17
E.6 References E-18

APPENDIX F: Aquatic Resources Technical Information and Analysis F-1

F.1 Introduction F-3
F.2 Aquatic Food Base Assessment F-4
F.2.1 Description of the Aquatic Food Base Downstream from Glen Canyon Dam F-4
F.2.1.1 The Aquatic Food Base Prior to Construction of Glen Canyon Dam F-5
F.2.1.2 The Aquatic Food Base of the Colorado River Downstream from Glen Canyon Dam F-5
F.2.1.3 Influence of New Zealand Mudsnail on the Aquatic Food Base F-13
F.2.2 Impacts of LTEMP Alternatives on the Aquatic Food Base F-14
F.2.2.1 Flow Effects on the Aquatic Food Base F-15
F.2.2.2 Temperature Effects on the Aquatic Food Base F-23
F.2.3 Conclusion F-26
F.3 Modeling Effects of LTEMP Alternatives on Rainbow Trout and Humpback Chub F-28
F.3.1 Model Overview F-28
F.3.1.1 Glen Canyon Trout Submodel F-29
F.3.1.2 Trout Movement Submodel F-36
F.3.1.3 Humpback Chub Population Submodel F-40
F.3.2 Results for LTEMP Alternatives F-52
F.3.2.1 Rainbow Trout Performance Measures F-52
F.3.2.2 Humpback Chub Performance Measures F-60
F.4 Modeling the Effects of LTEMP Alternatives on Temperature Suitability F-62
F.4.1 Model Overview F-64
F.4.2 Humpback Chub Aggregations F-67
F.4.2.1 Historic Temperature Suitability for Humpback Chub F-69
F.4.2.2 Results for LTEMP Alternatives F-70
F.4.3 Other Native Fish F-71
F.4.3.1 Historic Temperature Suitability for Native Fish F-73
F.4.3.2 Results for LTEMP Alternatives F-73

CONTENTS (Cont.)

F.4.4 Nonnative Fish F-78
F.4.4.1 Historic Temperature Suitability for Nonnative Fish F-79
F.4.4.2 Results for LTEMP Alternatives F-79
F.4.5 Aquatic Parasites F-81
F.4.5.1 Historic Temperature Suitability for Aquatic Parasites F-84
F.4.5.2 Results for LTEMP Alternatives F-86
F.5 References F-90

APPENDIX G: Vegetation Technical Information and Analysis G-1

G.1 Analysis Methods G-3
G.1.1 Old High-Water Zone Analysis G-4
G.1.2 New High-Water Zone G-5
G.1.2.1 Native Cover Metric G-6
G.1.2.2 Native Diversity Metric G-7
G.1.2.3 Native/Nonnative Ratio Metric G-7
G.1.2.4 Arrowweed Metric G-8
G.1.2.5 Overall Score G-8
G.1.3 Wetlands G-9
G.2 Alternative-Specific Impacts G-10
G.2.1 Alternative A (No Action Alternative) G-10
G.2.2 Alternative B G-10
G.2.3 Alternative C G-10
G.2.4 Alternative D (Preferred Alternative) G-11
G.2.5 Alternative E G-11
G.2.6 Alternative F G-12
G.2.7 Alternative G G-12
G.3 Summary G-12
G.4 References G-13

APPENDIX H: Cultural Resources Technical Information and Analysis H-1

H.1 Wind Transport of Sediment H-3
H.1.1 Wind Transport of Sediment—Methods H-4
H.1.2 Wind Transport of Sediment—Results H-5
H.2 Flow Effects on Cultural Resources in Glen Canyon H-8
H.2.1 Flow Effects on Cultural Resources in Glen Canyon—Methods H-9
H.2.2 Flow Effects on Cultural Resources in Glen Canyon—Results H-10
H.3 Time Off River H-13
H.3.1 Time Off River—Methods H-13
H.3.2 Time Off River—Results H-14
H.4 References H-16

CONTENTS (Cont.)

APPENDIX I: Tribal Resources Technical Information and Analysis I-1

I.1 Quantifiable Measures Used to Assess Impacts on Tribal Resources..... I-4
I.1.1 Riparian Diversity..... I-4
I.1.2 Wetland Abundance..... I-8
I.1.3 Trout Management Flows..... I-10
I.1.4 Mechanical Removal of Trout..... I-12
I.1.5 Water Levels at Lake Powell..... I-14
I.1.6 Access to Resources..... I-17
I.2 References..... I-18

APPENDIX J: Recreation, Visitor Use, and Experience Technical Information and Analysis..... J-1

J.1 Recreational Experience Metrics..... J-3
J.1.1 Grand Canyon Metrics..... J-4
J.1.2 Glen Canyon Metrics..... J-4
J.2 Metric Definitions, Analysis Methods, and Results..... J-5
J.2.1 Camping Area Index..... J-5
J.2.1.1 Camping Area Index—Methods..... J-6
J.2.1.2 Camping Area Index—Results..... J-7
J.2.2 Navigational Risk Index..... J-8
J.2.2.1 Navigational Risk Index—Methods..... J-9
J.2.2.2 Navigational Risk Index—Results..... J-10
J.2.3 Fluctuation Index..... J-11
J.2.3.1 Fluctuation Index—Methods..... J-12
J.2.3.2 Fluctuation Index—Results..... J-13
J.2.4 Time Off River..... J-14
J.2.4.1 Time Off River Index—Methods..... J-14
J.2.4.2 Time Off River Index—Results..... J-15
J.2.5 Glen Canyon Rafting Use..... J-15
J.2.5.1 Glen Canyon Rafting Use Metric—Methods..... J-17
J.2.5.2 Glen Canyon Rafting Use Metric—Results..... J-18
J.2.6 Glen Canyon Inundation Metric..... J-18
J.2.6.1 Glen Canyon Inundation Metric—Methods..... J-19
J.2.6.2 Glen Canyon Inundation Metric—Results..... J-21
J.3 Lake Powell and Lake Mead Dock Access..... J-21
J.4 Summary..... J-26
J.5 References..... J-26

CONTENTS (Cont.)

APPENDIX K: Hydropower Systems Technical Information and Analysis K-1

K.1 Economic Value of Glen Canyon Dam Powerplant Capacity and Energy Production K-3
K.1.1 Power Systems Background K-3
K.1.2 Glen Canyon Dam, Reservoir, and Powerplant Background K-5
K.1.3 Power Systems Geographic Scope K-8
K.1.3.1 Top Tier: General Western Interconnection Perspective Modeling K-9
K.1.3.2 Middle Tier: LTF Customer Utility Systems K-11
K.1.3.3 Bottom Tier: WAPA SLCA/IP Hydropower Resources K-15
K.1.4 Overview of Power Systems Methods K-16
K.1.5 Description of Individual Power System Models K-20
K.1.5.1 Colorado River Simulation System Model K-20
K.1.5.2 Representative Trace Tool K-21
K.1.5.3 Hydropower Outage Model K-21
K.1.5.4 Generation and Transmission Maximization-Lite K-21
K.1.5.5 Sand Budget Model K-29
K.1.5.6 Large SLCA/IP Powerplant Spreadsheets K-29
K.1.5.7 Small SLCA/IP Powerplant Spreadsheet K-30
K.1.5.8 Loads Shaping Algorithm K-30
K.1.5.9 AURORA K-31
K.1.5.10 LMP Calibration Spreadsheet K-34
K.1.5.11 Firm Capacity Spreadsheet K-35
K.1.6 SLCA/IP Market System, Data Sources, and Model K-38
K.1.6.1 Historical Data Sources K-38
K.1.6.2 AURORA Model Dispatch Results for 2013 ..... K-42
K.1.6.3 SLCA/IP Market System Projections K-43
K.1.7 Glen Canyon Dam Powerplant Capacity Cost and Benefit Methodology K-59
K.1.7.1 Treatment of Glen Canyon Dam Capital and Fixed O&M Costs K-61
K.1.7.2 WAPA's SLCA/IP LTF Obligations and Glen Canyon Dam Replacement Capacity K-61
K.1.7.3 WAPA SLCA/IP Firm Hydropower Capacity K-62
K.1.7.4 Firm Capacity Curves for LTEMP Power Systems Analyses for the Peak Month of August K-79
K.1.7.5 AURORA Capacity Expansion Reserve Margin Targets and Capacity Additions K-82
K.1.7.6 Dispatch Performed by AURORA Model Capacity Expansion Runs K-86
K.1.7.7 Rationale for the Selection of Hydrology Conditions Used for Capacity Expansion Runs K-90

CONTENTS (Cont.)

K.1.8 Glen Canyon Dam Energy Economic Benefits Methodology K-90
K.1.9 Net Present Value Calculations and Study Period Adjustments K-94
K.1.10 Power Systems Results K-96
K.1.10.1 Main Drivers of Differences among Alternatives K-97
K.1.10.2 Capacity Expansion Modeling K-101
K.1.10.3 Economic Impacts K-108
K.1.10.4 Sensitivity of Results to Exceedance Level K-116
K.1.10.5 Sensitivity of Results to Discount Rate K-121
K.1.10.6 Sensitivity of Results to the Base Capacity Expansion Path K-121
K.1.10.7 Sensitivity of Results to the Assumed Future Hydrological Conditions K-123
K.1.10.8 Sensitivity of Results to Changes in Ancillary Services K-125
K.1.10.9 Sensitivity of Results to Customer Capacity Expansion Assumptions K-129
K.1.10.10 Summary of Economic Ranking K-131
K.2 WAPA's SLCA/IP Firm Electric Service Rate Impacts K-131
K.2.1 Relationship between the Economic Impacts of LTEMP Alternatives and Impacts on SLCA/IP FES Rates K-133
K.2.2 Temporal Scope of the Analysis and Input Data K-133
K.2.3 SLCA/IP Rate Setting K-134
K.2.4 Calculation of Net Electrical Energy Expense K-135
K.2.4.1 SLCA/IP Electrical Production K-135
K.2.4.2 Sustainable Hydropower and Available Hydropower Capacity and Energy K-135
K.2.5 Calculation of Capacity Expenses and Total Net Costs K-139
K.2.6 WAPA Replacement Resources K-143
K.2.7 Post-2024 Marketing Period K-144
K.2.8 Power Repayment Studies to Determine Rate Impacts K-146
K.2.8.1 PRS Expenses K-146
K.2.8.2 PRS Revenue Distribution K-149
K.2.8.3 The SLCA/IP PRS K-149
K.2.8.4 Standard PRS Rate-Setting Method Versus the Method Used in This Analysis K-150
K.2.9 Results K-150
K.2.9.1 Pinch-Point Year K-152
K.2.10 Definitions Used in Section K.2 ..... K-153
K.3 Impacts on Retail Electricity Rates K-154
K.3.1 Analysis Approach K-154
K.3.1.1 Database of Sales, Rates, and SLCA/IP Allocation for Retail Utility Systems K-156
K.3.1.2 Incorporation of Power Systems Analysis and Capital Recovery Factors K-158

CONTENTS (Cont.)

K.3.1.3 Inflation Rates, Sales Growth, and Interest Rates from EIA K-161
K.3.1.4 Calculation Process for Computing Rate and Bill Impacts K-162
K.3.2 Results K-167
K.3.2.1 Grid Cost Changes Relative to WAPA Wholesale Revenues K-168
K.3.2.2 Retail Rate Changes for Individual Systems and SLCA/IP Power Relative to Total Resources K-169
K.3.2.3 Using Regression Equations to Approximate Retail Rate Changes for Systems Not Included in the Database K-171
K.3.3 Summary of Impacts K-172
K.3.3.1 Average Rate Impacts under LTEMP Alternatives over the 20-Year LTEMP Period K-172
K.3.3.2 Average Year-by-Year Rate Impacts K-174
K.3.3.3 Individual System Impacts and Summary Descriptions of LTEMP Alternatives K-179
K.3.4 Impacts on Small Systems K-185
K.3.5 Alternative-Specific Impacts K-187
K.3.5.1 Alternative A K-187
K.3.5.2 Alternative B K-187
K.3.5.3 Alternative C K-188
K.3.5.4 Alternative D K-189
K.3.5.5 Alternative E K-189
K.3.5.6 Alternative F K-190
K.3.5.7 Alternative G K-190
K.4 Financial Impacts of LTEMP Alternatives on American Indian Tribes K-190
K.4.1 Contractual Requirements for Calculating and Delivering Benefits to Tribes K-192
K.4.2 Calculation of Tribal Benefit Baseline under Alternative A (No Action Alternative) K-193
K.4.3 Calculation of Change in Tribal Benefit as a Result of LTEMP EIS Alternatives K-193
K.4.4 Impacts on Tribes through a Change in the Retail Rate of the Electrical Supplier to Tribal Lands K-194
K.4.5 Calculation of Tribal Impacts for Tribes That Are Direct SLCA/IP Recipients K-195
K.4.6 Total Impact of LTEMP EIS Alternatives: Benefit Change and Rate Effect K-196
K.4.7 Total Impact on Tribes and Tribal Members Versus Retail Rate Changes to Households K-202
K.4.8 Conclusions K-202
K.5 Impacts of LTEMP Alternatives on Lake Mead and the Hoover Dam Powerplant K-206

CONTENTS (Cont.)

K.5.1 Hoover Analysis Methods, Model, and Supporting Data K-209
K.5.2 Hoover Monthly Energy Production and Water-to-Power Conversion K-210
K.5.3 Hoover Maximum Operational Capacity and Firm Capacity K-213
K.5.4 Economic Value of Hoover Powerplant Energy K-213
K.5.5 Sensitivity of Model Results K-214
K.6 References K-215
Attachment K.1: Geographic Scope of the Analysis K-219
Attachment K.2: AURORA Western Interconnection Spot Market Energy Prices Adjustments K-223
Attachment K.3: Selection of Representative Trace K-226
Attachment K.4: Discounting Procedures K-244
Attachment K.5: Forced Outage Scenario Generation for Hydroelectric Power Facilities K-247
Attachment K.6: Forecast of Monthly Peak Loads and Energy by SLCA/IP Long-Term Firm Customer K-250
Attachment K.7: Analysis of the Timing of the Peak Load K-252
Attachment K.8: Analysis of Capacity Determinations — Comparing Results Using a Range of Exceedence Levels and Two Summer Peak Months K-258
Attachment K.9: Results of a Survey of Electric Utility Integrated Resource Plans K-260
Attachment K.10: Indices Used for Converting Dollars from One Year to Another K-270
Attachment K.11: Summary IRP of Capacity Additions in the Joint System and Surrounding Utility Systems through the End of CY2034 ..... K-275
Attachment K.12: Annual SLCA/IP Allocations to American Indian Tribes and Benefit Information K-277

APPENDIX L: Socioeconomic Technical Information and Analysis L-1

L.1 Recreation Economic Analyses L-3
L.1.1 Recreation Use Values L-3
L.1.1.1 Lake_Full Utility Model L-4
L.1.1.2 GCRec_Full Utility Model L-5
L.1.2 Recreation Non-Use Values L-6
L.1.3 Regional Recreation Economic Impacts L-10
L.1.4 Estimates of Recreational Economic Impacts L-12
L.2 Regional Electricity Analyses L-13
L.2.1 Regional Electricity Price Impacts L-13
L.2.2 Regional Electricity Generating Capacity Expansion Impacts L-15
L.3 Additional Socioeconomic Data L-15
L.3.1 Urban Population in the Six-County Region L-15
L.3.2 Urban Income in the Six-County Region L-20
L.4 References L-21

CONTENTS (Cont.)

APPENDIX M: Air Quality and Climate Change Technical Information and Analysis M-1

M.1 Analysis Methods M-4
M.1.1 System Power Generation M-4
M.1.2 Spot Market M-5
M.1.3 Generation Type M-6
M.2 Results M-6
M.2.1 SO_2 and NO_X M-6
M.2.2 GHG Emissions M-8
M.3 References M-9

APPENDIX N: Government-to-Government and National Historic Preservation Act Consultation N-1

N.1 Government-to-Government Consultation N-3
N.2 Consultation with the State Historic Preservation Office N-31
N.3 Reference N-31
Attachment N.1 ..... N-33
Attachment N.2 ..... N-75
Attachment N.3 ..... N-137

APPENDIX O: Biological Assessment for the Glen Canyon Dam Long-Term Experimental and Management Plan O-1

APPENDIX P: High-Flow Experiment Protocol for the Preferred Alternative P-1

P.1 Decision-Making Process P-3
P.1.1 Planning P-4
P.1.2 Modeling P-5
P.1.3 Decision and Implementation P-8
P.2 Operation of Glen Canyon Dam under the HFE Protocol P-9
P.2.1 Potential Operation of Glen Canyon Dam during the Fall HFE Implementation Window P-10
P.2.2 Potential Operation of Glen Canyon Dam during the Spring HFE Implementation Window P-10
P.3 High Flow Experiments to be Evaluated under the Preferred Alternative P-11
P.3.1 Sediment-Triggered Spring HFEs P-11
P.3.2 Proactive Spring HFEs P-12
P.3.3 Sediment-Triggered Fall HFEs P-13
P.3.4 Extended-Duration Fall HFEs P-13
REFERENCES P-14

APPENDIX Q: Responses to Public Comments on the Glen Canyon Dam Long-Term Experimental and Management Plan Draft Environmental Impact Statement Q-1

FIGURES

1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands 1-5

1-2 Glen Canyon Dam..... 1-6

1-3 Map of the Colorado River between Lake Powell and Lake Mead 1-20

1-4 Indian Reservations within or Adjacent to the LTEMP EIS Project Area..... 1-25

2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an 8.23-maf Year Based on Values Presented in Table 2-3 2-18

2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year 2-18

2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-19

2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4 2-21

2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year 2-22

2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-22

2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year 2-24

2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year..... 2-24

2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B for a Week in July in an 8.23-maf Year 2-25

2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5.... 2-26

2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year 2-28

2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-28

2-13 Decision Tree for Sediment-Related Actions under Alternative C..... 2-29

FIGURES (Cont.)

2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C 2-30

2-15 Example Implementation of a Two-Cycle TMF in June and July with Resumption of Normal Fluctuations between Cycles and Afterward 2-40

2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-6 2-42

2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8 2-45

2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year 2-47

2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-47

2-20 Decision Tree for Implementation of Sediment-Related Experimental Treatments under Alternative D..... 2-55

2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental Treatments under Alternative D..... 2-56

2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative D in an 8.23-maf Year Based on the Values Presented in Table 2-10 2-69

2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11 2-74

2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year..... 2-74

2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-75

2-26 Decision Tree for Sediment-Related Actions under Alternative E 2-76

2-27 Decision Tree for Trout-Related Actions under Alternative E..... 2-77

2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12 2-82

FIGURES (Cont.)

2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an 8.23-maf Year Based on Values Presented in Table 2-13 2-83

3.1-1 LTEMP Project Area and Surrounding Lands 3-2

3.2-1 Map of Lake Powell and Associated Major Tributaries 3-8

3.2-2 Pattern of Annual Historic Flows at Lees Ferry 3-12

3.2-3 Map of Lake Mead and Associated Major Tributaries 3-13

3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River 3-16

3.2-5 Water Temperature at Lees Ferry 3-18

3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 3-21

3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge 3-22

3.3-1 Geomorphic Features of the Colorado River 3-36

3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River 3-38

3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building 3-38

3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River 3-40

3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam 3-42

3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 3-42

3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River 3-44

3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers 3-49

3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE 3-52

FIGURES (Cont.)

3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates 3-54

3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE 3-55

3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 3-57

3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam 3-71

3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead 3-74

3.5-3 Estimated Adult Humpback Chub Abundance from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age 3-75

3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 3-76

3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence, 1995 to Present 3-81

3.5-6 Mean Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 3-96

3.5-7 Mean Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 3-99

3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam ... 3-114

3.7-1 Riparian Zones Used by Nesting Birds 3-124

3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor 3-135

3.8-1 Spencer Steamboat 3-148

3.8-2 A Roasting Pit Feature in a Grand Canyon Dune 3-148

FIGURES (Cont.)

3.8-3 An Archaic Period Site on the Colorado River in GCNP 3-151

3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA 3-151

3.8-5 Puebloan Era Architecture along the Colorado River in GCNP 3-152

3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA 3-155

3.10-1 Glen Canyon Reach Rainbow Trout 3-170

3.10-2 Mean Rainbow Trout Catch Per Unit Effort of Both Boat Anglers and Shore-Line Anglers from Creel Surveys at Lees Ferry 3-171

3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 and 2009..... 3-172

3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 3-173

3.10-5 Designated Campsite Areas in the Glen Canyon Reach 3-175

3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite 3-176

3.10-7 Pontoon Raft Operated by Colorado River Discovery..... 3-176

3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month 3-179

3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP..... 3-181

3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 3-182

3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006..... 3-182

3.12-1 Glen Canyon Viewed from the Colorado River 3-194

3.12-2 Horseshoe Bend 3-194

3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip 3-196

3.12-4 Colorado River and Granaries at Nankoweap..... 3-196

FIGURES (Cont.)

3.12-5 Entrance to Havasu Canyon 3-197

3.12-6 Vasey's Paradise 3-197

3.14-1 Minority Population Groups in the 11-County Area 3-219

3.14-2 Low-Income Population Groups in the 11-County Area 3-220

3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area 3-233

3.15-2 PSD Class I Areas in the 11-State Affected Area 3-235

3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand 3-238

4-1 Integrated Multiple-Resource Modeling Framework Showing Inputs, Intermediate Calculations, and Output 4-3

4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values 4-6

4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes 4-22

4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-24

4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-27

4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios..... 4-29

4.2-5 Lake Powell and Lake Mead End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives 4-32

4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces and Seven Alternatives 4-33

FIGURES (Cont.)

4.2-7 Percentage of Time in Different Operating Tier than Alternative 4-34

4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces..... 4-35

4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces..... 4-36

4.2-10 Frequency of Occurrence of Modeled Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives 4-37

4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases 4-39

4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives..... 4-40

4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives 4-42

4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry 4-46

4.3-1 Conceptual Depiction of the Sand Load Index 4-67

4.3-2 Conceptual Depiction of the Sand Mass Balance Model..... 4-68

4.3-3 Variation in Lake Powell Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-75

4.3-4 Variation in Lake Mead Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-76

4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives..... 4-77

4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-78

4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-79

4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem..... 4-89

FIGURES (Cont.)

4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios 4-121

4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives 4-123

4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives 4-124

4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-125

4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-127

4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations 4-129

4.5-7 Mean Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence and at Pumpkin Spring under Each Alternative..... 4-130

4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives 4-131

4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-135

4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam..... 4-136

4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam..... 4-177

FIGURES (Cont.)

4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-178

4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-179

4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model 4-187

4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives 4-243

4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives 4-245

4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives 4-288

4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS 4-326

4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives 4-341

4.13-3 Total NPV of Hoover Powerplant Energy over a 20-Year Period under LTEMP Alternatives 4-352

4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period 4-407

4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change 4-415

4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces 4-416

4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives 4-420

D-1 Operating Tiers as Specified by the 2007 Interim Guidelines for the Operations of Lake Powell and Lake Mead D-7

D-2 Monthly Releases for Each Alternative in an 8.23-maf Release Year D-21

FIGURES (Cont.)

D-3 Locations of CRSS 29 Natural Flow Nodes D-24

D-4 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell Annual Inflow, Lake Powell Water-Year Release Volume, and Lake Powell Monthly Release Volume D-25

D-5 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell End-of-December Water Elevations at the 10th, 50th, and 90th Percentiles D-25

D-6 Occurrences of Low Summer Flows in Applicable Alternatives D-28

D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the End of the Water Year per 20-yr Trace for Each of the Alternatives D-29

D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the Water-Year Releases by Trace for Each of the Alternatives D-30

D-9 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and B D-30

D-10 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and C D-31

D-11 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and D D-31

D-12 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and E D-32

D-13 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and F D-32

D-14 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and G D-33

D-15 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and B D-33

D-16 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and C D-34

FIGURES (Cont.)

D-17 Percentage of Traces below Lake Powell's Minimum Power and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and D D-34

D-18 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and E D-35

D-19 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and F D-35

D-20 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and G D-36

E-1 Comparison of Calendar, Water, and Sediment Years E-20

E-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output E-21

E-3 Conceptual Schematic of the Sand Budget Model E-22

E-4 Historical Paria Sediment Load per Accounting Period and the 20.5-year Load for the Trace That Begins in Each Fall Accounting Period E-22

E-5 Sediment Traces s1, s2, and s3 for the Paria River Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-6 Little Colorado River Sediment Traces for s1, s2, and s3 Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-7 Conceptual Representation of the Sand Mass Balance Index E-24

E-8 Average Sediment and Hydrology Triggered HFE Count by Type for Each Long-Term Strategy E-24

E-9 Average HFE Count for Sediment Traces s1, s2, and s3 for Each Long-Term Strategy E-25

E-10 Definition of the Statistics Represented by the Box and Whisker Plots Used in This Analysis E-25

FIGURES (Cont.)

E-11 Sand Load Index Statistics from 63 Simulations for Each Long-Term Strategy..... E-26

E-12 Standard Deviation of High Flows Statistics from 63 Simulations for Each Long-Term Strategy E-26

E-13 Correlation between SDHF and SLI E-27

E-14 Sand Mass Balance Index Statistics from 63 Simulations for Each Long-Term Strategy E-27

E-15 Correlation between SMBI and SLI E-28

E-16 Sand Load Index for Long-Term Strategies Using Climate Change Weights..... E-28

E-17 Comparison of the Sand Load Index between Climate Change and Historical Weights E-29

E-18 Standard Deviation of High Flows Using Climate Change Weights..... E-29

E-19 Comparison of the Standard Deviation of High Flows between Climate Change and Historical Weights E-30

E-20 Sand Mass Balance Index Using Climate Change Weights E-30

E-21 Comparison of the Sand Mass Balance Index between Climate Change and Historical Weights E-31

E-22 Comparison of Long-Term Strategies C1 and C2 for Hydrology Trace 1, Sediment Trace 3 ..... E-31

E-23 SMBI for Alternative E Plotted against Alternative C E-32

E-24 SLI for Alternative E Plotted against Alternative C E-32

E-25 Load-Following Curtailment Effects on SLI and SMBI..... E-33

E-26 Low Summer Flows for WY 2014, Hydrology Trace 1, Sediment Trace 1 ..... E-34

E-27 Hydrology Impacts on the Sand Load Index E-35

E-28 Hydrology Impacts on the Sand Mass Balance Index E-35

E-29 Conceptual Diagram of Water Surface Elevation Affecting Delta Location..... E-36

FIGURES (Cont.)

E-30 Historical Cumulative Sand Load Leaving Marble Canyon and Reaching the Gage above Diamond Creek E-36

E-31 Hydrology Impacts of Lake Powell Pool Elevations by Month across Alternatives E-37

E-32 Hydrology Impacts of Lake Mead Pool Elevations by Month across Alternatives E-37

F-1 Fit of Regressions Predicting the Log of Recruitment of Rainbow Trout in the Glen Canyon Reach Estimated by the Korman et al. Stock Synthesis Model as a Function of the Annual Release Volume from Glen Canyon Dam, the Range of Mean Daily Flows during May–August, and the Maximum Flow Each Year.... F-31

F-2 Relationship between Annual Estimates of the Asymptotic Length of Rainbow Trout in Lees Ferry Predicted by the Stock Synthesis Model as a Function of the Estimated Abundance for Fish >150 mm Each Year..... F-32

F-3 The Relationship between Annual Recruitment of Rainbow Trout in Lees Ferry Estimated by the Korman et al. Stock Synthesis Model and the Number of Trout That Emigrate from Lees Ferry into Marble Canyon the Following Year F-35

F-4 Fit of the Glen Canyon Rainbow Trout Simulation Model to Predictions of Recruitment, Asymptotic Length, and the Number of Out-migrants Predicted by the Korman et al. Stock Synthesis Model F-37

F-5 Predicted and Observed Annual Catch of Rainbow Trout by Year and River Reach..... F-41

F-6 Best-Fitting Distributions Describing Monthly Movement of Rainbow Trout in Marble Canyon Assuming Either a Normal or Cauchy Distribution..... F-43

F-7 Visual Summary of Humpback Chub Population Model Structure..... F-44

F-8 Modeled Effects of Trout Abundance and Temperature on Humpback Chub Survival and Growth F-48

F-9 Simulated Adult Abundances from Backcasted Model Compared to Patterns Reported in Coggins and Walters F-51

F-10 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under LTEMP Alternatives and Long-Term Strategies F-54

FIGURES (Cont.)

F-11 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-55

F-12 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and the Mean Number of Rainbow Trout Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-56

F-13 Modeled Mean Annual Angler Catch Rate for Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-57

F-14 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and Mean Angler Catch Rates during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies..... F-58

F-15 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-59

F-16 Modeled Frequency of Triggered Mechanical Removal for Rainbow Trout in the Little Colorado River Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-61

F-17 Modeled Minimum Population Size for Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-62

F-18 Relationship between Modeled Mean Numbers of Rainbow Trout Out-migrants from the Glen Canyon Reach and the Modeled Mean Minimum Abundance of Adult Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-63

F-19 Suitability for Spawning, Egg Incubation, and Growth of Humpback Chub as a Function of Water Temperature F-68

F-20 Months for Which Annual Temperature Suitability for Specific Life History Aspects of Humpback Chub Were Calculated..... F-68

F-21 Modeled Historic Water Temperatures in the Colorado River at Humpback Chub Aggregation Locations, Water Years 1990–2012 ..... F-70

FIGURES (Cont.)

F-22 Output from the Temperature Suitability Model for Humpback Chub Aggregation Locations Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-71

F-23 Mainstem Temperature Suitability for Humpback Chub Aggregation Locations under LTEMP Alternatives and Long-Term Strategies F-72

F-24 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Native Fish Species F-74

F-25 Months for Which Temperature Suitability for Specific Life History Aspects Were Considered for Native Fish Species F-74

F-26 Modeled Historic Water Temperatures in the Colorado River Downstream of Glen Canyon Dam, Water Years 1990–2012 ..... F-75

F-27 Annual Temperature Suitability Scores for Growth, Spawning, and Egg Incubation of Native Fish Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-76

F-28 Annual Temperature Suitability Scores for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-29 Mean Annual Overall Temperature Suitability for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-30 Mean Annual Mainstem Temperature Suitability for Native Fish under LTEMP Alternatives and Long-Term Strategies at RM 61, RM 157, and RM 225, and Overall Mean for RM 61–225 ..... F-78

F-31 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Nonnative Fish Species F-80

F-32 Months during Which Temperature Suitability for Specific Life History Aspects Were Calculated for Nonnative Fish Species F-81

F-33 Annual Temperature Suitability Scores for Spawning, Incubation, and Growth of Nonnative Fish Species at RM 225 Based on Modeled Temperatures for Water Years 1990 to 2012 ..... F-82

F-34 Mean Annual Temperature Suitability Scores for Nonnative Fish Species and for Temperature Groups by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-83

FIGURES (Cont.)

F-35 Mean Annual Overall Temperature Suitability Scores for Coldwater and Warmwater Nonnative Fish Species Groups Based on Modeled Historic Temperatures for Water Years 1990–2012 ..... F-83

F-36 Mean Annual Mainstem Temperature Suitability for Coldwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 15, RM 61, RS 157, and RM 225 ..... F-84

F-37 Mean Annual Mainstem Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 0, RM 61, RM 157, and RM 225 ..... F-85

F-38 Suitability of Various Water Temperatures for Host Activity and Infestation Rates of Parasite Species F-86

F-39 Annual Temperature Suitability Scores for Parasite Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-40 Mean Annual Temperature Suitability Scores for Parasite Species by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-41 Overall Means of Annual Suitability Scores for Parasite Species across All River Locations during the 1990–2012 Water Years F-88

F-42 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives and Long-Term Strategies for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam F-89

G-1 Native Cover Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-2 Native Cover Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-3 Native Diversity Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-4 Native Diversity Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-5 Native/Nonnative Ratio Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-48

FIGURES (Cont.)

G-6 Native/Nonnative Ratio Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term G-48

G-7 Arrowweed Metric for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less G-49

G-8 Arrowweed Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less Arrowweed G-49

G-9 Overall Combined Score for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-10 Overall Combined Score under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-11 Relative Change in Wetland Cover for the LTEMP Alternatives and Associated Long-Term Strategies G-51

G-12 Relative Change in Wetland Cover under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-51

H-1 Wind Transport of Sediment Index Values for the LTEMP Alternatives and Associated Long-Term Strategies H-6

H-2 Average Number of HFEs in the 20-Year LTEMP Period H-7

H-3 Daily Maximum Discharge in a Typical 8.23-maf Water Volume Release Year from the Glen Canyon Dam during the Windy Season of March–June H-8

H-4 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives and Long-Term Strategies H-10

H-5 Average Number of Days of an HFE Event per Year H-11

H-6 Modeled Glen Canyon Dam Discharge for the Same Year H-12

H-7 Time Off River Index Values for All LTEMP Alternatives and Associated Long-Term Strategies H-14

H-8 Daily Average Discharge for Representative Long-Term LTEMP Strategies H-15

I-1 Riparian Diversity for the LTEMP Alternatives and Associated Long-Term Strategies I-6

FIGURES (Cont.)

I-2 Riparian Diversity under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-7

I-3 Wetland Abundance for the LTEMP Alternatives and Associated Long-Term Strategies I-9

I-4 Wetland Abundance under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-10

I-5 Frequency of Trout Management Flows for the LTEMP Alternatives and Associated Long-Term Strategies I-12

I-6 Frequency of Trout Management Flows under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-13

I-7 Frequency of Mechanical Removal for the LTEMP Alternatives and Associated Long-Term Strategies I-14

I-8 Frequency of Mechanical Removal under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-15

I-9 Lake Powell Water Levels for the LTEMP Alternatives and Associated Long-Term Strategies I-16

I-10 Lake Powell Water Levels under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-17

J-1 Camping Area Index for LTEMP Long-Term Strategies J-8

J-2 Sand Load Index for LTEMP Long-Term Strategies J-9

J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies J-11

J-4 Fluctuation Index for LTEMP Long-Term Strategies J-14

J-5 Time Off River Index for LTEMP Long-Term Strategies J-16

J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP Alternatives J-16

J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies J-19

FIGURES (Cont.)

J-8 Average Number of HFEs in the 20-Year LTEMP Period for LTEMP Long-Term Strategies J-20

J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies J-22

J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Summer Season J-24

J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Fall and Spring Seasons J-24

J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Summer Season J-25

J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Fall and Spring Seasons J-25

K.1-1 Network Topology Used by the AURORA Western Interconnection Model K-10

K.1-2 Percentage of Total Generation Resources Owned by Individual Customers K-12

K.1-3 Simplified Network Topology of the SLCA/IP Market System K-13

K.1-4 Percentage of SLCA/IP Federal Hydropower Nameplate Capacity by Facility K-16

K.1-5 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS K-18

K.1-6 Illustration of a Typical GTMax-Lite Result for a 24-Hour Period K-24

K.1-7 GTMax-Lite Network Topology for the Large SLCA/IP Hydropower Resources Other Than Glen Canyon Dam K-26

K.1-8 Illustration of Temporal Modeling Method Used in the GTMax-Lite Five Large SLCA/IP Plant Configuration K-28

K.1-9 Example of the Load Scaling Algorithm LDC K-31

K.1-10 Example of the Load Scaling Algorithm Chronological Hourly Loads K-32

K.1-11 Projected Annual Average Calibrated AURORA LMPs at the Palo Verde Market Hub K-36

FIGURES (Cont.)

K.1-12 Historical Palo Verde On- and Off-Peak Electricity Prices Compared to Natural Gas Prices K-36

K.1-13 2014 AEO Projected Delivered Utility Natural Gas Prices K-37

K.1-14 Comparison of Modeled and Actual Annual Aggregated Generation Levels for Natural Gas, Coal, and Nuclear Powerplants under the No Action Alternative K-43

K.1-15 Total Non-coincidental Peak Loads for the SLCA/IP Market System K-49

K.1-16 Total Monthly Loads for the SLCA/IP Market System K-49

K.1-17 Projected 2014 AEO Natural Gas Prices at the Henry Hub K-56

K.1-18 2014 AEO Electricity Market Module Regions and the Mapping of States to Regions K-57

K.1-19 Projected AEO 2014 Coal Prices by Electricity Market Module Region K-59

K.1-20 WAPA SLCA/IP Hydropower Powerplants K-63

K.1-21 SLCA/IP Federal Hydropower Capacity Uses and Variability Factors K-64

K.1-22 Reductions in Operating Range when Providing Ancillary Services K-66

K.1-23 Illustration of the Trapezoidal Method Used to Compute Capacity at Flaming Gorge Dam K-72

K.1-24 Illustration of Ramping Time Increase as a Function of Increasing Water Volumes at Flaming Gorge Dam K-73

K.1-25 Capacity Values at Flaming Gorge Dam Calculated over a Wide Range of Daily Water Releases Using the Trapezoidal Method K-74

K.1-26 Average Historical Non-coincidental Annual Peak Loads for the Eight Large Customers and Percentages Relative to the Total K-75

K.1-27 Historical Coincidental Annual and Average Peak Loads for the Eight Large Customers during the CY 2006 through CY 2009 Time Period K-76

K.1-28 Historical Coincidental Annual and Average Peak Loads for Six Large Customers during the CY 2010 through CY 2012 Time Period K-77

FIGURES (Cont.)

K.1-29 SLCA/IP Models Used for Estimating SHP Capacity K-78

K.1-30 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in July K-80

K.1-31 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in August K-80

K.1-32 Comparison of Firm Marketable Capacity Determinations across Alternatives, Exceedance Levels, and Summer Peak Months..... K-81

K.1-33 Timing of Capacity Additions in AURORA K-83

K.1-34 Annual Average Hydropower Generation for the Glen Canyon Dam Powerplant and the Aggregate Generation for All Other SLCA/IP Resources K-88

K.1-35 Average Daily Glen Canyon Dam Powerplant Hydropower Generations by Month Based on the Average of All 21 CRSS/SBM Hydrology Traces K-89

K.1-36 Average Annual Glen Canyon Dam Powerplant Generation for the Representative CRSS/SBM Hydrology Trace K-92

K.1-37 Representative Trace Average Daily Glen Canyon Dam Powerplant Generations by Month..... K-93

K.1-38 Average Daily Generation by Month for Each Alternative K-97

K.1-39 Palo Verde Average Daily Electricity Market Price Statistics by Month during the 20-Year LTEMP Period K-98

K.1-40 Typical Hourly Winter/Summer Price Patterns in the Western United States K-99

K.1-41 Average Number of HFEs by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-42 Average Amount of Non-Power Water Releases by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-43 Average Annual Number of Hours the Lake Powell Elevation Is below the Penstock Intake by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-101

K.1-44 2014 Annual Energy Outlook Projections of Capacity Additions in the Western Interconnection over the LTEMP Period..... K-104

FIGURES (Cont.)

K.1-45 Cumulative Capacity Additions for Alternative A K-106

K.1-46 Cost Difference of Alternatives Compared to Alternative A at 50% Exceedance Level and 3.375% Discount Rate K-119

K.1-47 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate K-119

K.1-48 Cost Difference of Alternatives Compared to Alternative A at 99% Exceedance Level and 3.375% Discount Rate K-120

K.1-49 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 1.4% Discount Rate K-122

K.1-50 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combustion Turbines K-123

K.1-51 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combined Cycle K-124

K.1-52 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate Assuming Average Hydropower Conditions K-125

K.2-1 Determination of Energy Hourly Expense or Revenue K-140

K.2-2 Determination of Total Net Expense or Revenue by Year for Each Alternative..... K-142

K.3-1 Flowchart Diagram of Rate Impact Analysis Process K-156

K.3-2 Projected Carrying Charge Rates Used in Rate Impact Analysis K-161

K.3-3 Flowchart Diagram of Allocation Process K-162

K.3-4 Load Factors of SLCA/IP Power K-165

K.3-5 Scatter Plot of Preference Ratio and Annual Retail Sales K-169

K.3-6 Scatter Plots of Percent Retail Rate Change and the Preference Ratio..... K-171

K.3-7 Retail Rate Distribution under Alternative A K-173

FIGURES (Cont.)

K.3-8 Monthly Residential Bill Distribution under Alternative A K-173

K.3-9 Average Retail Rate Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-10 Average Residential Bill Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-11 Average Retail Percent Revenue Increase Relative to Alternative A K-176

K.3-12 Average Monthly Residential Bill Changes Relative to Alternative A K-177

K.3-13 Retail Rates under Alternative A K-188

K.4-1 Calculation of Change in Tribal Benefit Resulting from LTEMP EIS Alternatives K-194

K.4-2 Financial Impacts under Alternative B Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-3 Financial Impacts under Alternative C Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-4 Financial Impacts under Alternative D Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-5 Financial Impacts under Alternative E Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-6 Financial Impacts under Alternative F Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.4-7 Financial Impacts under Alternative G Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.5-1 Change in Lake Powell Monthly Water Release Volumes under LTEMP Alternatives K-207

K.5-2 Average Lake Mead EOM Pool Elevations under LTEMP Alternatives K-207

K.5-3 Average Monthly Difference in Turbine Water Releases Relative to Alternative A K-212

FIGURES (Cont.)

K.5-4 Average Monthly Hoover Powerplant Generation for All Power Systems under Primary LTEMP EIS Alternatives K-212

K.5-5 NPV of Hoover Powerplant Benefits Relative to Alternative A Resulting from LTEMP Alternatives K-214

L-1 Elements of the Lake_Full Utility Model L-5

L-2 Elements of the GCRec_Full Utility Model L-6

L-3 Elements of the Regional Recreation Impacts Analysis L-11

L-4 Elements of the Regional Electricity Price Impacts Analysis L-16

L-5 Elements of the Regional Electricity Generating Capacity Expansion Impacts Analysis L-17

P-1 Average Monthly Sand Load from the Paria River and Little Colorado River Showing the Fall and Spring HFE Accounting Periods and Implementation Windows P-4

TABLES

1-1	Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows	1-21
1-2	Selected Documents Included in the Law of the River	1-32
2-1	Operational Characteristics of LTEMP Alternatives	2-9
2-2	Condition-Dependent and Experimental Elements of LTEMP Alternatives	2-11
2-3	Flow Parameters under Alternative A in an 8.23-maf Year	2-17
2-4	Flow Parameters under Alternative B in an 8.23-maf Year	2-21
2-5	Flow Parameters under Alternative C in an 8.23-maf Year	2-26
2-6	Implementation Criteria for Experimental Treatments of Alternative C	2-31
2-7	Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year	2-42
2-8	Flow Parameters under Alternative D in an 8.23-maf Year	2-45
2-9	Implementation Criteria for Experimental Treatments of Alternative D	2-50
2-10	Flow Parameters for a Year with Low Summer Flows under Alternative D in an 8.23-maf Year	2-68
2-11	Flow Parameters under Alternative E in an 8.23-maf Year	2-73
2-12	Flow Parameters under Alternative F in an 8.23-maf Year	2-82
2-13	Flow Parameters under Alternative G in an 8.23-maf Year	2-83
2-14	Summary of Impacts of LTEMP Alternatives on Resources	2-93
3.5-1	Native Fish of the Colorado River through Glen and Grand Canyons	3-72
3.5-2	Nonnative Fish Found in the Colorado River through Glen and Grand Canyons	3-91
3.5-3	Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009	3-94
3.5-4	Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed	3-102

TABLES (Cont.)

3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins 3-113

3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead 3-122

3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead 3-133

3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013 3-177

3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders 3-184

3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013 3-208

3.14-1 Population in the Six-County Region 3-210

3.14-2 Income in the Six-County Region 3-212

3.14-3 Employment in the Six-County Region 3-213

3.14-4 Employment by Sector in 2011 3-214

3.14-5 Unemployment Rates in the Six-County Region 3-215

3.14-6 Minority and Low-Income Populations in the 11-County Area 3-217

3.14-7 Population in the Seven-State Region of Influence 3-222

3.14-8 Income in the Seven-State Region of Influence 3-223

3.14-9 Employment in the Seven-State Region of Influence 3-224

3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence 3-225

3.14-11 Unemployment in the Seven-State Region of Influence 3-226

3.14-12 State Minority and Low-Income Populations, 2010 3-227

3.15-1 Clean Air Act Prevention of Significant Deterioration Designations 3-230

TABLES (Cont.)

3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011 3-231

3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection 3-236

4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative 4-4

4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality 4-15

4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek 4-50

4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources 4-73

4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative 4-90

4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources 4-92

4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology 4-109

4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base 4-116

4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels 4-165

4.6-2 Vegetation States and Corresponding Mapped Vegetation Types 4-169

4.6-3 Summary of Impacts of LTEMP Alternatives on Vegetation 4-170

4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions 4-181

4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor 4-185

4.6-6 Summary of Impacts of LTEMP Alternatives on Special Status Plant Species 4-188

4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife 4-205

TABLES (Cont.)

4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species 4-217

4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons 4-239

4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover 4-253

4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources 4-263

4.10-1 Summary of Impacts of LTEMP Alternatives on Recreation, Visitor Use, and Experience 4-282

4.10-2 Amount of Sediment Transported Out of Marble Canyon under the LTEMP Alternatives over the 20-Year LTEMP Period 4-295

4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience 4-310

4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources 4-335

4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice 4-366

4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP Alternatives 4-376

4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012 4-380

4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives 4-380

4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives 4-381

4.14-6 Seven-State Economic Impacts under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033 4-383

4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A 4-384

4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers 4-389

TABLES (Cont.)

4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality 4-404

4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative 4-408

4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions 4-417

4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions 4-422

4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area 4-428

4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives 4-447

5.1-1 Summary of Cooperating Agency Involvement 5-3

B-1 Tolerable Flow Fluctuations for Recreational River Use B-13

D-1 Initial Reservoir Conditions D-5

D-2 Monthly Release Volumes by Water-Year Release for Alternative A D-11

D-3 Monthly Release Volumes by Water-Year Release for Alternative B D-12

D-4 Monthly Release Volumes by Water-Year Release for Alternative C D-13

D-5 Monthly Release Volumes by Water-Year Release for Alternative C with Low Summer Flows D-14

D-6 Monthly Release Volumes by Water-Year Release for Alternative D D-15

D-7 Monthly Release Volumes by Water-Year Release for Alternative D with Low Summer Flows D-16

D-8 Monthly Release Volumes by Water-Year Release for Alternative E D-17

D-9 Monthly Release Volumes by Water-Year Release for Alternative E with Low Summer Flows D-18

D-10 Monthly Release Volumes by Water-Year Release for Alternative F D-19

TABLES (Cont.)

D-11 Monthly Release Volumes by Water-Year Release for Alternative G D-20

D-12 Minimum Release Constraints Used for Each Alternative D-21

D-13 Input Demands by State D-27

E-1 Sources for Historical Tributary Sediment Load Data E-38

E-2 Historical Periods Used for Paria Sediment Traces s1, s2, and s3 ..... E-38

E-3 Historical Periods Used for Little Colorado River Sediment Traces s1, s2, and s3 ..... E-38

E-4 List of HFEs Available for Sediment-Triggered Experiments E-39

F-1 Average Mean Habitat-Weighted Invertebrate Biomass at Select Sites in the Colorado River, July 2006–June 2009 ..... F-8

F-2 Average Mean Habitat-Weighted Invertebrate Production at Select Sites in the Colorado River, July 2006–June 2009 ..... F-9

F-3 Average Mean Habitat-Weighted Invertebrate Abundance at Select Sites in the Colorado River, July 2006–June 2009 ..... F-10

F-4 Distribution, Ecological Importance, and Favorable Temperature Range for Select Primary Producers F-11

F-5 Temperature Requirements for Common Zooplankton F-24

F-6 Distribution, Importance to Higher Trophic Levels, and Temperature Range for Common Benthic Macroinvertebrates Downstream of Glen Canyon Dam F-25

F-7 Temperature Requirements for the Asian Tapeworm, Anchor Worm, and Trout Nematode F-26

F-8 Summary of Metrics Values from the Rainbow Trout-Humpback Chub Model F-53

F-9 Description of Input Parameters for the LTEMP Temperature Suitability Model F-66

F-10 Humpback Chub Aggregation Locations F-67

F-11 Locations Used for Temperature Suitability Modeling of Native Fish, Nonnative Fish, and Parasites F-73

TABLES (Cont.)

G-1 Vegetation States, Plant Associations, and Corresponding Submodels G-15

G-2 Hydrologic Events Considered in the Riparian Vegetation Model G-16

G-3 Riparian Vegetation Model Transition Rules G-17

G-4 New High-Water Zone and Old High-Water Zone Vegetation Classes Mapped from Lees Ferry to Diamond Creek G-22

G-5 Vegetation States and Corresponding Mapped Vegetation Types G-24

G-6 Example Results for the Native Cover Metric G-25

G-7 Example Results for the Arrowweed Metric G-25

G-8 Results for Alternative A G-26

G-9 Results for Alternative B, Long-Term Strategy B1 ..... G-27

G-10 Results for Alternative B, Long-Term Strategy B2 ..... G-28

G-11 Results for Alternative C, Long-Term Strategy C1 ..... G-29

G-12 Results for Alternative C, Long-Term Strategy C2 ..... G-30

G-13 Results for Alternative C, Long-Term Strategy C3 ..... G-31

G-14 Results for Alternative C, Long-Term Strategy C4 ..... G-32

G-15 Results for Alternative D, Long-Term Strategy D1 ..... G-33

G-16 Results for Alternative D, Long-Term Strategy D2 ..... G-34

G-17 Results for Alternative D, Long-Term Strategy D3 ..... G-35

G-18 Results for Alternative D, Long-Term Strategy D4 ..... G-36

G-19 Results for Alternative E, Long-Term Strategy E1 ..... G-37

G-20 Results for Alternative E, Long-Term Strategy E2 ..... G-38

G-21 Results for Alternative E, Long-Term Strategy E3 ..... G-39

TABLES (Cont.)

G-22 Results for Alternative E, Long-Term Strategy E4 ..... G-40

G-23 Results for Alternative E, Long-Term Strategy E5 ..... G-41

G-24 Results for Alternative E, Long-Term Strategy E6 ..... G-42

G-25 Results for Alternative F G-43

G-26 Results for Alternative G G-44

G-27 The Effects of LTEMP Long-Term Strategies on Wetlands G-45

I-1 Federal Regulations and Executive Orders Pertaining to Consultation with Tribes I-3

I-2 Vegetation States I-5

J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial Motor Guides, Commercial Oar Guides, and Private Trip Leaders Who Have Experienced Daily Fluctuations of at Least 15,000 cfs in the Grand Canyon J-12

J-2 Recreation Response to Daily Maximum Flow J-20

J-3 Summary of Recreation, Visitor Use, and Experience Metrics J-26

K.1-1 Cost and Performance Characteristics of Capacity Expansion Candidates K-51

K.1-2 Cumulative Annual Percentage Increase in Natural Gas Prices at the Henry Hub K-55

K.1-3 Cumulative Annual Percent Increase in Regional Coal Prices K-58

K.1-4 Cumulative Annual Percentage Increase in Regional Distillate Fuel Prices K-60

K.1-5 Assumed Ancillary Services Provided by SLCA/IP Hydropower Facilities from 2013 to 2030 ..... K-65

K.1-6 Summary of Utility IRPs for Four Large SLCA/IP Customers and Other Large Utilities in Areas Neighboring the SLCA/IP System K-87

K.1-7 SLCA/IP Marketable Capacity at the 90% Exceedance Level K-102

K.1-8 Difference in Cumulative Capacity Additions of Each Alternative Relative to Alternative A K-105

TABLES (Cont.)

K.1-9 Comparison of the Amount and Timing of New Capacity Additions for Alternatives A and F K-107

K.1-10 Total Economic Impacts by Alternative at the 90% Exceedance Level K-109

K.1-11 Estimated Cost of LTEMP Experiments K-116

K.1-12 Comparison of Marketable Capacity, Replacement Capacity, and Capacity Additions by Exceedance Level K-117

K.1-13 Firm SLCA/IP Federal Hydropower Capacity at Various Exceedance Levels at Glen Canyon Dam by Alternative and Ancillary Service Scenarios K-127

K.1-14 Comparison of Capacity and Energy Values at Glen Canyon Dam by Alternative and Ancillary Services Scenarios at the 90% Exceedance Level K-128

K.1-15 Difference Relative to Alternative A K-128

K.1-16 Alternative Cost Increase Estimates for Mixed NGCC/CT Technology Capacity Replacement Relative to CT Only Replacement as Estimated Using GTMax-Lite K-130

K.1-17 Summary of Economic Rankings for Baseline and All Sensitivity Scenarios K-132

K.2-1 SHP Contractual Obligations and Project Use Required Deliveries by Month K-136

K.2-2 SHP Hourly Load Shapes by Month and Type of Day K-137

K.2-3 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year K-141

K.2-4 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year Expressed as the Difference from Alternative A K-143

K.2-5 Total Net Purchase Power Expenses by Year and Alternative for the Continuous Current Obligations Scenario K-147

K.2-6 Total Net Purchase Power Expenses by Year and Alternative for the Reduced Obligations to Match Resource Scenario K-148

K.2-7 SLCA/IP Rate Impact by Alternative K-151

K.3-1 Energy Allocations for Systems Receiving Indirect SLCA/IP Allocations K-157

TABLES (Cont.)

K.3-2 Coverage of Retail Information from EIA Database Relative to SLCA/IP Preference Power Allocation K-159

K.3-3 Average Annual Grid Cost Relative to SLCA/IP Wholesale Revenues Relative to Alternative A K-168

K.3-4 Summary Table of Comparative Values K-178

K.3-5 Individual Systems with the Largest Percent Retail Rate Impacts Relative to Alternative A K-180

K.3-6 Individual Systems with the Smallest Percent Retail Rate Impacts Relative to Alternative A K-182

K.3-7 Individual Systems with the Largest Monthly Residential Bill Impacts Relative to Alternative A K-183

K.3-8 Individual Systems with the Smallest Monthly Residential Bill Impacts Relative to Alternative A K-184

K.3-9 Size and Preference Ratio for Utility Systems with Large Rate Impacts K-186

K.3-10 Rate Impacts for Selected Groups in Maximum Impact Year K-186

K.4-1 Monthly Change in Residential Electric Utility Bill for Tribes by Alternative K-197

K.4-2 Total Dollar Annual Impact on Tribes under LTEMP Alternatives Relative to Alternative A K-199

L-1 Total Regional Economic Impacts of Non-Local Recreation Expenditures, 2013 ..... L-13

L-2 Urban Population, Income, and Poverty in the Six-County Region L-18

M-1 Emission Factors by Plant for System Power Generation and Spot Market M-10

M-2 Power Generation Averaged over the 20-Year LTEMP Period by Alternative M-12

M-3 Summary of Potential Impacts of LTEMP Alternatives on Visibility and Regional Air Quality M-15

M-4 Annual SO_2 Emissions Averaged over the 20-Year LTEMP Period by Alternative M-16

TABLES (Cont.)

M-5 Annual NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative M-19

M-6 Summary of Impacts of LTEMP Alternatives on SO_2 and NO_x Emissions M-22

M-7 Annual Greenhouse Gas Emissions under LTEMP Alternatives M-23

M-8 Summary of Impacts of LTEMP Alternatives on CO_2e Emissions M-26

N-1 Summary of Tribal Participation Status N-5

N-2 Summary of Tribal Correspondence N-6

N-3 Summary of Major Face-to-Face Meetings, Webinars, and Conference Calls Involving Tribes N-25

N-4 Summary of Individual Tribal Consultation Meetings to Date N-27

N-5 Index of Project Tribal Government Consultation and Coordination Correspondence N-29

P-1 List of HFEs Available for Sediment-Triggered Experiments under the Preferred Alternative P-7

Q-1 Comment Issues and Location in the Report Q-6

Q-2 Commenter Distribution by State Q-10

Q-3 Commenter, Affiliation, and Location Where Responses Are Found Q-88

ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
ACHP	Advisory Council on Historic Preservation
AML	abandoned mine land
AMSL	above mean sea level
AMWG	Adaptive Management Work Group
AOP	Annual Operation Plan for Colorado River Reservoirs
APE	Area of Potential Effect
Argonne	Argonne National Laboratory
ASMR	Age-Structured Mark Recapture Model
AZGFD	Arizona Game and Fish Department
AZ-SGCN	Arizona Species of Greatest Conservation Need
BA	Balancing Authority (in Chapter 3 only) Biological Assessment (in all other sections)
BGEPA	Bald and Golden Eagle Protection Act of 1940
BIA	Bureau of Indian Affairs
BO	Biological Opinion
C	Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
CCC	Civilian Conservation Corps
CEQ	Council on Environmental Quality
CFMP	*Comprehensive Fisheries Management Plan*
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUE	catch per unit effort
CRBC	Colorado River Board of California
CRCN	Colorado River Commission of Nevada
CRD	Colorado River Discovery
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
CRSS	Colorado River Simulation System
CSU	Colorado Springs Utilities

DEIS	Draft Environmental Impact Statement
Deseret	Deseret Generation and Transmission Cooperative
DFC	desired future condition
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DPS	Distinct Population Segment
EA	Environmental Assessment
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ELCOM	Estuary, Lake and Coastal Ocean Model
EMS	emergency medical services
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ESA	Endangered Species Act of 1973, as amended
F	Fahrenheit
FCPP	Four Corners Power Plant
FES	Firm Electric Service
FONSI	Finding of No Significant Impact
FR	*Federal Register*
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCM	general circulation model
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
GHG	greenhouse gas
GMP	General Management Plan
GW	gigawatt(s)
GWh	gigawatt-hour(s)
GWP	global warming potential
H_2S	hydrogen sulfide
HBC	humpback chub
HFC	hydrofluorocarbon
HFE	high-flow experiment
hr	hour(s)

HRR	Hualapai River Runners
in.	inch(es)
IPM	Integrated Pest Management
IRP	integrated resource plan
ISM	Indexed Sequential Method
kaf	thousand acre-feet
kWh	kilowatt-hour(s)
lb	pound(s)
LCRMSCP	Lower Colorado River Multi-Species Conservation Program
LMM	Lake Mead Model
LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Long-Term Experimental and Management Plan
LTEP	Long Term Experimental Plan
LTF	long-term firm
maf	million acre-feet
MAMB	miscellaneous algae, macrophytes, and bryophytes
MBTA	Migratory Bird Treaty Act
MCL	maximum contaminant level
mi	mile(s)
MLFF	Modified Low Fluctuating Flow
MMt	million metric tons
MOA	Memorandum of Agreement
MT	metric ton(s)
MW	megawatt(s)
MWh	megawatt-hour(s)
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAU	Northern Arizona University
NC	no change
NEPA	National Environmental Policy Act of 1969, as amended
NERC	North American Electric Reliability Corporation
NEV	net economic use value
NGO	nongovernmental organization
NHPA	National Historic Preservation Act
NM	national monument
NO_2	nitrogen dioxide
NO_3	nitrate-nitrogen
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service

NPV	net present value
NRHP	*National Register of Historic Places*
NTUA	Navajo Tribal Unit Authority
O&M	operation and maintenance
O_3	ozone
OPAC	Office of Planning and Compliance
OSMRE	Office of Surface Mining Reclamation and Enforcement
PA	Programmatic Agreement
Pb	lead
PEPC	Planning, Environment, and Public Comment
PFC	perfluorocarbon
P.L.	Public Law
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
PM_{10}	particulate matter ≤10 μm in aerodynamic diameter
POM	particulate organic matter
PSAR	preventative search and rescue
PSD	Prevention of Significant Deterioration
RA	resource available
Reclamation	Bureau of Reclamation
RM	river mile
RMP	Resource Management Plan
ROD	Record of Decision
RSG	Reserve Sharing Group
SAAQS	State Ambient Air Quality Standards
SBM	Sand Budget Model
SCP	Salinity Control Project
SD	standard deviation
SDA	Structured Design Analysis
SE	standard error
Secretary, the	Secretary of the Interior
SF_6	sulfur hexaflouride
SHPO	State Historic Preservation Officer
SLCA/IP	Salt Lake City Area Integrated Projects
SO	Secretarial Order
SO_2	sulfur dioxide
SPC	Southern Paiute Consortium
SRP	Salt River Project
SRSG	Southwest Reserve Sharing Group
TCD	temperature control device
TCP	traditional cultural property

TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer
TL	total length
TMF	trout management flow
Tri-State	Tri-State Generation and Transmission Association
TWG	Technical Working Group
UAMPS	Utah Associated Municipal Power Systems
UBWR	Utah Board of Water Resources
UCRC	Upper Colorado River Commission
UMPA	Utah Municipal Power Agency
USC	*United States Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACM	Western Area Colorado-Missouri Region
WALC	Western Area Lower Colorado Region
WAUW	Western Area Upper Great Plains West Region
WECC	Western Electricity Coordinating Council
Western	Western Area Power Administration
YOY	young-of-year
yr	year(s)
ZHHPO	Zuni Heritage and Historic Preservation Office

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APPENDIX A:

ADAPTIVE MANAGEMENT WORKING GROUP DESIRED FUTURE CONDITIONS

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APPENDIX A:

ADAPTIVE MANAGEMENT WORKING GROUP DESIRED FUTURE CONDITIONS

The Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) joint lead agencies have used the 2012 Glen Canyon Dam Adaptive Management Program (GCDAMP) Desired Future Conditions (DFCs) as a basis for the resource goals and objectives of the EIS as presented in Section 1.4 of the EIS. The resource goals and objectives are based on and consistent with the DFCs, but are more concise and direct relative to the LTEMP purpose and need of the proposed action. The following text is based on the document *Desired Future Conditions for the Colorado River Ecosystem in Relation to Glen Canyon Dam* (DFC Ad Hoc Committee 2012).

The DFCs were intended to be used within the GCDAMP to help guide the development of recommendations concerning management of Glen Canyon Dam operations and related activities and dam impacts on Grand Canyon National Park (GCNP) and Glen Canyon National Recreation Area (GCNRA). The DFCs focus on those conditions that can be accomplished through dam operations and also identify those conditions that might be achieved through non-operational measures.

The Secretary of the Interior (the Secretary) is authorized to consider and implement both operational and non-operational measures to address downstream effects of Glen Canyon Dam if those measures meet the Grand Canyon Protection Act's (GCPA's) goal of protecting, mitigating adverse impacts on, and improving the resources downstream of the dam. Section 1802 of the GCPA provides the following:

a. *In General*—The Secretary shall operate Glen Canyon Dam in accordance with the additional criteria and operating plans specified in Section 1804 and exercise other authorities under existing law in such a manner as to protect, mitigate adverse impacts on, and improve the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use.

b. *Compliance with Existing Law*—The Secretary shall implement this section in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona v. California, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River basin.

c. *Rule of Construction*—Nothing in this title alters the purposes for which the GCNP or the GCNRA were established or affects the authority and

> responsibility of the Secretary with respect to the management and administration of the GCNP and GCNRA, including natural and cultural resources and visitor use, under laws applicable to those areas, including, but not limited to, the Act of August 25, 1916 (39 Stat. 535), as amended and supplemented.

The Bureau of Reclamation (Reclamation) is charged with balancing a complex set of interests in operating the dam. Those interests include not only the endangered species below the dam, but also Tribes in the region, the seven Colorado River basin states, large municipalities that depend on water and power from Glen Canyon Dam, agricultural interests, GCNP, GCNRA, and national energy needs at a time when clean energy production is becoming increasingly important. The DFCs will assist the Glen Canyon Dam Adaptive Management Work Group (AMWG) in providing recommendations to the Secretary of the Interior for future decision-making. The DFCs have evolved from discussions during the entire 16-year history of the AMWG, and were generated in the following form from the concerted work of the DFC Ad Hoc Group and the federal agency regional leadership during 2010 and 2011.

The vision and mission of the AMWG (adopted on July 21, 1999) was developed to guide adaptive management of Glen Canyon Dam, and helps explain how and why definition of desired conditions is important:

> *The Grand Canyon is a homeland for some, sacred to many, and a national treasure for all. In honor of past generations, and on behalf of those of the present and future, we envision an ecosystem where the resources and natural processes are in harmony under a stewardship worthy of the Grand Canyon.*
>
> *We advise the Secretary of the Interior on how best to protect, mitigate adverse impacts to, and improve the integrity of the Colorado River ecosystem affected by Glen Canyon Dam, including natural biological diversity (emphasizing native biodiversity), traditional cultural properties, spiritual values, and cultural, physical, and recreational resources through the operation of Glen Canyon Dam and other means.*
>
> *We do so in keeping with the federal trust responsibilities to Indian Tribes, in compliance with applicable federal, state, and Tribal laws, including the water delivery obligations of the Law of the River, and with due consideration to the economic value of power resources.*
>
> *This will be accomplished through our long-term partnership utilizing the best available scientific and other information through an adaptive ecosystem management process.*

The DFCs are intended to be statements of qualitative goals and objectives for the GCDAMP, realistic and achievable through the operation of Glen Canyon Dam and related activities, subject to the Law of the River and other laws and authorities and consistent with the GCPA. These DFCs may not be entirely or collectively achievable; there will be tradeoffs and

inherent limitations. This fact does not diminish their value. These DFCs of the affected resources have been identified by the stakeholders as appropriate goals for the GCDAMP and are based on information available at this time. As new information develops, the DFCs may need further revision and refinement. Therefore, these DFCs are neither fixed nor final. This is intended to be a "living document" that reflects advances in learning and understanding. This is consistent with the process—and application—of adaptive management.

The Colorado River Ecosystem (CRE) is defined as the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the fore bay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where the dam operations impact physical, biological, recreational, cultural, and other resources. The scope of GCDAMP activities may include limited investigations into some tributaries (e.g., the Little Colorado and Paria Rivers).

The majority of the CRE exists within the boundaries of two national parks and proposed wilderness areas. Despite these protections, the CRE could be considered "a human-dominated ecosystem, one whose aesthetic appeal, goods and services, and spiritual services are widely used and appreciated and needed by a broad cross-section of society. Adaptive management of the CRE has been adopted to ensure the sustainability of the natural environment with the least impact on the goods and services the CRE provides to society. As such, and as information about the CRE has increased, its stewardship is moving toward an ecosystem perspective, fully recognizing the role of humans, and this approach is reflected in the structure of this document" (DFC Ad Hoc Committee 2012).

The DFCs are divided into four categories, including the CRE, Power, Cultural Resources, and Recreation. There are many direct, indirect, short-term, and long-term ecosystem responses to dam existence and operations. The DFCs are directly or indirectly linked to each other on short- and long-term bases through dam-related flows, sediment retention and distribution, hydropower production, fish and wildlife populations, recreation, and visitor experience. The following sections are excerpted from the 2012 DFC document.

A.1 DESIRED FUTURE CONDITIONS: COLORADO RIVER ECOSYSTEM

A.1.1 DFC Description

The term "ecosystem" refers to the combined physical and biological components of an environment. An ecosystem is generally an area within the natural environment in which physical (abiotic) factors and processes of the environment, such as geology, climate, and soil development, function along with interdependent (biotic) organisms, such as plants and animals, in the same habitat and create a dynamic and interconnected system. Ecosystems usually encompass a number of food webs. An ecosystem is a functional unit within a given area consisting of living things and the nonliving chemical and physical factors of their environment, linked together through nutrient cycle and energy flow.

A.1.2 DFC Background and Legislation

Glen Canyon Dam has had a profound impact on the aquatic and terrestrial domains of the CRE from lower Lake Powell downstream to Lake Mead. The CRE DFCs are designed to be consistent with the GCPA, Law of the River, and other appropriate laws and mandates. The CRE DFCs apply the requirements of the GCPA, and are the goals that AMWG members will consider when making recommendations to the Secretary.

A.1.3 Why the Colorado River Ecosystem DFCs Are Important

These CRE DFCs address the natural resource values for which the GCNP and the GCNRA were established. The DFCs aim to comply with the GCPA and describe the individual resource objectives sought with the realization that they may not be achievable in the process of finding the most desirable mix of resources in the CRE and the natural habitats, and natural ecosystem processes. Native and nonnative species are to be managed in accord with federal regulations, policies, and guidelines. The CRE described herein includes most of the native natural resources found in the Colorado River. Those resources are managed, consistent with the Law of the River, described in part in Section 1802(b) of the GCPA, under the National Park Service (NPS) Organic Act, the Redwoods Amendment, NPS 2006 Management Policies, the Wilderness Act, the Antiquities Act, the Endangered Species Act (ESA), the GCPA, the Fish and Wildlife Coordination Act, and other federal legislation. The health of the river ecosystem and the protection of the resource values of GCNP and GCNRA are important to the nation, many Native American Tribes, the economy of the Southwest, and the millions of visitors to the parks and the region.

The CRE DFCs will provide a foundation for and help define the components of the Core Monitoring Program under development by the Grand Canyon Monitoring and Research Center (GCMRC). The Core Monitoring Program ultimately will be essential to quantifying, measuring, and reporting the status of the natural resources, allowing the Secretary and the GCDAMP to track progress toward desired outcomes. DFCs will also provide foundation support in the development of other planning and management assignments associated with the GCDAMP.

A.1.4 Colorado River Ecosystem DFCs

A.1.4.1 Sediment-Related Resources DFCs

High-elevation open riparian sediment deposits along the Colorado River in sufficient volume, area, and distribution so as to provide habitat to sustain native biota and desired ecosystem processes include the following:

- Nearshore habitats for native fish,
- Marsh and riparian habitat for fish (food chain maintenance),

- Cultural resource preservation, and
- Maintenance of camping beaches.

A.1.4.2 Water Quality DFCs

Water quality with regard to dissolved oxygen, nutrient concentrations and cycling, turbidity, temperature, and so forth, is sufficient to support natural ecosystem functions, visitor safety, and visitor experience to the extent feasible and consistent with the life history requirements of focal aquatic species including the following:

- Ecosystem-sustaining nutrient distribution, flux, and cycling.
- Hydro-physical conditions and characteristics of the CRE necessary to sustain aquatic biota.
- Acceptable water quality for human health and visitor experience.

A.1.4.3 Colorado River Ecosystem Aquatic Resource DFCs

Aquatic Food Base DFCs

- The aquatic food base will sustainably support viable populations of desired species at all trophic levels.
- Assure that an adequate, diverse, productive aquatic food base exists for fish and other aquatic and terrestrial species that depend on those food resources.

Native Species DFCs

- Native fish species and their habitats (including critical habitats) sustainably maintained throughout in each species' natural ranges in the CRE.
- Healthy, self-sustaining populations of other remaining native fish with appropriate distribution (flannelmouth sucker, bluehead sucker, speckled dace) so that listing under the ESA is not needed.

Humpback Chub DFCs

- Achieve humpback chub recovery in accord with the ESA and the humpback chub comprehensive management plan, and with the assistance of collaborators within and external to the GCDAMP.

- A self-sustaining humpback chub population in its natural range in the CRE.

- An ecologically appropriate habitat for the humpback chub in the mainstem.

- Spawning habitat for humpback chub in the Lower Little Colorado.

- Establish additional humpback chub spawning habitat and spawning aggregations within the CRE, where feasible.

- Adequate survival of young-of-year or juvenile humpback chub that enter the mainstem to maintain reproductive potential of the population and achieve population sizes consistent with recovery goals.

Rainbow Trout DFCs

A high-quality trout fishery in GCNRA, as further described in the Recreation DFC that does not adversely affect the native aquatic community in GCNP:

- Minimize emigration of nonnative fish from the Lees Ferry reach in GCNRA to downstream locations.

- Minimize emigration of nonnative warm water fish to the mainstem Colorado River.

Extirpated Species DFC

Re-establish fishes extirpated from Grand Canyon, where feasible and consistent with recovery goals for humpback chub and the recovery goals of those extirpated fishes. See the linkages that follow for further information.

Nonfish Biotic Communities DFCs

Native non-fish aquatic biota and their habitats are sustainably maintained with ecologically appropriate distributions:

- Populations of native non-fish species (invertebrates and vertebrates, including northern leopard frog).

- GCDAMP support, actions, and funding are limited to incorporation of dam operations that are conducive to restoration of extirpated species.

- Minimize the abundance and distribution of nonnative species in the CRE.

- Sustainable dam-influenced aquatic, wetland, and springs plant communities and associated biological processes, including those supporting threatened and endangered species and their habitats.

A.1.4.4 Colorado River Ecosystem Riparian Resource DFCs

Native riparian systems in various stages of maturity are diverse, healthy, productive, self-sustaining, and ecologically appropriate, as indicated by the following:

- Native, self-sustaining riverine wetlands, and riparian vegetation and habitat, with appropriate mixture of age classes.

- Healthy, self-sustaining populations of native riparian fauna (both resident and migratory).

- Habitat for sensitive species within the CRE.

- Encourage the resolution of the taxonomic status of the Kanab ambersnail (e.g., completely describe the taxa and subspecies).

- Habitat for neotropical migratory birds, waterfowl, and other appropriate native bird species.

- Ecological functions of tributary mouths and riverside springs, including habitat for native species.

A.1.5 Colorado River Ecosystem DFCs Additional Information

A.1.5.1 Colorado River Ecosystem Linkages

Physical characteristics, including climate, site-specific geomorphology, dam-related discharge and flow, and tributary flows, generally predominate over biological processes. The aquatic and riparian components of the CRE are linked to fluvial habitat distribution and the collection, composition, structure, and population dynamics of living organisms. “Lateral” bio-ecological processes, such as competition, and “top-down” processes, such as predation, parasitism, and decomposition, can influence some elements of these linkages over time.

In addition to physical and biological interactions, the CRE is linked to Native American cultural resources such as archeological and cultural properties. Recreation benefits have resulted from both dam operations and healthy ecosystem conditions.

A.1.5.2 Colorado River Ecosystem Metrics

These DFCs are intended to guide the gathering and analysis of data pertinent to the CRE in GCNP and GCNRA. The CRE DFCs and the related documents will be used to provide direction toward development of the core monitoring program under development by the GCMRC. Through diligent and consistent monitoring, GCMRC may inform the Secretary as to whether as to what degree these DFCs are being achieved. Such monitoring may include the following:

- Percentage of critical habitat lost or gained;
- Condition of species variability (native population, abundance, distribution);
- Carrying capacity thresholds; and
- Population estimates.

A.2 POWER DESIRED FUTURE CONDITIONS

A.2.1 Power DFC Description

Hydroelectric power is generated by the release of stored water through Glen Canyon Dam. The dam's eight generators can produce up to 1,320 megawatts: enough electricity to serve 1.3 million residential customers. The integration of hydropower and other resources provides an efficient and flexible operation of this region's electrical resources. Releases of water from Glen Canyon Dam are adjusted in part to follow customer loads.

A.2.2 Power DFC Background and Legislation

Glen Canyon Dam is an important component of the Colorado River Storage Project (CRSP), which stores water, the Western United States' most vital resource, during wet years for use in times of drought, much like a bank account. As part of the nation's critical infrastructure, the water stored by Glen Canyon Dam is vital to the growing water needs of the Western United States. More than 30 million people depend on the water stored behind the dam for drinking, irrigation, and other municipal and industrial uses.

Revenues from the sale of hydropower generation from Glen Canyon Dam and other CRSP facilities are used to repay reimbursable costs and interest on the interest-bearing costs of

the federal investment in the CRSP, and are also used to repay over 85% of the irrigation costs of CRSP federal irrigation projects. These revenues are also used, instead of annual federal appropriations, to pay for the yearly operation, maintenance, and replacement costs of Glen Canyon Dam and other CRSP facilities.

The Reclamation Project Act of 1939 provides that hydropower produced by Glen Canyon Dam and other CRSP facilities be offered for sale first to municipalities, other public corporations and cooperatives, and other nonprofit organizations financed in whole or in part by loans made pursuant to the Rural Electrification Act of 1936. Customers include rural electric associations, federal facilities, state agencies, universities, and 57 Native American entities.

A.2.3 Why the Power DFC Is Important

- Hydropower is an authorized purpose of Glen Canyon Dam.
- Hydropower produced by Glen Canyon Dam is under long-term contract to not-for-profit entities and 57 Tribal entities.
- Power revenues are a significant funding source (providing an estimated $20 million/year) for the GCDAMP, Upper Colorado River and San Juan River Endangered Fish Recovery Programs, and the Colorado River Salinity Control Program.
- Hydropower is a renewable resource that is an important component in the Western Electricity Coordinating Council (WECC). Hydropower production is a national objective to help meet the nation's needs for reliable, affordable, and environmentally sustainable electricity.
- Glen Canyon generation has the ability to "ramp up" to meet system reliability obligations that are important when regional power shortages or power/transmission system disruptions occur.

A.2.4 Power DFCs

- Glen Canyon Dam capacity and energy generation is maintained and increased, so as to produce the greatest practicable amount of power and energy, consistent with the other DFCs.
- Ensure continued delivery of Glen Canyon Dam hydropower to the existing customers who have entered into long-term firm power contracts with the Western Area Power Association (WAPA).
- Ensure sufficient and efficient production of Glen Canyon Dam hydropower in order to provide the revenues to support the CRSP facilities and purposes.

- Maintain the operational flexibility (including but not limited to load following capability, ramp rates, and emergency operations allowances) that enable Reclamation and WAPA to meet the system operating and other regulatory requirements of WECC, North American Electric Reliability Corporation, and the Federal Energy Regulatory Commission, as well as emergency operating criteria for safety and human health situations.

- Maximize the environmental benefits of hydropower generation at Glen Canyon Dam.

- Minimize carbon emissions through hydropower generation at Glen Canyon Dam.

A.2.5 Power DFC Additional Information

A.2.5.1 Power Linkages

- Operational changes, including experimentation and management actions, which include changes to volumes; release limitations (minimum and maximum); ramp rates; and hourly, daily, monthly, and seasonal variability, all potentially impact this resource.

- The above-identified parameters could have impacts to the CRE resources as well as recreational and cultural resources, depending on the operational design.

A.2.5.2 Power Metrics

- Valuation (measurement characterization for an average year):
  - Electric generating capacity (MW);
  - Electric generating energy (MWH);
  - Load following capability (MW/hr);
  - Ramp rate capability (MW/hr);
  - CO_2, SO_2, and NO_X emissions (tons);
  - Power plant water consumption (acre-feet); and
  - Costs ($ millions).

A.3 CULTURAL RESOURCES DESIRED FUTURE CONDITIONS

A.3.1 Cultural Resources DFC Description

Preservation and appropriate management of cultural resources are vital at many levels. At the most basic level, cultural resources are our history; they define and reaffirm us, and provide a tangible record of who we are and where we have been. Their importance may be to the nation as a whole, to a local community, or to a group traditionally associated with the area. This includes resources within the Grand Canyon region, such as resources along the river corridor in Glen and Grand Canyons.

A.3.2 DFC Background and Legislation

Recognition of the importance of cultural resources is codified through numerous statutes and executive orders that mandate protection, consideration, and preservation of cultural resources. Because of the structure of federal law, particularly the National Historic Preservation Act of 1966 (NHPA), cultural resources will be considered below in two broad groupings: (1) those that fall within the purview of the NHPA (*National Register of Historic Places* [NRHP] eligible historic properties); and (2) all other resources of traditional cultural importance. This is done for purely pragmatic reasons; there are specific legal requirements for cultural resources that fall under the NHPA umbrella that do not apply to the second class of cultural resources. The Cultural Resources DFCs apply the requirements of the Grand Canyon Protection Act to "protect, mitigate adverse impacts to, and improve the values for which GCNP and Grand Canyon National Recreation Area (GCNRA) were established," including cultural resources, and are the goals that AMWG members will consider when making recommendations to the Secretary.

A.3.3 Why the Cultural Resources DFCs Are Important

The cultural resources of the Grand Canyon provide a record of human history in the area. They also encompass the traditional cultural use and significance of the Grand Canyon. Maintaining these resources is important to the nation as a whole so we can better understand the long history of the people who came before us and to the traditional groups that consider this area to have traditional significance to them. A number of Native American groups believe the Grand Canyon is their place of origin. These DFCs will help to maintain compliance with relevant cultural resource laws, maintain traditional cultural linkage with the Grand Canyon, and maintain traditional cultural access to and use of resources in the Grand Canyon in accordance with applicable law.

A.3.4 NRHP Eligible (or Potentially Eligible) Historic Properties DFCs

These resources are historic properties that are eligible or potentially eligible for inclusion in the NRHP. The criteria for inclusion are defined in the NHPA, and are described in more detail in *National Register* Bulletins 15 and 38. Resources in the Grand Canyon include the following:

- Prehistoric archaeological sites (including trails, petroglyphs, and pictographs);

- Historic sites (boats, mining, European exploration, river running); and

- Traditional Cultural Properties—for the Grand Canyon, these include:
  - Archaeological sites,
  - Traditional resource use areas,
  - Sacred sites,
  - Landmarks/geographic features,
  - Springs,
  - The Colorado River,
  - Ethno-ecological resources,
  - Significant event locations, and
  - The Grand Canyon itself.

A.3.4.1 Prehistoric Archaeological Sites and Historic Sites

To the extent feasible, maintain significance and integrity through preservation in place:

- If preservation in place is not feasible or reasonable, then implementation of appropriate preservation treatments will be implemented to ensure reduction or elimination of threats consistent with NPS management policies, Tribal traditional values, and historic preservation law.

- Public access to historic properties on Tribal lands is managed by the respective Tribes. On lands administered by the NPS, access to some sites for users of the river corridor is maintained as long as integrity of the sites is not compromised.

A.3.4.2 Traditional Cultural Properties (TCPs)

- Attributes are maintained; for example, NRHP eligibility is not compromised. These attributes will be specific to traditionally associated peoples and will need to be identified by the federal agencies in consultation with those groups. Attributes may include aspects of location or physical integrity, and may be

intangible elements that link the resource to ongoing traditional cultural practices.

- The ability of traditionally associated people to maintain access to and use of the resources is preserved, in accordance with applicable law.

- Culturally appropriate conditions of resources are maintained based on traditional ecological knowledge; integration of the desired condition is included in relevant monitoring and management programs.

- Maintain ongoing consultation with the groups for whom the resource has traditional value. Because the desired condition of a TCP needs to be determined by the group for whom it has the traditional value, ongoing consultation is necessary to assess the condition of the resource.

- Mitigate impacts that affect the integrity of the TCPs. How and if effects can be mitigated will need to be determined in conjunction with the traditionally associated peoples for whom the resource holds value.

A.3.5 NRHP Eligible (or Potentially Eligible) Historic Properties DFC Additional Information

A.3.5.1 NRHP Eligible (or Potentially Eligible) Historic Properties Linkages

The goals for the following all have the potential to directly or indirectly affect the condition of the NRHP eligible properties (including some examples of effects):

- Flow
  - Direct inundation
  - Levels of sediment deposition
  - Fluctuation frequency and range

- Sediment
  - Distribution (laterally and vertically)

- Vegetation
  - Species composition
  - Density

- Recreation
  - Camping locations
  - Recreational visitation
  - Trailing

In addition, management and research actions have the potential to directly or indirectly impact these resources.

A.3.5.2 NRHP Eligible (or Potentially Eligible) Historic Properties Metrics

- Erosion (or deposition) rates of substrates in which the sites are contained, and
- Impacts at sites that will affect eligibility.

A.3.6 Resources of Traditional Cultural Significance but Not NRHP Eligible

These are resources of cultural significance to traditional peoples, often Native American Tribes, that do not meet some aspect for eligibility for inclusion in the NRHP. A common reason that a resource does not meet NRHP eligibility requirements is that the resource lacks a clearly defined boundary or does not remain in a fixed location.

Resources that have the potential to be considered of traditional cultural significance in the Grand Canyon include the following:

- Animal resources,
- Geologic materials,
- Landscapes,
- Plant resources,
- Soundscapes,
- Viewscapes, and
- Water.

A.3.7 Resources of Traditional Cultural Significance DFCs

- Maintain the ability of traditionally associated peoples to access and use the resource in accordance with applicable law.
- Maintain culturally appropriate resource conditions based on traditional ecological knowledge and integrate this desired condition into monitoring and management programs.

- Maintain effective consultation with the groups for whom the resource has traditional cultural significance.

A.3.8 Resources of Traditional Cultural Significance Linkages

The goals for the following resources all directly or indirectly affect the condition of resources with traditional cultural significance:

- Flow,
- Sediment,
- Vegetation, and
- Recreation.

In addition, management and research actions have the potential to directly impact these resources.

A.3.9 Resources of Traditional Cultural Significance Metrics

Because culture defines the roles resources play in that culture, only members of that culture can assess the status or health of the resources. Therefore, measures for resource status or health and appropriate management will need to be determined individually by federal agencies in consultation with the traditionally associated peoples.

A.4 RECREATION DESIRED FUTURE CONDITIONS

A.4.1 Recreation DFC Description

The Recreation DFCs are meant to describe goals and objectives for human use of the CRE through GCNRA and the GCNP. They are intended to include not only traditional recreational activities such as whitewater rafting, camping, and fishing, but also such things as educational activities, spiritual engagement, and other appropriate activities and values. Grand Canyon and Glen Canyon offer many ways for people to experience, appreciate, and learn from them, even to those who never visit in person.

A.4.2 DFC Background and Legislation

Recreational use on the Colorado River began before there were any dams there, although its exact beginnings are unknown. Recreational and other activities and values in the Grand

Canyon and Glen Canyon have increased greatly since the construction of Glen Canyon Dam. The Recreation DFC applies the requirements of the GCPA to "protect, mitigate adverse impacts to, and improve the values for which GCNP and Grand Canyon National Recreation Area (GCNRA) were established," including visitor use/recreation, and the goals that AMWG members will consider when making recommendations to the Secretary.

A.4.3 Why the Recreation DFC Is Important

A.4.3.1 Grand Canyon National Park

The Grand Canyon is a unique place in the world. Its natural beauty, challenging environment, fascinating history, wilderness character, biodiversity, and sheer size offer a rare and valuable experience. The river corridor is at the heart of the Grand Canyon. The river corridor and the canyon are worthy of the greatest possible respect, treatment, and protection that can be afforded them. They must be kept vital and intact for future generations.

A.4.3.2 Glen Canyon National Recreation Area

The river corridor through the GCNRA provides opportunity to enjoy outdoor beauty with relatively easy access. It supports a valuable and high-quality trout fishery and offers excellent outdoor opportunities that are more accessible and less demanding than those of the Grand Canyon. It is deserving of respect and protection, while also providing the recreational opportunities for which it was established.

A.4.4 Recreation DFCs

The recreation DFCs have been divided in to four subcategories, each corresponding to a different section of the overall ecosystem or type of use.

A.4.4.1 River Recreation in Grand Canyon National Park

- Stewardship worthy of the Grand Canyon so that it can be passed from generation to generation in as natural a condition as possible.

- Provide maximum opportunity to experience the wilderness character of the canyon.

- Wilderness experiences and benefits available in the canyon include solitude, connection to nature, personal contemplation, joy, excitement, the natural sounds and quiet of the desert and river, and extended time periods in a unique environment outside the trappings of civilization.

- A river corridor landscape that matches natural conditions as closely as possible, including extensive beaches and abundant driftwood.

- A river corridor ecosystem that matches the natural conditions as closely as possible, including a biotic community dominated in most instances by native species.

- A dynamic river ecosystem characterized by ecological patterns and processes within their range of natural variability.

- Numerous campable sandbars distributed throughout the canyon.

- Recreational and wilderness experiences minimally affected by research and management activities.

- River flows that continue to be within a range that is reasonably safe, given the inherent risks involved in river recreation.

A.4.4.2 River Recreation in Glen Canyon National Recreation Area

- A quality recreation experience in Glen Canyon.

- Camping beaches suitable for recreational use.

- A setting and ecosystem that is as close to natural conditions as possible.

- Quality river running and angling recreation opportunities.

A.4.4.3 Blue Ribbon Trout Fishery in Glen Canyon National Recreation Area

- A high-quality sustainable recreational trout fishery in the river corridor in GCNRA, while minimizing emigration of nonnative fishes.

- Operate Glen Canyon Dam to achieve the greatest benefit to the trout fishery in GCNRA without causing excessive detriment to other resources.

A.4.4.4 River Corridor Stewardship

- Management of Glen Canyon Dam that is significantly driven by concern for the cultural values and ecological integrity of the river corridor through the Grand Canyon, with preservation and protection considered over the long term (multiple generations).

- A well-informed public, confident that high-quality scientific information is being used for best stewardship practices in the CRE.

A.4.5 Recreation DFC Additional Information

A.4.6 Recreation Linkages

- A natural, healthy, and protected ecosystem is a fundamentally key element to the recreation experience and wilderness character of the river corridor.

- Cultural resources within and near the river corridor:
  - The history of human habitation and use is an important part of the recreation experience. Individual sites are valuable whether they are open for visitation or designated off-limits.
  - Outfitters and guiding opportunities.
  - Local businesses.

A.4.7 Recreation Metrics

- Socioeconomic value of river recreation in GCNP.

- Socioeconomic value of the river corridor visitation and the Grand Canyon itself, as a whole.

- Economic effects of Grand Canyon tourism.

- Factors that make up the "wilderness character" of the river corridor.

- Number and size of campable beaches, safe flows for an optimal recreation experience.

- Socioeconomic value of river recreation in GCNRA.

- Socioeconomic value of the river corridor itself in GCNRA.

- Socioeconomic value of the fishery in GCNRA.

- Effect of the trout on the ecosystem in GCNP and the social and economic costs of mitigation.

- Characteristics most valued for the fishery; for example, the number, condition, and size of fish, and the ease or challenge of catching them.

- River running visitation metrics.
- Water quality variables that influence river recreation.
- Other river running safety issues.

A.5 REFERENCE

DFC Ad Hoc Committee, 2012, *Desired Future Conditions for the Colorado River Ecosystem in Relation to Glen Canyon Dam.* Available at http://www.usbr.gov/uc/rm/amp/amwg/pdfs/recltr_12April30.pdf. Accessed July 24, 2015.

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APPENDIX B:

PERFORMANCE METRICS USED TO EVALUATE ALTERNATIVES

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APPENDIX B:

PERFORMANCE METRICS USED TO EVALUATE ALTERNATIVES

This appendix describes a set of scientifically based performance metrics that were used by the Environmental Impact Statement (EIS) team to evaluate the impacts of alternatives on key resources in the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) EIS. The metrics were also used in a structured decision analysis process to objectively evaluate how alternatives perform relative to stakeholder values and in the face of critical uncertainties (Appendix C). The metrics were developed in a series of workshops among subject matter experts working on the LTEMP EIS and were revised to incorporate feedback from Cooperating Agencies and other stakeholders. The performance metrics are intended to be objective measures of the performance of alternatives relative to goals for each affected resource evaluated in the EIS.

Evaluation of these metrics represents only a component of the impact analysis performed for the EIS. Other sources of both quantitative and qualitative information, in addition to the metrics described below, were used to assess the overall and relative performance of alternatives and their constituent elements.

The affected resources, associated goals, and performance metrics are described below.

B.1 AQUATIC ECOLOGY

B.1.1 Humpback Chub

Resource Goal: Meet humpback chub recovery goals, including maintaining a self-sustaining population, spawning habitat, and aggregations in its natural range in the Colorado River and its tributaries below the Glen Canyon Dam.

Performance Metrics

- **Number of Adult Humpback Chub.** This metric provides the estimated number of adult (200 mm+) humpback chub in the Little Colorado River population over the LTEMP period relative to the estimated adult population size in September 2011.

  The modeled number of humpback chub adults was calculated using a size-structured model that considers both the Little Colorado River and mainstem components of the Little Colorado River aggregation and used empirically derived estimates of growth and survival that differ for these two areas. In addition, the size structure of the modeled humpback chub population at the end of the 20-year traces was compared to evaluate possible differences

among alternatives. Growth and survival rates in the mainstem are based on inputs related to monthly water temperature for each of the Colorado River Simulation System (CRSS) traces (modeled using the Wright et al. 2008 model) and estimated annual trout abundance in the Little Colorado River reach occupied by humpback chub. Trout abundance was estimated using a trout emigration submodel that models the numbers of trout that leave the Glen Canyon reach (see description of trout fishery metrics below) and subsequently pass through Marble Canyon to the Little Colorado River reach.

- **Potential for Self-Sustaining Aggregations of Humpback Chub.** The potential for a self-sustaining aggregation of humpback chub to be supported at each of eight locations (river mile [RM] 30, 61 [Little Colorado River], 88, 108, 119, 125–128, 157, and 213) was based on the output of a temperature suitability model that considers how well water temperatures under a particular alternative meet temperature requirements for important humpback chub life history aspects (spawning, egg incubation, and growth) at each aggregation area. It was assumed that mainstem spawning and egg incubation would be required to support self-sustaining aggregations at each location except for the aggregation at the confluence of the mainstem and the Little Colorado River (RM 61), where successful tributary spawning is known to occur. At each location, the potential for successful spawning, egg incubation, and rearing for juvenile humpback chub at various temperatures was calculated using triangular probability functions based on the reported ranges of suitable temperatures and the reported optimal temperatures for each life history need as presented in Valdez and Speas (2007). A temperature suitability score for each life history need was generated for each day of the modeled LTEMP period using modeled predictions of water temperatures for the aggregation location (modeled using the Wright et al. 2008 model).

  Annual mean temperature suitability scores for each life history need were calculated by averaging daily suitability scores that occur during the appropriate portion of each water year (i.e., April–June for spawning and egg incubation and year-round for growth). The annual potential for an aggregation to be self-sustaining at a particular location was calculated as the geometric mean of the annual temperature suitability scores for each life history event within a particular water year (a value between 0 and 1), and the overall means of the annual scores for each hydrologic trace were used to statistically compare the potential for self-sustaining aggregations to be supported by the various alternatives.

  For each hydrologic trace, the number of aggregation locations where the estimated annual temperature suitability score is $\geq$0.5 was determined for each alternative. The mean number of aggregations with temperature suitability values $\geq$0.5 for all traces was used as an indicator of overall humpback chub temperature suitability for each alternative.

B.1.2 Other Native Fish

Resource Goal: Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

Performance Metrics

- **Temperature Suitability for Warmwater Native Fish.** The potential for self-sustaining populations of native warmwater fish (other than humpback chub) to be supported at each of five locations (RM 15, 0, 61, 157, and 225) was based upon the output of a temperature suitability model (similar to the modeling approach for humpback chub aggregation evaluations) that evaluates the suitability of water temperatures under a particular long-term (e.g., 20 years) operational regime for meeting identified needs for major life history aspects (spawning, egg incubation, and growth) of a group of native fish species. The model generates individual temperature suitability scores for four species of native fish (flannelmouth sucker, bluehead sucker, razorback sucker, and speckled dace) at each location. Modeled monthly temperatures at different locations under different alternatives (modeled using the Wright et al. 2008 model) were the primary input needed to generate the temperature suitability scores for this metric.

  The relative suitability of conditions under each alternative to support native fish was represented by the mean of the temperature suitability scores for these four species, calculated for each location, and also by an overall metric for each alternative that combined the temperature suitability scores for the four species at all locations.

B.1.3 Trout Fishery

Resource Goal: Achieve a healthy high-quality recreational trout fishery in Glen Canyon National Recreation Area and reduce or eliminate downstream trout migration consistent with National Park Service (NPS) fish management and Endangered Species Act (ESA) compliance.

Performance Metrics

- **Lees Ferry Trout Abundance Index.** For age 1+ fish.

- **Catch Rate Index (number/hr).** For age 2+ fish.

- **Emigration Estimate.** Number of age-0 trout moving into Marble Canyon from Glen Canyon.

- **Number of Trout >16 in. Total Length.** These metrics were estimated using a trout-humpback chub model developed specifically for the LTEMP EIS by

Lew Coggins (U.S. Fish and Wildlife Service), Josh Korman (Ecometrics), and Charles Yackulic (Grand Canyon Monitoring and Research Center [GCMRC]). The model uses inputs related to annual water volumes, water temperatures, and specifics of the release patterns (e.g., occurrence of high-flow experiments [HFEs], implementation of trout management flows, amount of daily flow fluctuation) to estimate recruitment and survival of trout within the Glen Canyon reach. Emigration of trout into Marble Canyon was based on statistical relationships to the abundance of trout in Glen Canyon. Size structure of trout within the Glen Canyon reach was modeled for age 1+ trout and the calculated number of trout that exceed 16 in. total length was calculated as an estimate of the quality of the fishery. Angling catch rate was calculated for age 2+ trout based on estimated vulnerability of different age classes.

B.1.4 Nonnative Aquatic Species

Resource Goal: Minimize or reduce presence and expansion of aquatic nonnative invasive species.

Performance Metrics

- **Potential for Establishment and Expansion of Nonnative Fish.** The potential for self-sustaining populations of nonnative warmwater and coldwater fish to be supported at each of five locations (RM –15, 0, 61, 157, and 225) was based upon the output of a temperature suitability model that considers how well water temperatures under a particular alternative meet identified needs for required life history aspects (spawning, egg incubation, and growth) of warmwater and coldwater groups of nonnative fish species. The model generates individual temperature suitability scores for four species of warmwater nonnative fish (channel catfish, green sunfish, smallmouth bass, and striped bass) and two species of coldwater fish (brown trout and rainbow trout) at each location.

  The relative suitability of temperature conditions under each alternative to support the two groups of nonnative fish was represented by the mean of the temperature suitability scores for the species within the groups, calculated for each location, and also by an overall metric composed of the temperature suitability scores for the groups at all locations. Modeled monthly temperatures at different locations under different alternatives (modeled using the Wright et al. 2008 model) were the primary input needed to generate the temperature suitability scores for this metric.

- **Potential for Establishment and Expansion of Aquatic Parasites.** A similar temperature suitability model was used to evaluate temperature suitability for the selected fish parasite species (Asian tapeworm, anchor worm, trout

nematode, and whirling disease) based on the suitability of specific temperatures to meet the requirements for host species activity and the development of infestations at each of five locations (RM 15, 0, 61, 157, and 225). As with the nonnative fish modeling, temperature suitability for the parasite species under each alternative was evaluated for the five identified locations using modeled water temperature regimes.

The relative suitability of temperature conditions under each alternative to support the parasite species was represented by the mean of the temperature suitability scores for the species group, calculated for each location, and also by an overall metric composed of the temperature suitability scores for the group at all locations.

B.2 ARCHAEOLOGICAL AND CULTURAL RESOURCES

Resource Goal: Maintain the integrity of potentially affected *National Register of Historic Places* (NRHP) eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

Performance Metrics

- **Wind Transport of Sediment Index.** This metric evaluated the availability of fine sediment for wind transport and potential deposition on historic properties at higher elevations (i.e., those properties located at stages above 45,000 cfs). Deposited sediment would serve to protect those resources from erosion. Optimal conditions for wind transport of sediment occur when (1) there is deposition of fine sediment by flows above the stage of normal operations, which represents the availability of sand at higher elevations, and (2) there are low flows which expose more sand during the windy season, which would make more dry sand available for redistribution by the wind. This criterion accounts for the two processes using the equation:

$$Wind\ Transport\ Index = FF \times SLI$$

where *FF* is the flow factor and *SLI* is the Sand Load Index produced by the Sand Budget Model.

The flow factor represents the relative amount of exposure of sand deposits on a 0–1 scale that occurs for each day of the windy period (March–June). The daily flow factor was calculated as follows:

FF = 1 for maximum daily flows less than or equal to 8,000 cfs, indicating maximum exposure of sand to wind transport;

FF = 0 for maximum daily flows greater than 31,500 cfs, indicating minimum exposure of sand to wind transport;

FF = 1.34 – (0.00004255 × maximum daily flow), for flows between 8,000 and 31,500 cfs. This equation represents the linear decrease in flow factor from 1 at flows of 8,000 cfs to 0 for flows of 31,500 cfs.

The yearly flow factor was calculated by averaging the daily flow factors for the March–June period.

The *SLI* is the ratio of the cumulative sand load transported by high flows (i.e., flows >31,500 cfs) to total cumulative sand load transported by all flows for the alternative (range 0–1; higher index indicates greater likelihood of sediment deposition for wind transport).

Wind Transport Index is a value of 0–1, where a value of 1 has the most exposure to possible movement of sediment by the wind and is therefore the most desirable.

The mean annual Wind Transport Index value for the 20-year modeling period was used as the performance metric for each alternative.

The metric reflects when alternatives create the conditions for movement of sediment by wind, and therefore the potential for cultural resources to be protected, under each alternative. Although windblown sand deposited from sandbars created by dam operations may provide some benefit to archaeological site preservation in Grand Canyon, both the extent to which this occurs and the extent to which wind-deposited sand provides long-term preservation of archaeological sites are not known.

- **Flow Effects on Historic Properties in Glen Canyon Index.** Within Glen Canyon, there is concern that significant archeological sites could be negatively affected by flow levels of certain magnitudes.

  Ninemile Terrace, which is considered representative of other archeological sites situated on terraces within Glen Canyon, is potentially affected by higher flows, which inundate and could erode the slope of the terrace. The toe of the slope begins to be inundated at flows above 23,200 cfs. Consequently, the flow metric is calculated as the mean number of days/year the maximum daily flow is greater than 23,200 cfs.

- **Time Off River Index.** In the Grand Canyon, higher flow levels increase the potential for discretionary time off the river for visitors. There is concern that there may be a greater potential for archaeological sites to be visited and possibly affected, if visitors have more time to explore during the day because of increased travel rates at higher flows.

  The calculated index is a yearly value ranging from 0 to 1, where 1 indicates the most potential for discretionary time for visitors (and the highest potential for increased visitation of archaeological sites).

  Calculation of the index involved computing mean daily flow from the hourly flow data and using this value to calculate an off river flow factor. The off river flow factor (ORFF) was calculated as follows:

  – *ORFF* = 0 for mean daily flows less than or equal to 10,000 cfs, indicating the increased time visitors would spend on the river.

  – *ORFF* = 1 for mean daily flows greater than 31,500 cfs, indicating faster river travel times and potentially increased time spent off the river.

  – *ORFF* = (0.0000465 × mean daily flow) – 0.465, for flows between 10,000 and 31,500 cfs. This equation represents the linear increase in the metric from 0 at flows of 10,000 cfs (lease negative effect) to 1 for flows of 31,500 cfs (greatest negative effect). Flows greater than 31,500 cfs are assigned flow metric values of 1 because of the increased potential for visitation of cultural sites that occur at elevations above normal operating flows.

  ORFF values for each season were summed and weighted to reflect the uneven use of the river throughout the year; 0.15 for winter months (Nov., Dec., Jan., Feb.), 0.31 for spring and fall months (March, April, Sept., Oct.), and 0.54 for summer months (May, June, July, Aug.) and normalized by the number of days in each season as shown in the following equation.

$$TOR = \{0.15\left(\frac{\sum_{winter} ORFF}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{\frac{spring}{fall}} ORFF}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{summer} ORFF}{\sum Days_{summer}}\right)\}$$

B.3 HYDROPOWER AND ENERGY

Resource Goal: Maintain or increase Glen Canyon Dam electric energy generation, load following capability and ramp rate capability, and minimize emissions and costs to the greatest extent practicable consistent with improvement and long-term sustainability of downstream resources.

Performance Metrics[1]

- **Combined Value of Hydropower ($).** This composite performance metric combined (1) the value of energy production, (2) the value of capacity, and (3) the value of operational flexibility, to provide a mean annual and total value estimate for Glen Canyon Dam hydropower under each of the alternatives. Performance metrics were developed that quantify the potential value of hydropower production under the limitations imposed by each alternative. These components were estimated using the GTMax-Lite power systems modeling and post-processing analysis, based on monthly and hourly release estimates for the LTEMP period:

  - **Value of Energy Production ($).** Results show mean annual and total quantities of energy production (MWh) and corresponding energy values ($), based on market price estimates ($/MWh) for the time periods generated. (Market price estimates were used to characterize the economic value of energy delivered to the grid.) This metric was obtained directly from GTMax-Lite hourly results and market price estimates.

  - **Value of Capacity ($).** Results show mean annual and total quantities of capacity available (MW) and corresponding capacity values ($), based on market price estimates ($/MW) for the relevant time periods. This metric, derived from GTMax-Lite results and market price estimates, represents an initial proxy for detailed capacity replacement analyses completed in other stages of the LTEMP analysis.

B.4 NATURAL PROCESSES

Resource Goal: Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

This resource goal incorporates many different physical and biological processes and ecological components of the river system. As a consequence, the goal does not lend itself to expression in a quantitative metric. Instead of a quantitative metric, alternatives were compared in the EIS by qualitatively evaluating each alternative's performance relative to this goal, considering impacts on various natural processes such as flow, sediment transport, water temperature, riparian vegetation, aquatic organisms, and terrestrial wildlife. This resource goal was not included in the structured decision analysis process.

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1 Hydropower performance metrics presented here were used for structured decision analysis and calculating the costs of experiments. Additional hydropower modeling was performed using the AURORA model to project economic impacts of alternatives on electric utilities in the Western Interconnection power grid (see Figure 4-1 in the EIS).

B.5 RECREATIONAL EXPERIENCE

Resource Goal: Maintain and improve the quality of recreational experiences for the users of the Colorado River ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

B.5.1 Grand Canyon Metrics

- **Camping Area Index.** It is important to develop and retain adequate medium (16–25 people) and large (>25 people) campsites to meet the visitor capacities established in the NPS Colorado River Management Plan. The availability of camping area above the stage of normal operations (25,000 cfs) is considered as part of the index.

  Camping area and campsite size are a function of the amount of sand deposited and retained. The output from the Sand Load Index, which simulates sediment conditions between RM 0 and 61 provides a proxy for indicating whether the alternatives are likely to create the conditions conducive to creating/retaining adequate campsite area.

  Camping area and campsite size also are a function of flow level. Lower flows provide more camping area (i.e., there is more camping area at 8,000 cfs than at 25,000 cfs).

  The index was calculated as follows:

  $$Camping\ Area\ Index = SLI \times SWFF$$

  where *SLI* is the Sand Load Index and *SWFF* is the seasonally weighted flow factor.

  SLI is a ratio of the cumulative sand load transported by high flows (i.e., flows >31,500 cfs) to the total cumulative sand load transported by all flows for an alternative (range 0–1; higher index indicates greater likelihood of sediment deposition for campsites).

  SWFF consists of a seasonal weighting (*SW*) and a flow factor (*FF*) component.

  SW is as follows: 0.15 for winter months (Nov., Dec., Jan., Feb.); 0.31 for spring and fall months (March, April, Sept., Oct.), and 0.54 for summer months (May, June, July, Aug.).

FF is as follows: 1 for daily maximum flows that are less than or equal to 8,000 cfs, 0 for daily maximum flows greater than 31,500 cfs, and 1.34 – (0.00004255 × maximum daily flow), for flows between 8,000 and 31,500 cfs. This equation represents the linear decrease in flow factor from 1 at flows of 8,000 cfs to 0 for flows of 31,500 cfs.

The computation of the *SWFF* involved taking hourly flow data and computing daily maximum flows resulting in a time series of daily maximum flows. The next step was to assign these daily maximum flows into seasonal compartments defined by *SW* for each year. *FF* values for each season were summed and normalized by the number of days in each season. The *SWFF* was then calculated as:

$$SWFF = 0.15\left(\frac{\sum_{winter} FF}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} FF}{\sum Days_{summer}}\right)$$

SWFF is a yearly value ranging from 0 to 1, where 1 is better for camping.

The Camping Area Index (*CAI*) is a yearly value that ranges from 0 to 1, where 1 is better for camping area.

- **Visitor Experience Indices.** Visitor experience in Grand Canyon is related to navigational safety, the magnitude of within-day flow fluctuations, and the amount of time visitors can spend off river. These factors are affected by flow levels and fluctuation regimes. This relationship is based on studies documenting difficulties of motor rigs navigating rapids at lower flows, and with oar boats having their travel time and time for off-river activities affected at lower flows. The highest level of recreational impacts occurs when flows are low.

  – **Navigational Risk Index.** The Navigational Risk Index (*NRI*) was calculated in a similar fashion to the *SWFF* component of the camping area index. The *NRI* was a yearly value ranging from 0 to 1, where 1 indicates the least risk, and 0 the most.

  The seasonal weighting for *NRI* was the same as the *SW* component of the *CAI*, specifically: 0.15 for winter months (Nov., Dec., Jan., Feb.); 0.31 for spring and fall months (March, April, Sept., Oct.), and 0.54 for summer months (May, June, July, Aug.).

  The main parameter involved with the calculation of the *NRI* was the number of days where the daily minimum flow was less than 8,000 cfs.

  The computation of the *NRI* involved taking hourly flow data and computing daily minimum flow resulting in a time series of daily minimum flows. The next step was to assign these daily minimum flows

into seasonal compartments defined by *SW* for each year. Then days where daily minimum flow was less than 8,000 cfs ($Days_{min}$) were identified for each season and the *NRI* was then calculated as:

$$NRI = 1 - \left\{0.15\left(\frac{\sum_{winter} Days_{min}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} Days_{min}}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} Days_{min}}{\sum Days_{summer}}\right)\right\}$$

– **Fluctuation Index.** The Fluctuation Index (*FI*) examined the daily range in flow fluctuations relative to a defined threshold, and is a yearly value ranging from 0 to 1, where 1 indicated a desirable recreational and wilderness experience.

The daily range was the difference between the daily maximum and daily minimum flows.

Daily flow fluctuations were described as whether they are "tolerable" for recreational river use (as identified by river guides) (Table B-1) in the pertinent study by Bishop et al. (1987).

We made two assumptions in using this table of fluctuation thresholds: (1) the river flow ranges shown in the left-hand column above were determined based on the mean daily flow, and (2) that the maximum fluctuation (in italics) given in the range of tolerable fluctuations in the right-hand column serves as the daily range threshold ($DR_{threshold}$) condition, above which fluctuations become increasingly more unacceptable to river users. At daily fluctuation levels greater than 10,000 cfs, fluctuations are clearly noticeable and have strong adverse effects on river users.

Fluctuations that are less than or equal to the threshold fluctuation ranges shown in Table B-1 were assigned a value of 1, indicating an optimal condition. As daily fluctuations increased above those thresholds, the *FI* decreased linearly until it reached 0 when fluctuations were at or above

TABLE B-1 Tolerable Flow Fluctuations for Recreational River Use

River Flow (cfs)	"Tolerable Fluctuation" (cfs)
5,000–8,999	2,400–*3,400*
9,000–15,999	3,900–*4,800*
16,000–31,999	6,400–*7,200*
32,000 and up	7,200–*9,800*

10,000 cfs. The equations used to calculate the FI when daily fluctuations exceeded the threshold flows shown in Table B-1 were as follows:

- For mean daily flows between 5,000 cfs and 8,999 cfs: (–0.00015 × daily fluctuation) + 1.5151)
- For mean daily flows between 9,000 cfs and 15,999 cfs: (–0.00019 × daily fluctuation) + 1.923)
- For mean daily flows between 16,000 cfs and 31,999 cfs: (–0.00036 × daily fluctuation) + 3.5714)
- For mean daily flows at or above 32,000 cfs: (–0.005 × daily fluctuation) + 50.000)

Calculation of the *FI* involved computing mean daily flow, minimum daily flow, maximum daily flow, and daily range from the hourly flow data.

The seasonal weighting for *FI* was the same as the *SW* component of the *CAI*, specifically: 0.15 for winter months (Nov., Dec., Jan., Feb.), 0.31 for spring and fall months (March, April, Sept. Oct.), and 0.54 for summer months (May, June, July, Aug.).

The daily flow values and daily ranges were defined by seasonal use. Then for each day, mean daily flow was examined to set the value of $DR_{threshold}$ (italicized flow values in the table). The *FI* then identified days that $DR_{threshold}$ was exceeded ($Days_{exceed}$) according to:

$$FI = \left\{0.15\left(\frac{\sum_{winter} Days_{exceed}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} Days_{exceed}}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} Days_{exceed}}{\sum Days_{summer}}\right)\right\}$$

– **Time Off River Index.** The Time Off River Index examined the amount of time visitors were able to engage in onshore activities such as hiking or visiting attractions, and was a yearly value ranging from 0 to 1, where 1 indicated the most available time off river for visitors. Calculation of the Time Off River Index involved computing mean daily flow from the hourly flow data and using this value to calculate an off river flow factor (*ORFF*).

The *ORFF* was determined as follows: 1 for mean daily flows that are greater than 31,500 cfs, 0 for flows less than 10,000 cfs, and a linear

function for flows between 10,000 and 31,500 cfs ([0.0000465 × mean daily flow] – 0.465).

The seasonal weighting for *TOR* was the same as the *SW* component of the *CAI*, specifically: 0.15 for winter months (Nov., Dec., Jan., Feb.), 0.31 for spring and fall months (March, April, Sept., Oct.), and 0.54 for summer months (May, June, July, Aug.).

ORFF values for each season were summed and normalized by the number of days in each season. The Time Off River Index was then calculated as:

$$0.15\left(\frac{\sum_{winter} ORFF}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} ORFF}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} ORFF}{\sum Days_{summer}}\right)$$

B.5.2 Glen Canyon Metrics

- **Glen Canyon Rafting Use Metric.** This metric represents the amount of recreational use lost in average number of visitors affected by HFEs. The metric is a single value for the 20-year analysis period (note that the range is not 0–1, but some value that is larger than 1 representing the number of lost visitor-days), where a higher value means greater adverse impact. The Glen Canyon rafting use metric uses an estimate of the average daily visitor (*ADV*) use for the months in which HFEs occur (March, April, May, Oct., Nov.). The number and duration of individual HFEs (T_{HFE}) are modeled as a part of the Sand Budget Model.

  The number of days lost for rafting because of an HFE (D_{lost}) is the duration of the HFE plus 2 days prior and 2 days post HFE ($D_{lost} = T_{HFE}$ + 2 days + 2 days) that represent the amount of time required to de-mobilize and re-mobilize rafting operations.

  The Glen Canyon rafting use metric is calculated as follows:

$$\sum_{20\ years} (ADV_{of\ HFE\ month}\left[\frac{visitors}{day}\right] \times D_{lost\ from\ HFE}[days])$$

  The units of the Glen Canyon rafting use metric are in number of visitor-rafting days lost.

- **Glen Canyon Inundation Metric.** The Glen Canyon inundation metric represents the percentage of time that flow is above critical flow elevations that affect recreational experiences. The Glen Canyon inundation metric is a

yearly value ranging from 0 to 1, where 1 indicates an optimal recreational experience.

The flow metric is calculated daily such that:

- Flow metric = 0 for daily maximum flows less than 3,000 cfs, indicating flows below 3,000 cfs are poor for boating and fishing.

- The flow metric between 3,000 cfs and 8,000 cfs was calculated using the linear function, (0.0002 × maximum daily flow) – 0.60, and flow metric values between 0 and 1. Fishing is better above 5,000 cfs, and flows for boating get progressively better up to 8,000 cfs.

- Flow metric = 1 for daily maximum flows between 8,000 and 20,000 cfs, indicating optimal conditions for boating, fishing, and shoreline access.

- The flow metric between 20,000 cfs and 31,500 cfs was calculated using the linear function, 2.739 – (0.00008695 × maximum daily flow), and flow metric values between 1 and 0. Flows above 20,000 cfs get progressively worse for boating, fishing, and shoreline access.

- Flow metric = 0 for daily maximum flows greater than 31,500 cfs. Flows above 31,500 cfs are poor for rafting, campable area, shoreline access, and fishing, and can adversely impact onshore recreational facilities.

B.6 RIPARIAN VEGETATION

Resource Goal: Maintain native vegetation and wildlife habitat, in various stages of maturity that is diverse, healthy, productive, self-sustaining, and ecologically appropriate.

Performance Metrics

- **Riparian Native States and Diversity Index.** The Riparian Native States and Diversity Index considers predicted changes over the 20-year LTEMP period in the relative cover of native vegetation community types and the relative diversity of community types. This metric was developed using a state-and-transition model developed by the GCMRC (Ralston et al. 2014), which uses characteristics of annual operations to predict transitions from one vegetation type to another on different geomorphic features of the riparian zone. The model evaluates the effects of five operations (extended low flow, extended high flow, HFE, pre-dam flow, and default operation) on transitions among seven vegetation states (bare sand, common reed/cattail, horsetail/coyote willow, tamarisk, Baccharis/coyote willow, arrowweed, and mesquite). The model divides operations into growing (April–September) and non-growing

seasons (October–March) and incorporates upper and lower bar submodels, using stage elevation as a division.

Operational characteristics of each alternative were used as input to the riparian model. Output from the model was used to calculate the following component indices, which together were used to develop the overall Riparian Native States and Diversity Index:

- Relative change in cover of native vegetation community types (PM_1) (other than arrowweed) on sandbars and channel margins using the total % increase in native states predicted by an existing state and transition model for riparian vegetation communities.

$$PM_1 = \text{cover}_{\text{final}}/\text{cover}_{\text{initial}}$$

- Relative change in diversity of native vegetation community types (PM_2) (other than arrowweed) on sandbars and channel margins using the Shannon Weiner Index for richness/evenness using the results of the state and transition model.

$$PM_2 = \text{diversity}_{final}/\text{diversity}_{initial}$$

- Relative change in the ratio of native (other than arrowweed)/nonnative dominated vegetation community types (PM_3) on sandbars and channel margins using the ratio of native/nonnative communities predicted by the state and transition model.

$$PM_3 = \text{ratio}_{\text{final}}/\text{ratio}_{\text{initial}}$$

- Relative change in the arrowweed state (PM_4) on sandbars and channel margins using the total % decrease in arrowweed states predicted by the state and transition model.

$$PM_4 = \text{arrowweed}_{initial}/\text{arrowweed}_{final}$$

These individual components were combined as follows:

$$PM_n = (\Sigma w_i PM_i)$$

Where: PM_n = the performance score for Alternative n
PM_i = the score for Performance Metric i

Therefore:

$$PM_n = (PM_1 + PM_2 + PM_3 + PM_4)$$

B.7 SEDIMENT

Resource Goal: Increase and retain fine sediment volume, area, and distribution in the Glen, Marble and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

Performance Metrics

Two metrics were used to reflect sandbar area in Marble and Grand Canyons above 8,000 and 25,000 cfs using existing sediment modeling tools:

- **Sand Load Index.** The Sand Load Index was defined as the cumulative sand load transported by high flows (flows > 31,500 cfs) divided by cumulative sand load for entire alternative (range 0–1; higher index means a greater likelihood of larger sandbars).

- **Sand Mass Balance Index.** The Sand Mass Balance Index was defined as the mean annual sand mass balance between RM 0 and RM 61 (sand mass value, thousand metric tons; higher index means larger mass of sand in the river on average).

B.8 TRIBAL RESOURCES

A large number of resource goals have been identified in discussions with stakeholder Tribes. Although all of these goals are important to the Tribes, not all of the resources were affected by the alternatives being considered in the LTEMP EIS. In the discussion below, resource goals that are likely to differ across LTEMP alternatives (and so matter in the selection of a preferred alternative) are listed separately from resource goals that are not likely to differ across LTEMP alternatives.

For those resource goals that are likely to distinguish LTEMP alternatives, performance metrics are identified. Performance metrics are ways that the achievement of the resource goal might be measured; these were the metrics used to evaluate the alternatives in the EIS. For some of these resource goals, specific metrics that were amendable to quantifying differences among alternatives were not identified. Instead, the Tribes developed narrative evaluations of alternatives that were included in the EIS. Resource goals that would be evaluated in this way in the EIS are identified below.

1. *Increase the health of the ecosystem in Grand, Marble, and Glen Canyons*. The ecosystems in the Canyons is more than the sum of its parts, and should be healthy as a whole. Historically, in the Glen Canyon Dam Adaptive Management Program (GCDAMP), the overall health of the ecosystem has been determined by evaluating the status of each part, but this reductionist approach might possibly miss some important aspects. There are a variety of indicators of ecosystem health, including, but not limited to: the health of the

river and its ability to sustain life; the color of the water; the absence of contaminants, pollutants, and disease in the water; the potability of the water; the quality of the water that reaches Lake Mead; and the viability and health of wildlife and plants in the Canyons. It is important to understand that for many Tribes, the Colorado River is a sentient being and the spiritual center of the ecosystem, as it has the capability of giving and taking life, and it is prone to anger if mistreated; the health of the ecosystem depends on the health of the River.

This resource goal requires consideration of traditional ecological knowledge (TEK), and an evaluation of alternatives applying TEK was included in the narrative EIS analysis, but not the structured decision analysis.

2. *Protect and preserve sites of cultural importance*. There are specific sites within the Canyons that are important for cultural reasons and for preservation of Tribal/religious society/kiva group/clan history (e.g., shrines, sacred sites, ancient burial sites, springs, plant collection areas, mineral collection areas, offering places, and other elements). These sites can be threatened by erosion, loss of sediment inputs, and intrusive human use (especially, non-Tribal, outside visitors). Both flow and non-flow actions (e.g., education, permitting, research/monitoring, and interpretation) may affect these sites.

    a. Performance metric: *Wind Transport of Sediment Index* (see Section B.2). This index focuses on the availability of fine sediment for wind transfer to protect NRHP eligible or listed sites (see Archaeological and Cultural Resources).

        It should be noted that the sites and resources that are individually NRHP eligible or listed do not represent a full set of Tribal concerns. Tribal input was necessary to identify impacts to other culturally important sites or resources, and to develop an appropriate measure of their protection and preservation.

    b. Performance Metric: *Flow Effects on Historic Properties in Glen Canyon Index* (see Section B.2). In Glen Canyon, flow levels could affect resources through inundation (see Archaeological and Cultural Resources).

    c. Performance Metric: *Time Off River Index* (see Section B.2). In Grand Canyon, flow levels could increase the potential for discretionary time off the river for visitors, which could in turn result in an increased potential for archaeological sites to be visited and possibly adversely affected (see Archaeological and Cultural Resources).

d. Performance metric: *Riparian Diversity Index*. Using results from the "Riparian Vegetation" state and transition model, this metric employed the Shannon-Weiner Index for richness and evenness to compare relative changes in diversity of six vegetation states found on sandbars and channel margins. The equation for the Shannon-Weiner Index is:

$$-\sum_{i=1}^{n}(p_i)(\log_2 p_i)$$

where p_i is the proportion of the *i*th state of the total bar-years. The Riparian Diversity Index was the proportion of model run diversity divided by the initial diversity found on sandbars and channel margins.

e. Performance metric: *Marsh Habitat.* Using results from the "Riparian Vegetation" state and transition model, this metric modeled change in marsh habitat. This metric compared the modeled change in marsh vegetation states (clonal wet marsh and perennial marsh) for each alternative.

f. Performance metric: *Native Fish*. Temperature suitability reflects protection and preservation of a resource important to Tribes (see Section B.1.2).

g. Assessment: *Access to Springs.* For most Tribes, all springs and seeps are sacred. Access to culturally important springs may be affected by flow levels. Springs were evaluated in the EIS to determine if alternatives differ in terms of the ability of Tribes to access them under varying flow conditions.

3. *Preserve and enhance respect for life*. The Tribes see life itself as sacred and believe that human activities should protect and promote life, not destroy life. There are two aspects to this objective: first, minimize the taking of life; and second, encourage the expansion and proliferation of life forms. These are both complex concepts. The Tribes recognize that it is appropriate for humans to take other life in some circumstances, especially when it promotes other life (particularly our own consumption for survival), but this taking needs to be minimal and respectful because there are spiritual consequences associated with the taking of life. The promotion of life does not necessarily imply a return to historical or "natural" conditions—the Glen Canyon Dam has encouraged new life in Glen, Marble, and Grand Canyons, so a return to pre-Dam conditions is not necessarily implied by this objective, nor is there a strong distinction between native and nonnative species among all Tribes.

a. Performance metric: *The average number of years in which trout mechanical removal trips occur.* As a coarse measure of the impact of killing trout, this allows a distinction between alternatives that minimize mechanical removal. But the nature of the take, the purpose behind it, the methods of take, the disposition of the trout taken, and the mindset of those killing the fish also affect the sacred treatment of living beings. This performance metric was calculated from the coupled trout-humpback chub models.

b. Performance metric: *The average number of years in which trout management flows occur*. Trout management flows, designed to reduce reproduction or survival of juvenile trout, are considered to be killing by some Tribes, and should be minimized. Alternatives that include trout management flows are likely to differ in how often the flows are triggered, so this performance metric might ultimately help to distinguish the alternatives. This performance metric was calculated from the coupled trout-humpback chub models.

4. *Preserve and enhance the sacred integrity of Grand, Marble, and Glen Canyons*. Grand, Marble, and Glen Canyons are sacred to many Tribes, and the preservation of their sacred integrity is important. The sanctity of the Canyons may be threatened by human impacts and behaviors, development, and the presence of artificial structures and activities. An important aspect of the sanctity is the intentionality of visitors: when outsiders enter the Canyons (on boat or hiking trips), the respect they show to the Canyons and Colorado River can affect the spiritual integrity. There are many consequences of the disturbance of this sanctity, including, but not limited to, a reduction of the spiritual strength of plants gathered and used by the Navajo for medicinal and cultural purposes; an inability to retire Navajo sacred objects into the Colorado River when they have become too old for continued use; weakening of the sacred role the Canyons play as a final resting place for Hopi; and an overall disruption of the state of mind and spirit of Zuni religious leaders and their experience of being within a very sacred place that embodies the Zuni emergence, migrations, creation of medicine bundles, and the communion with the spirits of Zuni ancestors.

a. Assessment: This resource goal, while of profound importance to the Tribes, is not thought to differ measurably across the alternatives under consideration in the LTEMP EIS, because it is not driven by flow operations from the dam or currently envisioned attendant activities. Future science plans could include activities that are objectionable to the Tribes. Future science planning should include meaningful consultation with the Tribes. This goal was evaluated in the narrative EIS analysis, but not the structured decision analysis.

5. *Maintain and enhance healthy stewardship opportunities*. Several of the Tribes have been given a sacred stewardship responsibility for the preservation and harmony of the world. For example, the Hopi have a covenant with *Ma'saw* to be stewards of the earth; other Tribes have similar stewardship ethics grounded in spiritual traditions. To maintain these stewardship responsibilities, the Tribes need to be an active part of stewardship of the Canyons. This stewardship includes ceremonial activities, whether performed in the Canyons or in the villages; participation in management of the Canyons, including water management, both through traditional practices and Western management activities; and education, to maintain cultural knowledge and connection with the Canyons. The Tribes note that the federal government also has stewardship responsibilities that arise out of federal legislation; because this federal involvement has sometimes taken stewardship responsibility from the Tribes, it is critical that the federal government be accountable for its stewardship. At times, the colonial presence of the federal government has made it more difficult for Tribes to carry out their stewardship responsibilities; the Tribes need the autonomy to undertake their responsibilities. Successful development of joint stewardship among the Tribes and federal government will require continued building of mutual respect and trust between those entities.

    a. Assessment: Tribal stewardship opportunities are not tied to individual alternatives being considered in the LTEMP EIS, but could be crafted to apply to any of the alternatives. Thus, this resource goal, while of critical importance to the Tribes individually, as well as to the ongoing relationship between the Tribes and the federal government, may not help distinguish among the alternatives. This goal was evaluated in the narrative EIS analysis, but not the structured decision analysis.

6. *Maintain and enhance the Tribal connections to the Canyons*. The spiritual, historical, and cultural connections that Tribes have to the Canyons require the protection of sacred sites and the integrity of the Canyons as a whole, but protection alone is not enough. The Tribes also need opportunities for access, education, and stewardship to keep their connections vibrant. Access can be undermined by physical barriers, by the requirement of permits from a colonial authority, and by the effects of human activity that decrease the power of those sites and the experience when at them (e.g., lack of privacy, disturbance of the soundscape and viewshed).

    a. Assessment: Like the sacred integrity and stewardship resource goals, this resource goal is not thought to differ across the alternatives. The flow operations of Glen Canyon Dam are not likely to affect Tribal access, education, spiritual ceremonies, or other connections to the Canyons. This resource goal may be more appropriately addressed through government-to-government consultation in other forums. This goal was evaluated in the EIS, but not the structured decision analysis.

7. *Increase economic opportunity*. The Canyons, the Colorado River, and the dam are sources of economic benefit for the Tribes in the area. The Canyons provides tourism and other opportunities that enhance the economic well-being of Tribes. (As an important note, tourism can also undermine the well-being of Tribes in aspects other than economic; see the other Tribal resource goals.). Glen Canyon Dam provides affordable electricity for Tribal needs, as well as for development projects.

    a. Assessment: *projected annual economic benefit for the Hualapai Tribe associated with river-running tourism.* During discussions with Tribal representatives, one particular economic concern was raised by Hualapai river runners, namely, the effect on tourism operations of extensive sediment deposition downstream of Diamond Creek. There is a narrative analysis of the effect of dam operations on Hualapai River running in the EIS.

    b. Assessment: Note that the economic benefit directly associated with hydroelectric power is measured through the hydroelectric performance metrics. A recreation economics model was used to determine the value of recreational use of Lake Powell, Lake Mead, and the Colorado River downstream of Glen Canyon Dam.

8. *Maintain Tribal water rights and supply*. Tribes in the area depend on the Colorado River for many of their water needs, so the preservation of established, traditional, and desired water rights, both now and into the future, is important. There are a number of claims to water rights that have been asserted by the Tribes, but for which there are not yet quantified rights through decree or negotiated settlement; these water rights are as important as the established water rights.

    a. Sidebar for LTEMP EIS alternatives: based on its purpose and need, the LTEMP EIS is not intended to include any alternatives that violate agreed-upon Tribal water rights.

    b. Performance metric: *Lake Powell water elevation.* This metric evaluates the frequency with which Lake Powell elevations drop below critical levels where existing or proposed intakes are.

9. *Process objectives*. There are several important process objectives—objectives that govern *how* the LTEMP decision is made, rather than what decision is made. The first of these is the genuine incorporation of Tribal input to the LTEMP process, as a reflection of Federal trust responsibilities. The second is the importance of incorporating learning, to improve management over time; in this spirit, an experimental approach that can result in adaptive management is favored.

a. Assessment: (a) It is the intention of the U.S. Department of the Interior and the joint-lead federal agencies to genuinely incorporate Tribal input into the LTEMP process, and this has been undertaken through face-to-face meetings with individual Tribes who have requested such meetings, as well as regular conference calls with Tribal representatives. The Tribes are included in all Cooperating Agency and stakeholder meetings. Continued involvement of Tribes in the LTEMP process will occur. (b) The evaluation of experimental alternatives and the development of a long-term monitoring program associated with the LTEMP EIS will occur in a later stage of analysis. The purpose and need for the EIS include the appropriate incorporation of learning. Thus, this resource goal is an important part of how the process was designed for LTEMP, but it does not help distinguish among the alternatives (because the alternatives do not differ in this regard).

B.9 WATER DELIVERY

Resource Goal: Ensure that water delivery continues in a manner that is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in *Arizona v. California*, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin.

Calculated Metrics (not used in the structured decision analysis process)

- Frequency of deviation from Alternative A (No Action Alternative) to Lake Powell Annual Operating Tier as specified by the 2007 Interim Guidelines (Reclamation 2007). The Operating Tier was predicted using the CRSS RiverWare model.

- Probability over time of Lake Powell being in each Operating Tier as specified in the 2007 Interim Guidelines (Reclamation 2007). The Operating Tier was predicted using the CRSS RiverWare model.

- Frequency and volume of exceptions to meeting the annual release target volumes specified by the 2007 Interim Guidelines (Reclamation 2007). The target and actual annual release volumes were predicted using the CRSS RiverWare model.

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APPENDIX C:

DECISION ANALYSIS TO SUPPORT DEVELOPMENT OF THE GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN

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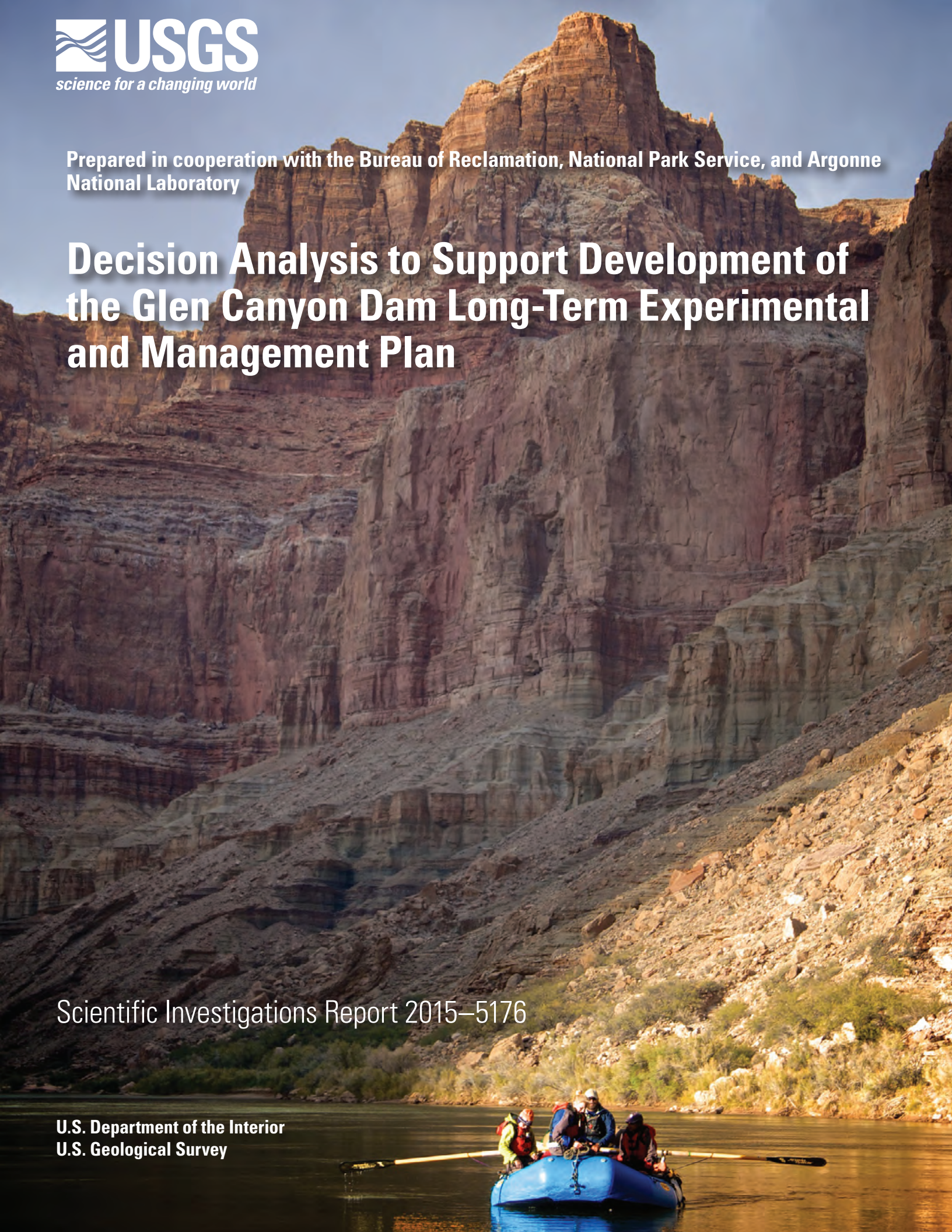

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Covers. Front: An oar boat with university students from Northern Arizona University's Grand Canyon Semester passes river mile 61 near the confluence of the Little Colorado River and the Colorado River. This area is known for its biological and cultural significance, as the stronghold of the endangered humpback chub, and a place of importance in many tribal histories. Photograph taken by Amy S. Martin, Northern Arizona University, November 2014.

Back: Lower Beaver Falls lies approximately 4 miles up Havasu Creek from its confluence with the Colorado River at river mile 157 and is the site of ongoing endangered humpback chub translocations. Photograph taken by Amy S. Martin, National Park Service, October 2013.

Decision Analysis to Support Development of the Glen Canyon Dam Long-Term Experimental and Management Plan

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Prepared in cooperation with the Bureau of Reclamation, National Park Service, and Argonne National Laboratory

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Suggested citation:
Runge, M.C., LaGory, K.E., Russell, Kendra, Balsom, J.R., Butler, R.A., Coggins, L.G., Jr., Grantz, K.A., Hayse, John, Hlohowskyj, Ihor, Korman, Josh, May, J.E., O'Rourke, D.J., Poch, L.A., Prairie, J.R., VanKuiken, J.C., Van Lonkhuyzen, R.A., Varyu, D.R., Verhaaren, B.T., Vesekla, T.D., Williams, N.T., Wuthrich, K.K., Yackulic, C.B., Billerbeck, R.P., and Knowles, G.W., 2015, Decision analysis to support development of the Glen Canyon Dam Long-Term Experimental and Management Plan: U.S. Geological Survey Scientific Investigations Report 2015–5176, 64 p., http://dx.doi.org/10.3133/sir20155176.

ISSN 2328-0328 (online)

Acknowledgments

A project this large owes a debt of gratitude to many people who generously offered their support, insights, and expertise. The authors thank Anne Castle and Lori Caramanian from the Department of the Interior for their vision and support for the inclusion of decision analysis methods in the development of the Environmental Impact Statement. Ted Melis (U.S. Geological Survey Grand Canyon Monitoring and Research Center) provided extensive insights during the first 2 years of this project, helping shape the design of this analysis. Jack Schmidt and Scott VanderKooi (U.S. Geological Survey Grand Canyon Monitoring and Research Center) shared their expertise and leadership, and provided access to the scientific experts at their Center.

This project required expertise from many agencies outside of the U.S. Geological Survey. Too numerous to list here, the many members of the subject-matter expert teams provided critical input to the development of performance metrics and the quantitative evaluation of alternatives. The efforts to articulate and attempt to quantify tribal viewpoints would have been impossible without the dedication and expertise of many representatives, including Kurt Dongoske (Pueblo of Zuni), Mike Yeatts (Hopi Tribe), Loretta Jackson-Kelly and Peter Bungart (Hualapai Tribe), Charley Bulletts (Southern Paiute Consortium), Robert Kirk and Tony Joe (Navajo Nation), and Sarah Rinkevich (U.S. Fish and Wildlife Service). Terry Walshe and David Smith provided insightful comments on an earlier draft of this report. Rich Valdez and Carl Walters shared their depth of knowledge and astute perspectives on many aspects of the Grand Canyon ecosystem. The authors are deeply grateful to the representatives from the stakeholder agencies who participated in the swing-weighting exercise; and worked diligently, enthusiastically, and with integrity to share their perspectives.

Funding for this project was provided by the Bureau of Reclamation.

Contents

Acknowledgments iii
1 Abstract 1
2 Introduction 2
3 Decision Analysis 4
3.1 Structured Decision Making 4
3.2 Multicriteria Decision Analysis 4
3.2.1 A Full Articulation of Resource Goals 5
3.2.2 Performance Metrics 5
3.2.3 Transparent and Quantitative Evaluation of Alternatives 6
3.2.4 Tradeoff Analysis 6
3.3 Uncertainty, Value of Information, and Adaptive Management 6
3.3.1 Adaptive Management Versus Experimental Management 6
3.3.2 Articulating Uncertainty as Competing Hypotheses 7
3.3.3 Deconstructing Complex Alternatives 7
3.3.4 Value of Information 8
3.3.5 Experimental and Adaptive Design 8
4 Resource Goals and Performance Metrics 9
4.1 Aquatic Ecology 9
4.1.1 Humpback Chub 9
4.1.2 Other Native Fish 9
4.1.3 Rainbow Trout Fishery 9
4.1.4 Nonnative Aquatic Species 9
4.2 Archaeological and Cultural Resources 10
4.3 Hydropower and Energy 11
4.4 Natural Processes 11
4.5 Recreational Experience 11
4.6 Riparian Vegetation 11
4.7 Sediment 12
4.8 Tribal Resources 12
4.8.1 Health of the Ecosystem 12
4.8.2 Sites of Cultural Importance 12
4.8.3 Respect for Life 13
4.8.4 Sacred Integrity of Grand, Marble, and Glen Canyons 13
4.8.5 Stewardship 13
4.8.6 Tribal Connections to the Canyons 14
4.8.7 Economic Opportunity 14
4.8.8 Tribal Water Rights and Supply 14
4.8.9 Process Objectives 14
4.9 Water Delivery 14
5 Alternatives 15
5.1 Action Elements 15
5.1.1 Monthly Release Pattern and Other Base Operations 15

5.1.2 High-Flow Experiments 15
5.1.3 Trout Management Flows 15
5.1.4 Other Flow Manipulations 15
5.1.5 Nonflow Actions 17
5.1.6 Long-Term Strategies 17
5.2 Alternative A (No Action) 18
5.3 Alternative B 18
5.3.1 Alternative Long-Term Strategies 18
5.4 Alternative C 18
5.4.1 Alternative Long-Term Strategies 18
5.5 Alternative D 19
5.5.1 Alternative Long-Term Strategies 19
5.6 Alternative E 19
5.6.1 Alternative Long-Term Strategies 20
5.7 Alternative F 20
5.8 Alternative G 20
6 Quantitative Methods 20
6.1 Modeling Overview 20
6.2 Hydrology 22
6.2.1 Critical Uncertainty 22
6.3 Sediment Dynamics 22
6.3.1 Critical Uncertainty 22
6.4 Temperature 23
6.5 Coupled Rainbow Trout-Humpback Chub Dynamics 23
6.5.1 Critical Uncertainties 23
6.6 Fish Habitat Suitability 23
6.7 Archaeological and Cultural Resources 24
6.8 Hydropower 24
6.9 Recreation 25
6.10 Riparian Vegetation 25
7 Consequence Analysis Results 25
7.1 Humpback Chub Results 25
7.2 Rainbow Trout Fishery Results 26
7.3 Archeological and Cultural Resources Results 32
7.4 Hydropower Generation and Capacity Results 32
7.5 Recreational Experience Results 32
7.6 Riparian Vegetation Results 32
7.7 Sediment Results 37
7.8 Tribal Resources Results 37
7.9 Full Consequence Table 37
8 Decision Analysis Results 42
8.1 Swing-Weighting Method and Results 42
8.2 Multicriteria Decision Analysis 42
8.3 Expected Value of Information 48
8.4 Effects of Climate Change 51

9 Discussion 52
9.1 Evaluation of Alternatives 52
9.2 Motivation for Adaptive Management 53
9.3 Decision Analysis and the National Environmental Policy Act 54
10 Summary 54
11 References Cited 54
12 Appendix 1. Disclaimers 59
12.1 Standard Disclaimer 59
12.2 Arizona Department of Water Resources Disclaimer 59
12.3 Arizona Game and Fish Department Disclaimer 60
12.4 Salt River Project Explanatory Letter 60
12.5 Utah Associated Municipal Power Systems Explanatory Letter 61
12.6 Colorado River Energy Distributors Association Submittal Letter 61

Figures

1. Map showing the Colorado River ecosystem below Glen Canyon Dam, depicting the Glen Canyon Dam Adaptive Management Program project area 3
2. Diagram showing model flow for the analysis of the Long-Term Experimental and Management Plan long-term strategies against the performance metrics 21
3. Graphs showing uncertainty in the humpback chub population dynamics as represented by four alternative sets of parameters 24
4. Box plots showing minimum number of adult humpback chub (performance metric 1) forecast for 19 long-term strategies with equal weighting of traces 26
5. Box plots showing temperature suitability index for humpback chub at river mile 157 and 213 (performance metric 2) forecast for 19 long-term strategies with equal weighting of traces 30
6. Box plots showing rainbow trout catch rate (performance metric 3) forecast for 19 long-term strategies with equal weighting of traces 30
7. Box plots showing rainbow trout emigration rate from Glen Canyon (performance metric 4) forecast for 19 long-term strategies with equal weighting of traces 31
8. Box plots showing abundance of high-quality rainbow trout (performance metric 5) forecast for 19 long-term strategies with equal weighting of traces 31
9. Box plots showing wind transport of sediment index (performance metric 6) forecast for 19 long-term strategies with equal weighting of traces 33
10. Box plots showing Glen Canyon flow index (performance metric 7) forecast for 19 long-term strategies with equal weighting of traces 33
11. Box plots showing cultural resources time-off-river index (performance metric 8) forecast for 19 long-term strategies with equal weighting of traces 34
12. Box plots showing annualized net present value of hydropower generation (performance metric 9) forecast for 19 long-term strategies with equal weighting of traces 34
13. Box plots showing annualized net present value of hydropower capacity (performance metric 10) forecast for 19 long-term strategies with equal weighting of traces 35

14. Box plots showing camping area index (performance metric 11) forecast for 19 long-term strategies with equal weighting of traces 35
15. Box plots showing fluctuation index (performance metric 12) forecast for 19 long-term strategies with equal weighting of traces 36
16. Box plots showing Glen Canyon rafting use metric (performance metric 13) forecast for 19 long-term strategies with equal weighting of traces 36
17. Box plots showing riparian vegetation index (performance metric 14) forecast for 19 long-term strategies with equal weighting of traces 38
18. Box plots showing sand load index (performance metric 15) forecast for 19 long-term strategies with equal weighting of traces 38
19. Box plots showing marsh vegetation ratio (ratio of average marsh cover over 20-year period to current marsh cover, performance metric 16) forecast for 19 long-term strategies with equal weighting of traces 39
20. Box plots showing frequency of mechanical removal (performance metric 17) forecast for 19 long-term strategies with equal weighting of traces 39
21. Box plots showing frequency of trout management flows (performance metric 18) forecast for 19 long-term strategies with equal weighting of traces 40
22. Graphs showing principal components analysis of the weights on the performance metrics across stakeholder agencies....45
23. Box plots showing joint-lead agency weighted performance across 18 metrics forecast for 19 long-term strategies using equal weighting of hydrological traces....46
24. Box plots showing joint-lead agency weighted performance across 18 metrics, sorted by mean performance, forecast for 19 long-term strategies using equal weighting of hydrological traces 48
25. Box plots showing weighted performance across 18 metrics, for four stakeholder agencies, sorted in descending order of mean performance....49
26. Box plots showing mean annual inflow to Lake Powell during the 20-year period of the Long-Term Experimental and Management Plan for 21 historical hydrological traces and 112 climate-change-influenced hydrological traces....51
27. Box plots showing joint-lead agency weighted performance across 18 metrics forecast for 19 long-term strategies using the climate-change weighting of hydrological traces....52

Tables

1. Summary of the 18 performance metrics used in the decision analysis 10
2. Operational characteristics of Long-Term Experimental and Management Plan alternatives 16
3. Triggered and experimental elements of the Long-Term Experimental and Management Plan long-term strategies 17
4. Effect of critical uncertainty on minimum adult humpback chub population size (performance metric 1) 27
5. Effect of hydrological trace on minimum adult humpback chub population size (performance metric 1) 28
6. Expected value of information, by performance metric, for resolving critical uncertainty 29
7. Full consequence table showing the mean value of each performance metric for each long-term strategy 41
8. Swing-weighting response form 43
9. Agencies participating in the swing-weighting exercise 44
10. Weighted performance for 19 long-term strategies using the weights on the performance metrics expressed by 14 participating agencies 47
11. Expected value of perfect information for resolving various uncertainties, as a function of the agency-specific weights 50

Conversion Factors

[Inch/Pound to International System of Units]

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acrea-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

ADWR	Arizona Department of Water Resources
AGFD	Arizona Game and Fish Department
AMWG	Adaptive Management Working Group
Argonne	Argonne National Laboratory
Aurora	AURORAxmp
AZGFD	Arizona Game and Fish Department
BIA	Bureau of Indian Affairs
CMIP3	Coupled Model Intercomparison Project Phase 3
CREDA	Colorado River Energy Distributors Association
CRSP	Colorado River Storage Project
CRSS	Colorado River Simulation System
DEIS	Draft Environmental Impact Statement
DFC	desired future condition
DOI	U.S. Department of the Interior
DT	Decision-Theoretic school of adaptive management
EIS	Environmental Impact Statement
ESA	Endangered Species Act of 1973
EVPI	expected value of perfect information
EVXI	expected value of partial information
FWS	U.S. Fish and Wildlife Service
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
GCPA	Grand Canyon Protection Act of 1992
GCRG	Grand Canyon River Guides
GTMax-Lite	Generation and Transmission Maximization model, spreadsheet version
HBC	humpback chub (*Gila cypha*)
HFE	high-flow experiment
IFFF	International Federation of Fly Fishers
LTEMP	Long-Term Experimental and Management Plan
MCDA	multicriteria decision analysis
MLFF	Modified Low Fluctuating Flow
NEPA	National Environmental Policy Act
NPCA	National Parks Conservation Association
NPS	National Park Service

NPV	net present value
O&M	operating and maintenance
RBT	rainbow trout (*Onchorhynchus mykiss*)
RE	Resilience-Experimentalist school of adaptive management
Reclamation	Bureau of Reclamation
RM	river mile
ROD	Record of Decision
SDA	structured decision analysis
SDM	structured decision making
SLI	sand load index
SMART	Simple Multi-attribute Rating Technique
SME	subject-matter expert
SRP	Salt River Project
TMF	trout management flow
UAMPS	Utah Associated Municipal Power Systems
WAPA	Western Area Power Administration
WTSI	wind transport of sediment index

Decision Analysis to Support Development of the Glen Canyon Dam Long-Term Experimental and Management Plan

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1 Abstract

The U.S. Geological Survey, in cooperation with the Bureau of Reclamation, National Park Service, and Argonne National Laboratory, completed a decision analysis to use in the evaluation of alternatives in the Environmental Impact Statement concerning the long-term management of water releases from Glen Canyon Dam and associated management activities. Two primary decision analysis methods, multicriteria decision analysis and the expected value of information, were used to evaluate the alternative strategies against the resource goals and to evaluate the influence of uncertainty.

A total of 18 performance metrics associated with 8 out of 12 resource goals (fundamental objectives) were developed by the Bureau of Reclamation and National Park Service in partnership with subject-matter teams composed of Federal, State, tribal, and private experts. A total of 19 long-term strategies associated with 7 alternatives were developed by the Bureau of Reclamation, National Park Service, Argonne National Laboratory, U.S. Geological Survey, and Cooperating Agencies. The 19 long-term strategies were evaluated against the 18 performance metrics using a series of coupled simulation models, taking into account the effects of several important sources of uncertainty. A total of 27 Federal, State, tribal, and nongovernmental agencies were invited by the Assistant Secretary of Interior to participate in a swing-weighting exercise to understand the range of perspectives about how to place relative value on the resource goals and performance metrics; 14 of the 27 chose to participate. The results of the swing-weighting exercise were combined with the evaluation of the alternatives to complete a multicriteria decision analysis. The effects of uncertainty on the ranking of long-term strategies were evaluated through calculation of the value of information.

The alternatives and their long-term strategies differed across performance metrics, producing unavoidable tradeoffs; thus, there was no long-term strategy that was dominated by another across all performance metrics. When the performance of each alternative was weighted across performance metrics, three alternatives (B, D, and G) were top-ranked depending on the set of weights proposed: Alternative B was favored by those stakeholders that placed a high value on hydropower; Alternative G was favored by those stakeholders that placed a high value on the restoration of natural processes, like beach-building and natural vegetation; and Alternative D was favored by the remaining stakeholders. Surprisingly, these rankings were not sensitive to the critical uncertainties that were evaluated; that is, the choice of a preferred long-term strategy was sensitive to the value-based judgment about how to place relative weight on the resource goals but was not sensitive to the uncertainties in the system dynamics that were evaluated in this analysis. The one area of uncertainty that did slightly affect the ranking of alternatives was the long-term pattern of hydrological input; because of this sensitivity, some attention to the possible effects of climate change is warranted.

The results of the decision analysis are meant to serve as only one of many sources of information that can be used to evaluate the alternatives proposed in the Environmental Impact Statement. These results only focus on those resource goals for which quantitative performance metrics could be formulated and evaluated; there are other important aspects of the resource goals that also need to be considered. Not all the stakeholders who were invited to participate in the decision

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analysis chose to do so; thus, the Bureau of Reclamation, National Park Service, and U.S. Department of Interior may want to consider other input.

2 Introduction

The Glen Canyon Dam is on the Colorado River in Arizona, United States, within the boundaries of Glen Canyon National Recreation Area and upstream from Grand Canyon National Park (fig. 1) and is managed by the Bureau of Reclamation (hereinafter referred to as "Reclamation"). The Glen Canyon Dam Adaptive Management Program (GCDAMP) was established in 1997 to provide research and monitoring of downstream resources to Reclamation and the U.S. Department of the Interior (DOI). The GCDAMP project area stretches along the Colorado River from the forebay of Glen Canyon Dam to the westernmost boundary of Grand Canyon National Park. Locations along the Colorado River are indexed by river miles (RM) with a reference point at Lees Ferry (RM 0). The Glen Canyon Dam is at RM -15.5 (15.5 mi upstream from Lees Ferry). Other important locations that are referenced in this report include the following: Paria River (RM 1.0), Little Colorado River (RM 61.4), and Bright Angel Creek (RM 87.8) (fig. 1). The reach from Glen Canyon Dam to Lees Ferry is known as Glen Canyon, the reach from Lees Ferry to the Little Colorado River is known as Marble Canyon, and Grand Canyon proper begins at the Little Colorado River.

In October 1996, the Secretary of the Interior signed a Record of Decision (ROD) documenting the selection of operating criteria for Glen Canyon Dam (Bureau of Reclamation, 1996) as analyzed in the 1995 Final Environmental Impact Statement (Bureau of Reclamation, 1995). The preferred alternative, known as Modified Low Fluctuating Flow (MLFF), has governed the operation of Glen Canyon Dam for the last 19 years (1996 to present) with important modifications described in "Final Environmental Impact Statement—Colorado River interim guidelines for lower basin shortages and the coordinated operations for Lake Powell and Lake Mead" (Bureau of Reclamation, 2007), "Environmental Assessment—Development and implementation of a protocol for high-flow experimental releases from Glen Canyon Dam" (Bureau of Reclamation, 2011a), "Environmental Assessment—Non-native fish control downstream from Glen Canyon Dam" (Bureau of Reclamation, 2011b), and many other regulatory documents. The Bureau of Reclamation (1996) also established the GCDAMP and Grand Canyon Monitoring and Research Center (GCMRC), which has led extensive monitoring and research aimed to improve the management of the Colorado River and its environs below Glen Canyon Dam.

In July 2011, the Secretary of the Interior announced the intent to develop a Long-Term Experimental and Management Plan (LTEMP) and Environmental Impact Statement (EIS) for Glen Canyon Dam as the first comprehensive review of dam operations in 15 years and as an opportunity to integrate the considerable scientific information collected since the GCDAMP began in 1996. The Bureau of Reclamation and National Park Service (NPS) are serving as joint-lead agencies for the EIS. The following agencies are participating as Cooperating Agencies in development of the EIS: Arizona Game and Fish Department (AGFD), Bureau of Indian Affairs (BIA), Colorado River Board of California, Colorado River Commission of Nevada, the Havasupai Tribe, the Hopi Tribe, the Hualapai Tribe, the Kaibab Band of Paiute Indians, the Navajo Nation, the Pueblo of Zuni, Salt River Project (SRP), U.S. Fish and Wildlife Service (FWS), Upper Colorado River Commission, Utah Associated Municipal Power Systems (UAMPS), and Western Area Power Administration (WAPA).

The purpose of the LTEMP is to provide a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of federal law (Bureau of Reclamation and National Park Service 2015); thus, the preferred alternative ultimately selected for the LTEMP will govern the management of water releases at Glen Canyon Dam for the next 20 years, specifying condition-dependent seasonal, weekly, and daily patterns of release, as well as nonflow actions, including vegetation management and the potential for mechanical removal of nonnative fish. The goals for the LTEMP are to meet the requirements of the GCPA; and to minimize, consistent with the law, adverse effects on the downstream natural, recreational, and cultural resources in Glen Canyon National Recreation Area and Grand Canyon National Park, including resources of importance to American Indian Tribes, while ensuring water delivery and maintaining or increasing hydroelectric capacity and generation. The need for the LTEMP arises from scientific information developed since the 1996 record of decision (Bureau of Reclamation, 1996), the use of which will better inform DOI decisions on dam operations and other management and experimental actions so that the Secretary of the Interior may continue to meet statutory obligations to protect resources downstream from Glen Canyon Dam for future generations, conserve species listed under the Endangered Species Act of 1973 (ESA), avoid or mitigate effects on National Register eligible properties, and protect tribal interests, while meeting water delivery obligations and providing hydropower generation. The list of resources of concern in the analysis of alternatives includes the following: tribal resources and interests, sediment deposition and retention, riparian vegetation, humpback chub (HBC) (*Gila cypha*) and other native fish, historic properties, recreation, the rainbow trout fishery in Glen Canyon, water delivery, and hydropower. There is uncertainty about how management actions in this system affect the resources of concern, which complicates the analysis of alternatives. There is an acknowledged need for adaptive management (Walters, 1986), perhaps even for experimental actions chosen to accelerate learning for the benefit of selecting future management actions. The decision problem, therefore, can be characterized as one of multiple objective tradeoffs in the face

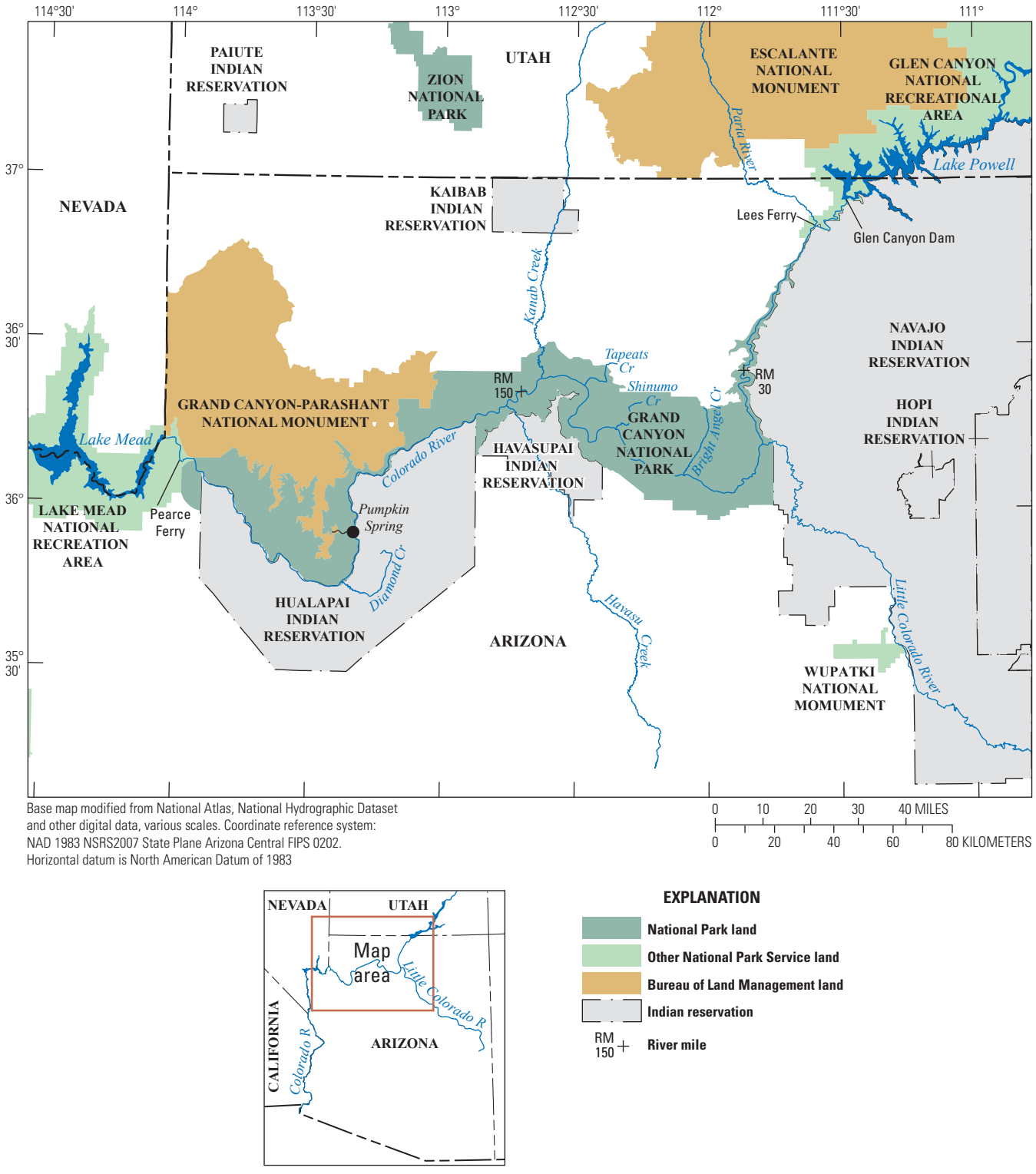

Figure 1. The Colorado River ecosystem below Glen Canyon Dam, depicting the Glen Canyon Dam Adaptive Management Program project area.

of uncertainty, where the management actions themselves are condition-dependent, information-dependent, and complex; and where there is the opportunity to reduce uncertainty early on to improve later actions through adaptive implementation.

In July 2012, the Assistant Secretary of the Interior for Water and Science, Reclamation, and NPS embraced the idea of using structured and formal decision analysis as one of several tools to evaluate alternatives in this EIS. Formal decision analysis was seen as a way to address multiple objectives, engage stakeholders, and evaluate the degree to which uncertainty is an impediment to the selection of management actions.

The purpose of this report is to document the formal decision analysis completed by the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, National Park Service, and Argonne National Laboratory, as one component of the evaluation of alternatives for the LTEMP EIS. This report is a stand-alone document and an appendix to the Draft EIS (Bureau of Reclamation and National Park Service, 2015); it is also anticipated to be an appendix to the Final EIS. The emphasis in this report is on the decision analysis; the reader is referred to the Draft EIS (DEIS) and its appendixes for many other details, including the following: the legal, ecological, and cultural context of the LTEMP; an indepth description of the alternatives; the details of the quantitative models used to evaluate the alternatives; and a comprehensive comparison of the alternatives and their effects on resources of concern, including qualitative assessments that were not included in the decision analysis.

3 Decision Analysis

The DOI is including formal decision analysis tools to accompany more traditional qualitative tools to evaluate alternatives in the Glen Canyon Dam LTEMP EIS. The LTEMP EIS concerns the management of a very complex system with many, possibly competing, resources of interest and considerable uncertainty about the relations between management strategies and the responses of resources of interest to management strategies; furthermore, there are multiple stakeholder viewpoints to consider, and the DOI wants to use a structured process as one of the tools for better evaluating and understanding stakeholder viewpoints. This section provides an overview of decision analysis and describes the quantitative methods the DOI used to analyze the alternatives.

3.1 Structured Decision Making

"Structured decision making" (SDM) is a term of art, used by a community of practitioners in the United States, Canada, and Australia, to refer to the application of a broad array of decision analysis tools to natural resource management (Gregory and others, 2012). The analytical tools used in any application will depend on the specific needs of that decision setting, so SDM can look quite different from case to case. The set of analytical tools that might be used include the following: multicriteria decision analysis (MCDA), decision trees, expert elicitation, objectives hierarchies, value of information, stakeholder involvement, predictive modeling, utility theory, dynamic optimization, portfolio analysis, and many others. The common features in any application of decision analysis are (1) an attention to value-focused thinking (Keeney, 1996), recognizing that any decision is an attempt to achieve something of value to the decision maker; and (2) decomposing the decision problem into basic elements (objectives, alternatives, consequences, and tradeoffs) (Runge, 2011). The goal of SDM is to provide a transparent process for articulating objectives, developing alternatives, and evaluating those alternatives against the objectives. Note, however, that SDM does not substitute for a decision maker, and the application of the SDM process does not make a decision; rather, SDM only serves to aid the decision maker in understanding and organizing the complexities of the problem. The DOI prefers to use the term "structured decision analysis" or simply "decision analysis" for the LTEMP EIS process because the Secretary of the Interior retains the responsibility and authority to make a decision. In the context of the LTEMP EIS, two key decision analysis tools are used to evaluate the alternatives: MCDA and the expected value of perfect information (EVPI).

3.2 Multicriteria Decision Analysis

Many objectives associated with management of Glen Canyon Dam are important to stakeholders, including tribal cultural and spiritual values, endangered species, hydropower generation, sediment conservation, and recreation. It is possible that some of these objectives compete; if so, no single strategy will be best at achieving all the objectives. One of the difficulties the decision maker faces, then, is the value judgment regarding how to weight this host of objectives based on the many statutes governing Glen Canyon Dam operation and resource protection. Multicriteria decision analysis is a formal decision analysis tool designed to help evaluate the competing objectives and explore how to weight them within the context of the statutes (Figueira and others, 2005), and has been applied to a wide variety of natural resource management problems (Herath and Prato, 2006). Considerable literature advocates the use of MCDA in National Environmental Policy Act (NEPA) processes (Gregory and others, 1992; Kulkarni and others, 1993; Prato, 1999; Sheehy and Vik, 2002; Kiker and others, 2005; Linkov and others, 2006a, 2006b, 2006c; Stich and Holland, 2011; Marcot and others, 2012). Although not common, a few examples of NEPA documents explicitly incorporate MCDA methods (National Oceanic and Atmospheric Administration, 1995a, 1995b; Kimbrough and others, 2008; Nobrega and others, 2009; Bureau of Reclamation, 2011b; Runge and others, 2011a). Notably, the value of using MCDA for evaluation of management alternatives for Glen Canyon Dam has been argued by Flug and others (2000).

One of the key advantages of MCDA in the context of the LTEMP EIS is that it provides a structured and transparent method for receiving detailed stakeholder input about the resource goals, ways to evaluate performance of the alternatives against the resource goals, and the value of resource goals relative to each other. Stakeholders have legitimate differences in viewpoint about the relative importance of the objectives affected by the LTEMP alternatives, differences that stem from policy judgments rather than scientific judgments. Multicriteria decision analysis provides a way for stakeholders to articulate those judgments. By clearly understanding those different viewpoints, Reclamation and NPS (hereinafter referred to as the "joint-lead agencies") were better able to analyze and compare the alternatives and ultimately advise the Secretary of the Interior regarding her choice of a preferred alternative. In selecting a preferred alternative, the Secretary of the Interior needed to consider the appropriate suite of laws, regulations, agency guidance, and policies; the language in the purpose and need statement; stakeholder input; and the public input at various points in the process. The MCDA helped organize at least part of that complex input.

3.2.1 A Full Articulation of Resource Goals

The first step in a MCDA is a full articulation of the resource goals important to the decision maker, stakeholders, and the public. The set of resource goals should be (1) complete because it should cover the full range of concerns relevant to the decision; (2) concise because it should not contain redundant or irrelevant resource goals; (3) sensitive so that the resource goals are able to distinguish the performance of the alternatives under consideration; (4) understandable so that the resource goals directly communicate what matters; and, if possible, (5) independent so that the resource goals describe unique aspects of the problem (Gregory and others, 2012). The completeness of the set of resource goals is often very important because it provides objectivity and transparency to otherwise invisible values (Turner and others, 2008).

In an MCDA, the focus of the resource goals should be should be on objectives that are fundamental (called "fundamental objectives") to the decision maker, stakeholders, and public. Fundamental objectives, as distinguished from means objectives, are objectives that are important in their own right—they are the desired outcomes of the decision, not because they lead to something else of importance but because of their inherent value. Means objectives are pursued as a pathway to fundamental objectives but are not themselves of inherent value to the decision maker; for example, a high juvenile survival rate of HBC is important as a means to achieving a sustainable population of HBC in the Colorado River below Glen Canyon Dam, but juvenile survival is not itself the objective that the decision maker fundamentally cares about. Achieving population sustainability with low or moderate juvenile survival rates of HBC, if possible, would be acceptable; thus, the fundamental objective concerns population sustainability.

The joint-lead agencies, in consultation with the tribes and Cooperating Agencies and with input from public scoping comments, developed a set of resource goals, which represent the fundamental objectives to be pursued in the LTEMP EIS. Some of these resource goals are closely aligned with the desired future conditions (DFCs) developed by the Adaptive Management Working Group (AMWG); and are grounded in the laws, regulations, and policies relevant to the joint-lead agencies. In a few instances, the resource goals differ from the DFCs to more clearly identify a set of fundamental objectives for the specific context of the LTEMP EIS that meet the characteristics described previously in this section (complete, concise, sensitive, understandable, and independent). In a parallel effort, the joint-lead agencies worked directly with interested tribes to develop resource goals that are specific to tribal perspectives.

3.2.2 Performance Metrics

Performance metrics are scales of measurement on which the fundamental objectives (resource goals) can be evaluated. By developing performance metrics that are closely tied to the resource goals, the assessment of alternatives can include a quantitative, rather than solely narrative, analysis. Also, articulation of performance metrics forces considerable clarity about the resource goals; thus, using performance metrics encourages a high degree of transparency in the analysis of alternatives. It is difficult, however, to express all the resource goals in quantitative form. The use of performance metrics, therefore, does not preclude use of narrative analyses to evaluate additional resource goals in a NEPA process.

Ideally, performance metrics should directly reflect the resource goals, but this is often very difficult to achieve because the resource goals can be subtle, nuanced, complex, and difficult to quantify. There are also cases where a desired performance metric can be articulated, but the scientific tools do not exist to predict the performance of alternatives on that scale; thus, development of performance metrics is a very important science-policy interface. For the management agency, the desire is to have performance metrics that closely track the corresponding resource goals, but for the scientists, the desire is to have performance metrics that can be predicted with high confidence. When the difference between these desires is large, the question is how far the quantitative assessment can stretch toward the desired performance metric while maintaining a robust scientific foundation. There is, of course, a tendency to want to use proxy metrics that can be reliably predicted (for example, temperature as a proxy for HBC recruitment), but this only shifts a difficult burden to the decision maker who has to then make invisible judgments about how closely the proxy aligns with the underlying resource goal. The performance metrics developed for this decision analysis span the gamut from direct, natural measures of resource goals to distant proxies, depending on the science available to support their assessment. An effort has been made

to transparently articulate the relation between each performance metric used and the resource goal it represents.

The joint-lead agencies in conjunction with subject-matter expert (SME) teams from all relevant disciplines developed performance metrics corresponding to the resource goals that were used as the scales on which alternatives were quantitatively evaluated. During the course of development, the joint-lead agencies sought feedback on draft performance metrics from the Cooperating Agencies, tribes, and other stakeholders.

3.2.3 Transparent and Quantitative Evaluation of Alternatives

As part of the effects analysis for the LTEMP EIS, and as a supplement to the traditional narrative analysis, Argonne National Laboratory (hereinafter referred to as "Argonne") and collaborators completed quantitative analyses of the alternatives against the performance metrics. These quantitative analyses are an exercise in forecasting—predicting the relative performance of the alternatives against the resource goals using the best available science. In some cases, existing models were available for this task; in other cases, new predictive models were developed; and in still other cases, formal methods of expert elicitation (Martin and others, 2012) were needed. But, in all cases, the methods for assessing the alternatives provide transparency to the evaluation.

The ecological, economic, and social systems being evaluated in the LTEMP EIS are complex, and even though the systems are some of the best studied systems in the world, they are nevertheless incompletely understood; thus, the models used to predict performance of the alternatives were necessarily simplifications of the real world and had to account for uncertainty. Specific details about how uncertainty was handled in the decision analysis are described in section 3.3, "Uncertainty, Value of Information, and Adaptive Management."

A traditional, narrative evaluation of alternatives has to make all the same assumptions as a quantitative evaluation does. The use of a quantitative approach raises the degree of transparency about these assumptions and allows better inspection by interested parties. Also, quantitative analysis of the alternatives provides the raw material for later steps in a decision analysis.

3.2.4 Tradeoff Analysis

The outcome of the assessment phase can be viewed as a "consequence table"—a summary of how each alternative is expected to perform against each resource goal (as expressed by the corresponding performance metric). That assessment phase is a scientific endeavor—an evaluation of the current knowledge of the system to forecast how the system will respond to any proposed alternative. The consequence table provides a visual way to compare the alternatives and is an important analytical and communication step. Selection of a preferred alternative involves a policy choice based on sound science, which requires a values judgment about how to comply with the laws applicable to the proposed action while achieving a multitude of fundamental objectives, particularly if there are tradeoffs among the objectives. Some fundamental objectives, because of legal and policy considerations, may take precedence over other objectives; the remaining objectives need to be balanced appropriately. The joint-lead agencies, in evaluating the alternatives and providing a recommendation to the Secretary of the Interior, wanted to understand how Cooperating Agencies and other stakeholders would individually value the range of resource goals. This structured input was not the only consideration; in the NEPA process, decisions are also informed by the legal and policy framework, including relevant laws, regulations, agency policies and guidance, court cases, consultation with tribes, and public comment at various points in the process.

Multicriteria decision analysis provides tools for eliciting and investigating the values judgments associated with balancing tradeoffs. There are a variety of MCDA methods; we used the Simple Multi-Attribute Rating Technique (SMART) (Edwards, 1971; Goodwin and Wright, 2004) with swing weighting (Winterfeldt and Edwards, 1986). Stakeholders were asked to individually complete a swing-weighting exercise to express how they valued the resource goals relative to one another, while accounting for the range in performance across alternatives. The weights derived were combined with the consequence table to rank the alternatives from the viewpoint of each participating stakeholder. These individual viewpoints were provided as input to the joint-lead agencies and are documented in this report.

3.3 Uncertainty, Value of Information, and Adaptive Management

The second major set of tools from decision analysis that were used in the development and assessment of alternatives for the LTEMP EIS concern how to articulate, evaluate, and address uncertainty in an adaptive design. The primary analytical tool that informed this process is the expected value of information (Raiffa and Schlaifer, 1961; Howard, 1966). In a decision analysis context, the value of information is the best method for sensitivity analysis (Felli and Hazen, 1998). Runge and others (2011b) describe how the value of information can be used to design an adaptive management program that focuses on finding the best management strategy (rather than reducing the most uncertainty).

3.3.1 Adaptive Management Versus Experimental Management

Several different schools of adaptive management, which differ in their emphasis on various decision analysis tools and approach to experimental design, exist (McFadden and others, 2011). All the schools trace their lineage back to Walters

(1986), but their current approaches can look very different. In the Resilience-Experimentalist (RE) school of adaptive management, emphasis is placed on experimental design focused on policy choices (management alternatives) as the elements of uncertainty. To some extent, the RE school is most focused on "unknown unknowns"—uncertainty that cannot be anticipated in advance—and, therefore, advocates robust experimental designs composed of management alternatives to provide accelerated learning about the system dynamics in response to management. This accelerated learning might not be formally linked to subsequent long-term management planning because of a sense that there is too much hubris in making long-term plans when so much surprise is expected. The RE school perhaps draws more inspiration from Walters and Holling (1990) than from the seminal text (Walters, 1986). Examples of adaptive management that are often associated with the RE school include management in the Columbia River Basin, water management in the Everglades, and past management in the GCDAMP (McFadden and others, 2011).

In the Decision-Theoretic (DT) school of adaptive management, the emphasis is placed on a priori articulation of uncertainty through alternative hypotheses about system response to management and derivation of optimal strategies that solve the "dual-control problem" of achieving long-term management objectives by balancing the benefits and costs of learning in the short term. The DT school is most focused on known unknowns—uncertainty that can be explicitly articulated—and, therefore, advocates adaptive design that seeks resolution of this uncertainty but only to the degree that such resolution will improve future management. Learning is explicitly linked to future management decisions by associating particular courses of action with the degree of evidence in support of the alternative hypotheses; in this way, long-term management is articulated as part of the adaptive program, so the natural transition from experimentation to implementation is specified up front. The tenets of the DT school are arguably a more direct expression of Walters (1986) than other schools of adaptive management. The example most commonly associated with the DT school is the adaptive harvest management of mallards in North America (Johnson and others, 1997).

It seemed appropriate that the 1995 Glen Canyon Dam Final EIS and the GCDAMP embraced an RE school approach to adaptive management. At the time, there was very significant uncertainty about the dynamics of the Colorado River system below Glen Canyon Dam, so an approach that emphasized learning about unknown unknowns made sense. Several policy experiments have been completed, and a great deal has been invested in research; together these have greatly advanced the state of knowledge. It would have been difficult in 1995 to anticipate all the discoveries and specify clearly how and when management of Glen Canyon Dam would move from an experimental phase to a long-term implementation phase. The current question for the joint-lead agencies is if the last two decades of research and experimentation have generated enough knowledge to allow the articulation of uncertainty as known unknowns and pursue a DT school approach to adaptive management. The joint-lead agencies believe this is the case, and approached the development of the LTEMP EIS with this philosophy in mind.

3.3.2 Articulating Uncertainty as Competing Hypotheses

For many, if not all, of the resource goals, the performance of the alternatives is uncertain. Some of that uncertainty can be captured simply by including estimates of variance around the forecasts, but some uncertainty is pervasive enough that it could change the ranking of the alternatives relative to a particular resource goal and, thus, could impede the identification of a preferred alternative. For these critical uncertainties, the SME teams characterized the uncertainty in the predictive models as a set of competing hypotheses. The focus of the uncertainty was on the mechanisms or parameters in the models, not on a holistic statement of uncertainty about whether a particular management intervention will work or not; thus, for example, rather than state the uncertainty as whether or not a particular management alternative will build and sustain beaches, the uncertainty was expressed as competing hypotheses about the long-term rate of sediment input from the Paria River. Likewise, whether trout management flows (TMFs) work or not was expressed as competing hypotheses about the rate of recruitment of juvenile rainbow trout when TMFs are used.

Development of competing hypotheses to capture critical uncertainty is challenging. It requires very deliberative thought about the limits of knowledge and the nature of uncertainty that would affect the ranking of management alternatives. To do so with a small number of discrete hypotheses requires a simplification of the full degree of uncertainty. But careful thought along these lines allows a transparent and explicit statement of the uncertainty that is the focus of experimental and adaptive design. In a NEPA context, such explicit articulation of critical uncertainty allows full disclosure of the motivation for experimental design and explanation of how subsequent management will respond to newfound knowledge.

3.3.3 Deconstructing Complex Alternatives

Several of the alternatives under consideration in the DEIS (especially Alternatives C, D, and E; see explanations of each in the "Alternatives" sections 5.4, 5.5, and 5.6) include, either explicitly or implicitly, complex experimental or adaptive designs (see, for example, figs. 2–13 and 2–14 in Bureau of Reclamation and National Park Service, 2015). These strategies prescribe different management interventions depending on state and information conditions. It is particularly important to distinguish state-dependent triggers from information-dependent triggers. State-dependent triggers are conditions of the state of the system that would lead to implementation of a different management action, primarily in recognition that the Colorado River is a stochastic ecosystem, and it is important

to be able to respond to natural variation. Most obviously, all the alternatives contain state-dependent triggers under the Bureau of Reclamation (2007) guidelines that specify, among other parameters, the annual volume for water release from Glen Canyon Dam. Other state-dependent triggers are designed to guard against chance reductions in HBC or other resources of concern. State-dependent triggers are in contrast to information-dependent triggers, which are indications that the state of knowledge has changed substantially and a new approach to management is warranted; for example, Alternatives C and E propose experimental implementation of TMFs, and it is at least implicit in both that if those TMFs are ineffective in reducing downstream migration of rainbow trout from Lees Ferry, they would be discontinued. This is an information-dependent trigger. To the extent possible, information-dependent triggers should be explicit in that they specify the weight of evidence that would be needed on one hypothesis or another to induce a change in management strategy.

A complex experimental or adaptive strategy can be viewed as a portfolio of simpler strategies combined and implemented in a manner to reduce critical uncertainty, with the ultimate intention to implement one of the simpler strategies as the operational standard in the long term. The information-dependent triggers govern the switch between these simpler strategies. To evaluate such a complex design, the first step is to understand what the simpler strategies are; thus, the complex strategies were deconstructed into simpler long-term strategies, each of which might have state-dependent triggers but not information-dependent triggers. In other words, an experimental or adaptive strategy can be viewed as a set of simpler, operational strategies arrayed against a set of competing hypotheses. Resolution of the competing hypotheses would lead to identification of a long-term strategy, but of course, in the short term, an experimental design is needed to achieve that resolution. The first step in development of such a complex strategy is the articulation of the simpler component strategies and the attendant competing hypotheses; the development of the experimental design is a later step.

3.3.4 Value of Information

The essence of the DT school of adaptive management is a focus on uncertainty that is an impediment to the decision maker; that is, resolution of the uncertainty could affect the choice of the long-term management strategy. To evaluate the importance of a source of uncertainty, we used a technique known as the value of information (Raiffa and Schlaifer, 1961; Howard, 1966; Runge and others, 2011b), which was also advocated by Walters (1986) as the motivation for adaptive management. The idea behind the value of information is to compare the expected performance if a decision has to be made in the face of uncertainty with the expected performance if uncertainty can be resolved before committing to a decision. This contrast, known as the EVPI, sets an upper bound on the value of experimental or adaptive management measured on the scale of the management objective(s). To make a decision in the face of uncertainty, a decision maker chooses to implement an action that achieves the highest expected performance against the uncertainties, but that decision carries the risk of being wrong (because some other action could have performed better); the value of information measures how important it is to eliminate that risk. There are two related methods: (1) the expected value of partial information (EVXI) allows calculation of the value of reducing some component of uncertainty, while remaining uncertain about the rest; and (2) the expected value of sample information takes into account the noise in the monitoring.

To calculate the value of information, uncertainty must be explicitly articulated (as competing hypotheses with evidentiary weights or as a probability distribution on a set of parameters). With a small set of competing hypotheses, the calculations involve several steps: (1) forecasting the performance of each long-term strategy under each hypothesis, (2) calculating a weighted performance across hypotheses to identify an optimal decision in the face of uncertainty, (3) calculating the expected performance if uncertainty could be fully resolved before the management alternative was chosen, and then (4) comparing the expected values in steps 2 and 3.

In a single-objective setting, the EVPI is measured on the scale of that objective; thus, it could be expressed, for example, as the expected increase in the probability of persistence of HBC if uncertainty could be resolved before committing to a long-term management strategy. In a multiple-objective setting, EVPI is calculated on the composite utility scale (in which the full array of objectives is weighted); thus, an evaluation of the importance of uncertainty cannot be calculated without first completing a MCDA to understand the value weights on the resource goals. The sequence of assessment matters; the LTEMP EIS process was crafted to accommodate this series of steps. First, the long-term strategies (the elements of the full alternatives broken down into their constituent parts) were analyzed against the array of performance metrics under all the competing hypotheses. Second, using the expected value across hypotheses, MCDA (with input from stakeholders) was used to generate a preliminary weighting of fundamental objectives. Third, with those weights, the individual competing hypotheses were investigated, and the expected value of information (perfect and partial) was calculated.

3.3.5 Experimental and Adaptive Design

The motivation for the EVPI analysis was to provide guidance useful for developing an experimental or adaptive design for implementing management actions, taking into account their value as long-term strategies and the value of reducing uncertainty. This report only describes the results from the decision analysis, with a brief discussion of the implications of the results for experimental design (section 9.2, “Motivation for Adaptive Management”); the development of the experimental design is described in the DEIS.

4 Resource Goals and Performance Metrics

In February 2010, the Assistant Secretary of the Interior asked an ad hoc group of the AMWG to develop a set of DFCs, which were outcomes of fundamental importance that were "achievable through the operation of Glen Canyon Dam, subject to the Law of the River and consistent with the Grand Canyon Protection Act" (Castle, 2010, p. 2) During the next 2 years, this ad hoc group worked with the AMWG and DOI to develop the set of DFCs, which were adopted by the AMWG and recommended to the Secretary of the Interior in February 2012. The set of DFCs formed the basis for the development of the resource goals for the LTEMP EIS. The resource goals express the fundamental objectives for the LTEMP EIS and are described in the nine subsections that follow (4.1 through 4.9).

Associated with the resource goals, the joint-lead agencies developed metrics to evaluate the relative performance of the LTEMP alternatives. These scientifically based performance metrics were developed in a series of workshops among SMEs working on the LTEMP EIS and were revised to incorporate feedback from Cooperating Agencies and other stakeholders. The performance metrics are intended to be objective measures of the performance of alternatives relative to goals for each affected resource being evaluated in the LTEMP EIS. Note that these performance metrics are not the full impacts analysis for the LTEMP EIS. Other sources of quantitative and qualitative information, in addition to the performance metrics, were used to assess the overall and relative performance of alternatives and their constituent elements for the LTEMP EIS. A summary of the performance metrics used in the decision analysis is given in table 1.

4.1 Aquatic Ecology

The resource goals associated with aquatic ecology focused on the persistence of HBC and other native fish, the quality of the rainbow trout (RBT) (*Oncorhynchus mykiss*) fishery, and absence or containment of nonnative aquatic species.

4.1.1 Humpback Chub

Resource Goal.—Meet HBC recovery goals including maintaining a self-sustaining population, spawning habitat, and aggregations in the natural range of the HBC in the Colorado River and its tributaries below the Glen Canyon Dam.

Performance Metric 1.—Expected minimum number of adult (greater than or equal to [≥] 200 millimeters [mm]) HBC in the Little Colorado River population during the LTEMP planning period (20 years).

Performance Metric 2.—Average temperature suitability index (scale 0–1) for HBC at RM 157 (Havasu Creek) and RM 213 (Pumpkin Spring) (fig. 1). The potential for a self-sustaining aggregation of HBC at each of these locations was based on a temperature suitability model that considered how well water temperatures met requirements for important HBC life-history stages (spawning, egg incubation, and growth) using triangular probability functions based on the reported ranges of suitable temperatures for each life-history stage (Valdez and Speas, 2007). The composite temperature suitability index was the geometric mean of the suitability indices for each of the life-history stages.

4.1.2 Other Native Fish

Resource Goal.—Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

In the analysis for the EIS, temperature suitability indexes for other native fish, similar to the one for HBC, were developed. They did not, however, show much differentiation among alternatives, and they did not differ much from each other and from the HBC temperature suitability metric. These metrics were not, subsequently, used in the decision analysis; the HBC temperature suitability metric was assumed to stand in for other native fish as well.

4.1.3 Rainbow Trout Fishery

Resource Goal.—Achieve a healthy high-quality recreational RBT fishery in the Glen Canyon National Recreation Area and reduce or eliminate downstream RBT migration consistent with NPS fish management and ESA compliance.

Performance Metric 3.—Rainbow trout catch rate in Glen Canyon National Recreation Area (age 2+ fish per angler-hour).

Performance Metric 4.—Rainbow trout emigration rate (number of age-0 RBT moving into Marble Canyon from Glen Canyon per year).

Performance Metric 5.—Abundance of high-quality RBT (greater than [>] 16 inches total length) in the Glen Canyon reach.

4.1.4 Nonnative Aquatic Species

Resource Goal.—Minimize or reduce the presence and expansion of aquatic nonnative invasive species.

In the analysis for the EIS, temperature suitability metrics for nonnative warm-water and cold-water fish and aquatic parasites, similar to the one for HBC, were developed. They did not, however, provide much differentiation among the alternatives. These metrics are reported in the EIS but were not used in the decision analysis.

Table 1. Summary of the 18 performance metrics used in the decision analysis.

[The range for each performance metric captures the amount of variability in the metric because of the effects of the different alternatives, the hydrological and sediment traces, and structural and parametric uncertainty. The range shown was used in the swing-weighting elicitation. HBC, humpback chub; RBT, rainbow trout; #, number; >, greater than]

Number	Resource goal	Performance metric	Units	Desired direction	Range
1	Humpback chub	Minimum number of adult HBC	# adults	Increase	3,000–8,500
2		HBC temperature suitability	Index (0–1)	Increase	0.0–0.2
3	RBT fishery	RBT catch rate	Fish/angler-hour	Increase	1.0–5.0
4		RBT emigration rate	Trout/year	Decrease	15,000–125,000
5		Abundance of high-quality RBT	# fish > 16 inches	Increase	400–1,200
6	Archaeological and cultural resources	Wind transport of sediment index	Index (0–1)	Increase	0.0–0.5
7		Glen Canyon flow index	Days/year	Decrease	0–75
8		Time-off-river index	Index (0–1)	Increase	0.60–0.95
9	Hydropower and energy	Hydropower generation	Million $/year	Increase	120–200
10		Hydropower capacity	Million $/year	Increase	10–50
11	Recreation	Camping area index	Index (0–1)	Increase	0.0–0.5
12		Fluctuation index	Index (0–1)	Increase	0.0–1.0
13		Rafting use index	Visitor-days/year	Decrease	0–1,300
14	Riparian vegetation	Riparian vegetation index	Sum of ratios	Increase	2.0–6.0
15	Sediment	Sand load index	Proportion (0–1)	Increase	0.0–0.6
16	Tribal resources	Marsh vegetation ratio	Ratio	Increase	0.0–1.5
17		Mechanical removal	Years (out of 20)	Decrease	0–5
18		Trout management flows	Years (out of 20)	Decrease	0–20

4.2 Archaeological and Cultural Resources

Resource Goal.—Maintain the integrity of potentially affected National Register of Historic Places eligible or listed historic properties in place, where possible, with preservation methods used on a site-specific basis.

Performance Metric 6.—Wind transport of sediment index (WTSI). This WTSI metric captures the availability of fine sediment for movement by wind. The potential settlement of such sediment over historic properties may provide protection from erosion. The WTSI is the product of the sand load index (SLI; see section 4.7, "Sediment"), which is a proxy for the availability of sediment, and a flow factor, which is higher when low flows happen during the windy season. The WTSI can range between 0 and 1, with higher values indicating more opportunity for transport of sediment.

Performance Metric 7.—Glen Canyon flow index (number of days per year that the maximum daily flow is greater than 23,200 cubic feet per second [ft^3/s]). There are a number of archaeological sites within the Glen Canyon National Recreation Area that could be negatively affected by high flows. Ninemile Terrace is considered representative of other archaeological sites on terraces within the Glen Canyon National Recreation Area; the toe of its slope is at an elevation that corresponds to flows from Glen Canyon Dam of 23,200 ft^3/s.

Performance Metric 8.—Time-off-river index. This metric reflects the availability of discretionary time off river for rafting parties, which allows for greater visitation of archaeological sites. From the standpoint of protection of archaeological and cultural sites, such discretionary time is not desirable. The time-off-river index is calculated from the mean daily flow levels in the river: daily flows less than 10,000 ft^3/s receive a score of 1 (because rafting progress is slow and there is little discretionary time); daily flows greater than 31,500 ft^3/s receive a score of 0 (because rafting progress is fast, allowing the most discretionary time); and daily flows between 10,000 and 31,500 ft^3/s receive a score based on linear interpolation. The daily scores are averaged within seasons: summer (May–August), winter (November–February), and spring and fall (March–April and September–October, respectively). An annual value is calculated using a weighted average across seasons, with higher weight (0.54) given to summer than to spring and fall (0.31) or winter (0.15). The final metric ranges between 0 and 1, with higher values indicating better potential to protect archaeological resources.

4.3 Hydropower and Energy

Resource Goal.—Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability; and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

Performance Metric 9. —Value of hydropower generation (million dollars per year). The value of hydropower energy production over a 20-year trace is discounted at 3.375 percent per year. The total net present value of energy production is divided by 20 to provide an annualized measure.

Performance Metric 10.—Value of hydropower capacity (million dollars per year). The WAPA enters into long-term firm contracts that obligate them to deliver firm electric service to their customers. For the purpose of the LTEMP EIS, the value of these contracts is estimated by first calculating the amount of power (megawatt [MW]) that can be contracted, then multiplying by the replacement cost for that capacity (dollars per MW-year). The capacity itself is calculated by finding the 90-percent exceedance value (10th percentile) for the daily maximum generation in August (August is the month with the highest demand) during a 20-year trace. The replacement cost used was $50,100/MW-year based on a natural gas combustion turbine.

Additional metrics associated with hydropower generation, including the retail rate effects on residential and nonresidential consumers, are examined in the LTEMP EIS but were not available in time to be included as part of the decision analysis.

4.4 Natural Processes

Resource Goal.—Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

A quantitative performance metric to capture this resource goal was not developed because of its multifaceted complexity. In the EIS, the alternatives are compared qualitatively against this resource goal, but it was not used in the decision analysis.

4.5 Recreational Experience

Resource Goal.—Maintain and improve the quality of recreational experiences for the users of the Colorado River ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

Performance Metric 11.—Camping area index. This metric captures the availability of medium (16–25 people) and large (>25 people) campsites on beaches along the Colorado River. The camping area index is the product of the SLI (see section 4.7, "Sediment"), which measures the availability of sediment for beach forming, and a flow factor, which reflects exposure of the beaches. The flow factor is calculated from the maximum daily flows. A score of 1 is given to flows less than 8,000 ft^3/s (because the lower flow means a lower elevation of the water and hence more beach exposure); a score of 0 is given to flows greater than 31,500 ft^3/s; and an intermediate score is determined by linear interpolation for flows between 8,000 and 31,500 ft^3/s. The flow factor is averaged over days within each season, and then over seasons, with higher weight given to the summer season (0.54) than the spring and fall (0.31) or winter (0.15) seasons. The camping area index can range between 0 and 1, with higher values indicating greater availability of medium and large campsites.

Performance Metric 12.—Fluctuation index. This index measures the fraction of time that the daily fluctuations in flow are within a tolerable range; tolerable is defined based on the study by Bishop and others (1987). As the mean daily flow increases, greater fluctuations are tolerable. For mean daily flow in the range from 5,000 to 8,999 ft^3/s, the daily fluctuation index is 1 if the daily fluctuation is less than 3,400 ft^3/s; for daily flow in the range from 9,000 to 15,999 ft^3/s, the fluctuation index is 1 if the daily fluctuation is less than 4,800 ft^3/s; for daily flow in the range from 16,000 to 31,999 ft^3/s, the fluctuation index is 1 if the daily fluctuation is less than 7,200 ft^3/s; and for daily flow greater than 32,000 ft^3/s, the fluctuation index is 1 if the daily fluctuation is less than 9,800 ft^3/s. In all cases, the daily fluctuation index is 0 if the daily fluctuation is greater than 10,000 ft^3/s. For fluctuation index values between 1 and 0, the index is determined by linear interpolation between the tolerable threshold and 10,000 ft^3/s. The daily values for the fluctuation index are averaged within seasons, then averaged across seasons with higher weight (0.54) given to summer months than to spring and fall (0.31) or winter months (0.15). The fluctuation index can range between 0 and 1, with higher values indicating a better visitor experience as influenced by fluctuation in water levels.

Performance Metric 13.—Glen Canyon rafting use metric (average boat seats lost per year because of high-flow experiments [HFEs]). During HFEs and for 2 days before and after, Glen Canyon day-rafting operators cannot take recreational passengers. This metric calculates the average number of boat seats lost per year.

Several other metrics reflecting the recreational experience were analyzed in the LTEMP EIS. In some cases, these did not help to discriminate among the alternatives, and in other cases, these metrics were highly correlated with other metrics. For these reasons, the metrics were not included in the decision analysis and are not described here.

4.6 Riparian Vegetation

Resource Goal.—Maintain native vegetation and wildlife habitat, in various stages of maturity, such that they are

diverse, healthy, productive, self-sustaining, and ecologically appropriate.

Performance Metric 14.—Riparian vegetation index. This index summarizes predicted changes during the 20-year LTEMP period in the relative cover of native vegetation community types and the relative diversity of community types, as described by a seven-state state-and-transition model (Ralston and others, 2014). The index is calculated as the sum of four component ratios: the ratio of final to initial native vegetation cover, the ratio of final to initial vegetation state diversity, the ratio of final to initial native to nonnative dominant vegetation state, and the ratio of initial to final cover of arrowweed. An index value of 4.0 indicates an unchanged vegetation condition; values greater than 4.0 indicate improved vegetation conditions; values less than 4.0 indicate degraded vegetation conditions.

4.7 Sediment

Resource Goal.—Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

Performance Metric 15.—The SLI (the cumulative sand load transported by high flows [greater than 31,500 ft^3/s] divided by the cumulative sand load transported in total). The range of this metric is 0–1, with higher values reflecting the potential for larger sandbars because more of the sediment is transported at higher river volumes and hence higher elevations. A number of other metrics that summarize the transportation and deposition of sediment were analyzed in the LTEMP EIS. They were all fairly highly correlated; only the SLI was used in the decision analysis.

4.8 Tribal Resources

Resource Goal.—Maintain the diverse values and resources of traditionally associated tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons.

In discussions with tribal representatives during the course of the development of the LTEMP EIS, a large number of important resource goals were identified. A concerted effort was made to understand these goals as clearly as possible, but it was challenging to express some of them in terms amenable to measurement. Although all these goals are important aspects of the importance to the tribes of the Grand Canyon, the Colorado River, and their management, not all of them will be affected by the alternatives being considered in the LTEMP EIS. All of these resource goals are discussed and evaluated in the LTEMP EIS. The full set of goals is described in this section, but only those for which performance metrics were identified are included in the decision analysis.

4.8.1 Health of the Ecosystem

The ecosystem in Glen, Marble, and Grand Canyons is more than the sum of its parts and, in the view of the tribes, should be healthy as a whole. Historically, in the GCDAMP, the overall health of the ecosystem has been examined by evaluating the status of each part, but this reductionist approach might possibly miss some important aspects. There are a variety of indicators of ecosystem health that could be considered including, but not limited to, the following: the health of the river and its ability to sustain life; the color of the water; the absence of contaminants, pollutants, and disease in the water; the potability of the water; the quality of the water that reaches Lake Mead; and the viability and health of wildlife and plants in Glen, Marble, and Grand Canyons. It is important to understand that, for many tribes, the Colorado River is a sentient being and the spiritual center of the ecosystem because it has the capability of giving and taking life and is prone to anger if mistreated. The health of the ecosystem depends on the health of the Colorado River.

Because of the holistic nature of this resource goal, it was difficult to find a single performance metric that summarized it. A narrative analysis of this resource goal is found in the LTEMP EIS, but it was not included in the decision analysis.

4.8.2 Sites of Cultural Importance

There are specific sites within Glen, Marble, and Grand Canyons that are important for cultural reasons; and for preservation of tribal, religious society, kiva group, and clan history (for example, shrines, sacred sites, ancient burial sites, springs, plant collection areas, mineral collection areas, offering places, and other elements). These sites can be threatened by erosion, loss of sediment inputs, and intrusive human use (especially nontribal, outside visitors). Flow and nonflow actions (for example, education, permitting, research and monitoring, and interpretation) may affect these sites.

Performance Metric 16.—Marsh vegetation ratio (ratio of frequency of wetland states during the course of 20 years to frequency of wetland states if the initial abundance remained unchanged). Wetlands are a rare and important habitat type along the Colorado River; within Glen, Marble, and Grand Canyons, there are currently approximately 4.6 acres of such habitat. Maintenance and increase of marsh vegetation is important from a tribal perspective. The metric is calculated by looking at the marsh and shrub wetland states in the riparian state-and-transition model (Ralston and others, 2014) during the course of a 20-year projection and comparing that to the current abundance. The metric is a ratio; thus, a value of 1.0 indicates an unchanged abundance of marsh (on average), a value greater than 1.0 indicates an average increase, and a value less than 1.0 indicates an average decrease.

A number of aspects of this resource goal are also reflected in other performance metrics described in previous sections. The WTSI (performance metric 6) focuses on the availability of fine sediment for transfer to protect National

Register eligible or listed sites. Such sites, however, do not represent the full set of places of tribal concern, so other metrics must also be considered. The Glen Canyon flow index (performance metric 7) reflects the protection of some important sites in Glen Canyon. The time-off-river index (performance metric 8) measures the degree to which the discretionary time off river of rafters might affect cultural resources, including those of tribal importance.

In additions to these performance metrics, a number of other considerations are evaluated narratively in the LTEMP EIS, including riparian vegetation diversity, native fish diversity, and access to springs.

4.8.3 Respect for Life

To many of the tribes associated with the Colorado River and Glen, Marble, and Grand Canyons, life itself is sacred. Human activities should protect and promote life, not destroy it. There are two aspects to this resource goal: first, minimize the taking of life; and second, encourage the expansion and proliferation of life. These are both complex concepts. The tribes recognize that it is appropriate for humans to take other life in some circumstances, especially when it promotes other life (particularly, our own consumption for survival), but this taking needs to be minimal and respectful because there are spiritual consequences associated with the taking of life. The promotion of life is also important but does not necessarily imply a return to historical or "natural" conditions. The Glen Canyon Dam has encouraged new life in Glen, Marble, and Grand Canyons, so a return to predam conditions is not necessarily implied by this objective. It is worth noting that many of the tribes do not make a strong distinction between native and nonnative species.

Performance Metric 17.—Frequency of mechanical removal, as measured by the average number of years in which trout mechanical removal trips happen. Several of the alternatives considered in the LTEMP EIS include the use of electrofishing and removal of nonnative trout at the confluence of the Colorado River with the Little Colorado River in an effort to reduce the piscivory of juvenile HBC by trout. A number of tribes, especially Hopi and Zuni, have raised concerns about this taking of life. As a coarse measure of the cultural, spiritual, and ethical effects of killing trout, this performance metric allows distinctions among alternatives, favoring those that make an effort to minimize mechanical removal. But the nature of the take, the purpose behind it, the methods of the take, the disposition of the trout taken, and the mind set of those killing the fish all also affect the sacred treatment of living beings.

Performance Metric 18.—Frequency of trout management flows, as measured by the average number of years in which TMFs happen. Several of the alternatives considered in the LTEMP EIS include the potential for use of TMFs. The TMFs, designed to reduce reproduction or survival of juvenile trout, are considered to be killing by some tribes and should be minimized. Alternatives that include TMFs are likely to differ in how often the flows are triggered, so this performance metric helps to distinguish among the alternatives.

4.8.4 Sacred Integrity of Grand, Marble, and Glen Canyons

Glen, Marble, and Grand Canyons are sacred to many tribes, and the preservation of their sacred integrity is important. The sanctity of Glen, Marble, and Grand Canyons may be threatened by human activities and behaviors, development, and the presence of artificial structures and activities. An important aspect of the sanctity is the intentionality of visitors: when outsiders enter Glen, Marble, and Grand Canyons (on boat or hiking trips), the respect they show to the canyons and Colorado River can affect the spiritual integrity. There are many consequences of the disturbance of this sanctity, including, but not limited to, the following: a reduction of the spiritual strength of plants gathered and used by the Navajo for medicinal and cultural purposes; an inability to retire Navajo sacred objects into the Colorado River when they have become too old for continued use; weakening of the sacred role the canyons play as a final resting place for Hopi; and an overall disruption of the state of mind and spirit of Zuni religious leaders and of their experience of being within a very sacred place that embodies the Zuni emergence, migrations, and communion with the spirits of Zuni ancestors.

This resource goal, although of profound importance to the tribes, is not thought to differ measurably across the alternatives under consideration in the LTEMP EIS because it is not driven by flow operations from Glen Canyon Dam or currently envisioned attendant activities. This goal is evaluated in the narrative EIS analysis but not in the formal decision analysis.

4.8.5 Stewardship

According to their traditions, several of the tribes understand that they have been given a sacred stewardship responsibility for the preservation and harmony of the world; for example, the Hopi have a covenant with the caretaker of this world, Masaw, to be stewards of the earth; other Tribes have similar stewardship ethics grounded in spiritual traditions. To maintain these stewardship responsibilities, the tribes need to be an active part of stewardship of the Glen, Marble, and Grand Canyons. This stewardship includes the following: ceremonial activities, whether performed in the canyons or in the villages; participation in management of the canyons, including water management, through traditional practices and western management activities; and education to maintain cultural knowledge and connection with the canyons. The tribes note that the Federal government also has stewardship responsibilities that arise out of Federal legislation; because Federal involvement has sometimes taken stewardship responsibility from the tribes, it is critical that the Federal government be accountable for its stewardship. At times, some tribes believe

the presence of the Federal government has made it more difficult for them to carry out their stewardship responsibilities. Successful development of joint stewardship among the tribes and Federal government will require continued building of mutual respect and trust between those entities.

Tribal stewardship opportunities are not tied to individual alternatives being considered in the LTEMP EIS but could be crafted to apply to any of the alternatives; thus, this resource goal, although of critical importance to the tribes individually and to the ongoing relationship between the tribes and Federal government, may not help distinguish among the alternatives. This goal is evaluated in the narrative EIS analysis but not in the formal decision analysis.

4.8.6 Tribal Connections to the Canyons

The spiritual, historical, and cultural connections that tribes have to Glen, Marble, and Grand Canyons require the protection of sacred sites and the integrity of the canyons as a whole, but protection alone is not enough. The tribes also need opportunities for access, education, and stewardship to keep their connections vibrant. Access can be undermined by physical barriers and by the effects of human activity that decrease the power of those sites and the experience when at them (for example, lack of privacy, disturbance of the soundscape, and viewshed).

Like the sacred integrity and stewardship resource goals, this resource goal is not thought to differ across the alternatives. The flow operations of Glen Canyon Dam are not likely to affect tribal access, education, spiritual ceremonies, or other connections to Glen, Marble, and Grand Canyons. This resource goal may be more appropriately addressed through government-to-government consultation in other forums. This goal is evaluated in the narrative EIS analysis but not in the formal decision analysis.

4.8.7 Economic Opportunity

The Glen, Marble, and Grand Canyons, Colorado River, and Glen Canyon Dam are sources of economic benefit for the tribes in the area. The canyons provide tourism and other opportunities that enhance the economic well-being of tribes. (As an important note, tourism can also undermine the well-being of tribes in aspects other than economic; see the other tribal resource goals.) The Glen Canyon Dam provides affordable electricity for tribal needs and for development projects.

The hydroelectric performance metrics (especially hydroelectric generation, performance metric 9) may reflect one aspect of economic opportunity in that provision of affordable hydroelectricity is a component of economic development. Other economic effects are evaluated in the narrative EIS but were not included in the formal decision analysis.

4.8.8 Tribal Water Rights and Supply

Tribes in the area depend on the Colorado River for many of their water needs; so the preservation of established, traditional, and desired water rights, now and into the future, is important to them. There are a number of claims to water rights that have been asserted by the tribes but for which there are not yet quantified rights through decree or negotiated settlement; some Tribes have indicated that these claims to water rights are as important as established water rights.

Based on its purpose and need, the LTEMP EIS was not intended to include any alternative that violated agreed-upon water rights. The effect of the Lake Powell water elevation on Navajo access to water was examined and was not determined to differ across alternatives.

4.8.9 Process Objectives

The tribes also expressed several important process objectives—objectives that govern how the LTEMP decision is made, rather than what decision is made. The first of these is the genuine incorporation of tribal input to the LTEMP process as a reflection of Federal trust responsibilities. The second is the importance of incorporating learning to improve management with time; in this spirit, an experimental approach that can result in adaptive management is favored.

Because these were process objectives, they were not evaluated in the formal decision analysis, which focused on objectives that could help discern among the alternatives.

4.9 Water Delivery

Resource Goal.—Ensure that water delivery continues in a manner that is fully consistent with and subject to the Colorado River Compact, Upper Colorado River Basin Compact, Water Treaty of 1944 with Mexico, decree of the Supreme Court in *Arizona* v. *California*, and provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River Basin; and consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 interim guidelines (Bureau of Reclamation, 2007).

The scope and need of the LTEMP EIS was designed to preserve existing agreements concerning water delivery; thus, none of the alternatives considered were meant to differ with regard to aspects of water delivery. A number of water delivery metrics were evaluated to make certain that this part of the purpose and need was upheld. None of the alternatives were determined to differ with regard to these metrics; thus, they were not included in the decision analysis.

5 Alternatives

Seven alternatives were considered in the LTEMP EIS. Each of these alternatives is a complex combination of flow and nonflow actions, often with condition-dependent and information-dependent triggers for various components. Four of the alternatives (B, C, D, and E) also contain variants (called long-term strategies) to represent different combinations of actions that would be taken once critical uncertainties were resolved. In total, 19 long-term strategies were evaluated. A brief summary of these alternatives is given here to provide context for the decision analysis with an emphasis on those elements that differ across alternatives. A full description of these alternatives, with the rationale for each, is given in chapter 2 of the LTEMP EIS.

5.1 Action Elements

The alternatives are composed of flow actions, which govern how water flow through Glen Canyon Dam is to be managed on hourly, daily, and monthly scales, as well as nonflow actions, which govern other activities meant to complement the flow actions to achieve the resource goals.

5.1.1 Monthly Release Pattern and Other Base Operations

The seven alternatives differ in the operational characteristics that govern flow through Glen Canyon Dam (table 2). All alternatives follow the 2007 interim guidelines (Bureau of Reclamation, 2007), which specifies the annual volume of water to be passed through Glen Canyon Dam. The alternatives differ in how they apportion the annual volume to monthly volumes, ranging from patterns that match releases under the previous EIS to patterns that match monthly demand for electricity to patterns that approximate the unregulated flow in the Colorado River. The minimum flow at any time differs across alternatives, with a range from 5,000 to 8,000 ft^3/s. The maximum flow for base operations is the same for all alternatives (25,000 ft^3/s). The daily range specifies the limit to how much variation there can be between the minimum and maximum flow on a given day and ranges between 0 and 12,000 ft^3/s across alternatives. The ramp rates limit how quickly the flow can change; for all alternatives the ramp rate for increasing flow is 4,000 cubic feet per second per hour (ft^3/s-h); the ramp rate for decreasing flow is lower, ranging from 1,500 to 4,000 ft^3/s-h.

5.1.2 High-Flow Experiments

Since 1996, there have been a number of experimental high-flow releases of water through Glen Canyon Dam, designed to mimic natural high flows and deposit sediment at higher elevations, in an effort to rebuild sandbars and restore other ecosystem processes in Glen, Marble, and Grand Canyons. High-flow releases exceed the operational maximum daily flow and can be as high as 45,000 ft^3/s depending on the number of generation units available. The Bureau of Reclamation (2011a) established a protocol for determining when HFE releases were warranted and how they should be implemented. To date, the HFEs that have been implemented under the 2011 HFE protocol have happened in the fall, although the HFE protocol allows them to happen in the spring after 2015. The LTEMP EIS alternatives differ in if, when, and how they allow fall HFEs and spring HFEs (table 3). In addition, some of the alternatives allow proactive spring HFEs; these are HFE releases designed to protect sand supply in years when the annual guidelines call for high annual volumes (>10 million acre-feet). Most of the HFEs are limited to a maximum duration of 96 hours, but some of the alternatives allow extended-duration HFEs if adequate sediment supply is available (table 3).

5.1.3 Trout Management Flows

High flows, whether through high annual volumes or HFEs, have been determined to increase RBT production in the Glen Canyon reach. Because of the concern about the effect of RBT on HBC, methods have been sought to manage RBT populations. One proposed method is TMFs. These are patterns of high-water release (for example, 20,000 ft^3/s) for 2–7 days to encourage young-of-the-year trout to move to higher elevation shallow-water habitats followed by a rapid drop to a low flow (for example, 5,000 to 8,000 ft^3/s) during the day to strand young trout and expose them to sunlight and heat. The intention is to reduce RBT production and, hence, reduce emigration of trout from Glen to Marble Canyon, lowering the risk to HBC farther downstream. The TMFs have not previously been implemented at Glen Canyon Dam. They are considered an experimental element in several of the alternatives (table 3).

5.1.4 Other Flow Manipulations

A variety of other flow manipulations are built into the alternatives. Low summer flows are designed to produce warmer conditions for juvenile HBC growth in the Colorado River at the confluence with the Little Colorado River by reducing flows from July through September. These flows would be implemented experimentally in those alternatives that allow them (table 3).

Sustained low flows for benthic invertebrate production ("bug flows") are an experimental action considered under Alternative D for restoring mayflies, stoneflies, and caddisflies to Glen and Marble Canyons. If implemented, steady minimum flows would be provided every weekend from May through August, to ensure that eggs laid during weekends would not be subject to drying because of lower water levels during egg development. Demand for electricity is lower on

Table 2. Operational characteristics of Long-Term Experimental and Management Plan alternatives.

[maf,, megaacre-foot; kaf, kiloacre-foot; ft^3/s, cubic foot per second; >, greater than]

Elements of base operations	Alternative						
	A	B	C	D	E	F	G
Monthly pattern in release volume	Historic monthly release volumes.	Same as Alternative A	Highest volume in high electric demand months; February–June volumes proportional to contract rate of delivery; lower volumes August–November	Comparable to Alternative E, but August and September volume increased, with additional volume taken from January through July	Monthly volumes proportional to the contract rate of delivery, but with a targeted reduction in August–October volumes; volume released in October, November, and December=2.0 maf in > 8.23-maf years	Relative to Alternative A, higher release volumes in April–June; lower volumes in remaining months	Equal monthly volumes, adjusted with changes in runoff forecast.
Minimum flows (ft^3/s)	8,000 during day; 5,000 during night	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	5,000	5,000
Maximum flows (ft^3/s)	25,000	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A.
Daily range (ft^3/s)	5,000, 6,000, or 8,000 depending on monthly volume	December and January: 12,000 February, July, and August: 10,000 October, November, March, June, and September: 8,000 April and May: 6,000	Equal to 7 × monthly volume in kaf in all months; 2,000 ft^3/s following significant sediment input in summer or fall	Equal to 10 × monthly volume in kaf in June–August, and 9 × monthly volume in kaf in other months; not to exceed 8,000 ft^3/s	Equal to 12 × monthly volume in kaf in June–August, and 10 × monthly volume in kaf in other months; 2,000 ft^3/s following significant sediment input in summer or fall	0	0
Ramp rates (ft^3/s-hr)	4,000 up 1,500 down	4,000 up 4,000 down November–March 3,000 down in other months	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 2,500 down	4,000 up 1,500 down	4,000 up 1,500 down.

Table 3. Triggered and experimental elements of the Long-Term Experimental and Management Plan long-term strategies.

[A filled circle (●) indicates the element in question is implemented fully in the long-term strategy; an open circle (○) indicates the element in question is implemented in some partial degree; and -- indicates that element is not part of that long-term strategy. HFE, high-flow experiment]

Element	Alternative																	
	A	B		C				D				E						F	G
	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
Fall HFEs	○	○	○	●	●	--	●	●	●	●	●	●	●	--	●	--	--	●	●
Spring HFEs	○	○	○	●	●	--	--	○	○	○	○	○	○	--	--	--	--	●	●
Proactive spring HFEs	--	--	--	●	●	--	--	●	●	●	●	--	--	--	--	--	--	--	●
HFEs longer than 96-hour duration	--	--	--	●	●	--	●	○	○	○	○	--	--	--	--	--	--	--	●
Trout management flows	--	●	●	●	--	--	--	●	●	--	●	●	--	--	--	--	●	--	●
Low summer flows	--	--	--	--	●	--	--	○	○	○	--	--	●	--	--	●	--	--	--
Bug flows	--	--	--	--	--	--	--	--	●	--	--	--	--	--	--	--	--	--	--
Hydropower improvement flows	--	--	●	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Steady flows before HFEs	--	--	--	●	●	--	●	●	●	●	●	●	●	--	●	--	--	●	●
Steady flows after HFEs	--	--	--	●	●	--	●	●	●	●	●	--	--	--	--	--	--	●	●
Mechanical trout removal	●	●	●	--	--	●	●	●	●	●	●	--	--	●	●	--	--	--	●

weekends, so timing the benthic invertebrate production flows during the weekends minimizes the effect on the value of hydropower generation.

Hydropower improvement flows are an experimental action considered under Alternative B to increase hydropower generation during high-demand months (December–February and June–August) in years when the annual volume is less than or equal to (≤) 8.23 million acre-feet. These flows work largely by allowing a greater daily range and higher ramp rates.

Some of the alternatives use steady flows before an HFE to conserve sediment for the high-flow release, after an HFE to reduce erosion of newly built sandbars, or both (table 3). These steady flows stop the load-following patterns of hourly releases and are sometimes called "load-following curtailment."

5.1.5 Nonflow Actions

Under a 2011 assessment (Bureau of Reclamation, 2011b), experimental methods of controlling trout populations were evaluated and implemented. These methods include mechanical removal of brown trout (*Salmo trutta*) and RBT at the Little Colorado River through electrofishing, selective removal, and beneficial use of the fish removed. Many of the LTEMP EIS alternatives allow for continued use of mechanical removal with specific requirements for when such removal would be triggered (table 3).

Under all alternatives except Alternative A (no-action alternative), the NPS would implement experimental vegetation restoration to modify the cover and distribution of plant communities along the Colorado River. This restoration would include removal of nonnative species, prevention of new introductions, planting of native species, management of vegetation at campsites, and removal of windrows that block wind transport of sediment.

5.1.6 Long-Term Strategies

Four of the seven alternatives (Alternatives B, C, D, and E) were conceived as experimental and adaptive strategies, with elements that would be deployed experimentally to allow resolution of uncertainty and subsequent adaptation of the strategy in response to the information acquired; thus, within each of these alternatives are a number of implicit long-term strategies that might result after resolution of uncertainty. Not all of those possible long-term strategies were analyzed, but a representative set from each alternative was articulated and analyzed to capture the possible range of environmental effects and evaluate the importance of resolving the underlying uncertainty; thus, for example, under Alternative C, whether or not to implement fall HFEs, spring HFEs, TMFs, low summer flows, or mechanical removal will depend on the efficacy of those actions in achieving their intended purpose, the strengths of undesirable side effects of those actions, and the underlying effect of RBT on HBC. The long-term strategies C1, C2, C3, and C4 represent a range of possible solutions once such uncertainty is resolved; if, for instance, spring HFEs have a beneficial effect on sediment deposition and only a small effect on RBT production, TMFs are ineffective, but low summer flows benefit HBC, then long-term strategy C2 might be the best version of Alternative C to use. All of the 19 long-term strategies (table 3) were evaluated against the critical uncertainties described in sections 6.2.1, 6.3.1, and 6.5.1.

5.2 Alternative A (No Action)

Alternative A, the no-action alternative, represents continued operation of Glen Canyon Dam under the existing guidelines in Bureau of Reclamation (1996), interim guidelines in Bureau of Reclamation (2007), and the two 2011 EAs (Bureau of Reclamation, 2011a, 2011b), as well as other applicable guidance. This alternative has a base operation pattern that was called MLFF in Bureau of Reclamation (1996). Both of the 2011 EAs expire after 2020, so the elements specified in them (HFEs and mechanical removal) would cease at that point (Bureau of Reclamation 2011a, 2011b). Beyond the actions discussed in Bureau of Reclamation (2011a, 2011b), there are limited experimental options that can be tested under this alternative.

5.3 Alternative B

Alternative B was designed to increase the value of hydropower generation while limiting negative effects to other resources. This alternative was submitted by the Colorado River Energy Distributors Association (CREDA), a member of AMWG. The base operations are designed to generate more valuable power than Alternative A by increasing the daily range and ramp rates to allow power generation to more closely follow power demand. This alternative limits the implementation of HFEs to one every other year because HFEs release water without generating power and require water volumes to be shifted from months when the value of power is potentially higher to other months. To moderate some of the negative effects of this water-release pattern on other resources, Alternative B includes mechanical removal, evaluation of TMFs, and experimental implementation of vegetation restoration.

5.3.1 Alternative Long-Term Strategies

Alternative B includes two long-term strategies, one with its base operations (B1) and one that includes hydropower improvement flows (B2), maximum power plant capacity flows implemented as many as four times during the LTEMP period, in years when the annual volume is ≤8.23 million acre-feet (table 3). Such years, because of their lower volume of release, typically require the most purchases by WAPA to meet contractual demand, so the higher flows could mitigate costly purchases in high-demand months. Whether B1 or B2 is a better long-term strategy, when the effects across all resource goals are taken into account, depends on the strength of negative effects of greater power generation on other resources. Specific hypotheses for these negative effects, which are uncertain, were not explicitly articulated when Alternative B was submitted. The long-term strategies B1 and B2 were evaluated, however, against the set of uncertainties developed in the context of other alternatives.

5.4 Alternative C

Alternative C was developed by the joint-lead agencies to maintain or improve multiple resources, with some priority placed on HBC, sediment, and hydropower. Called the "condition-dependent adaptive strategy" in interim public documents during the preparation of the EIS (Bureau of Reclamation and National Park Service, 2014), Alternative C has information-dependent and condition-dependent triggers, seeks to test critical hypotheses, and contains explicit instructions for how new insights will affect subsequent implementation of action elements.

Compared to many of the other alternatives, the base operations for Alternative C shift monthly volumes from the monsoon months (August through November) to high-demands months (December, January, and July) to reduce sediment transport during the monsoonal high-sediment-input period and limit effects on the value of power generation. The reduced volume in late summer is also intended to provide warmer river temperatures for the benefit of HBC and other native fish.

Alternative C includes a number of condition-dependent (triggered) elements; among them are fall HFEs, spring HFEs, proactive spring HFEs, extended duration HFEs, TMFs, low summer flows, load-following curtailment, and mechanical removal of trout. The specific details of the triggers for these events are found in chapter 2 of the EIS. Most of these elements are experimental, and so there are information-dependent triggers as well; that is, monitoring and evaluation of all these elements would be completed, and elements would be dropped or retained depending on if the evidence supported their retention.

5.4.1 Alternative Long-Term Strategies

Four long-term strategies (C1, C2, C3, and C4) were developed to capture the range of possible outcomes from adaptive implementation of Alternative C (table 3). The motivation for the creation of these long-term strategies was the recognition that there are critical uncertainties that impede identification of the best long-term strategy. The key questions concerned the following: the magnitude of increase in RBT production in the Glen Canyon reach caused by fall HFEs, the relative effects of temperature and trout density on survival and growth of juvenile HBC at the Little Colorado River, and the effectiveness of TMFs in reducing RBT production. The relevance of these uncertainties arises because of the possible tradeoffs among the objectives of supporting the HBC population, maintaining a strong rainbow trout fishery, increasing sediment deposition and sandbar building, and affirming tribal values concerning the respect for life (especially aquatic life). Each of the action elements under consideration (HFEs, TMFs, low summer flows, and mechanical removal) is meant to increase achievement of one or more of those objectives, but the question is if the benefits to one objective come at the expense of others. Alternative C was designed under the

assumption that the best mix of action elements (the best long-term strategy) depends on resolution of the critical uncertainties.

Long-term strategy C1 allows use of all the triggered elements from Alternative C except for low summer flows and mechanical removals; such a strategy has been hypothesized to be warranted, for instance, if the effect of spring HFEs on trout production was weak, TMFs were effective, and low summer flows were not effective. Long-term strategy C2 is similar to C1 except that it calls for low summer flows but not TMFs. Long-term strategy C3 does not allow HFEs and might be called for if HFEs are determined to cause a very strong increase in trout recruitment and other actions are ineffective at mitigating the effect of trout on HBC. Long-term strategy C4 allows fall HFEs but not spring HFEs and manages the effect of trout on HBC through mechanical removal.

Whether or not the resolution of the critical uncertainties actually matters to the ranking of the long-term strategies is one of the central questions in section 8.3, "Expected Value of Information."

5.5 Alternative D

Alternative D was developed by the joint-lead agencies after a full analysis of the other six LTEMP alternatives had been completed. The initial analysis suggested that there were strong characteristics of Alternatives C and E that contributed to achievement of resource goals and motivated creative thinking about how to achieve more of those benefits in a single alternative. Alternative D adopts characteristics of Alternatives C and E.

The base operations for Alternative D are in many respects a compromise between those of Alternatives C and E (table 2). The monthly pattern of release is most similar to that of Alternative E, with an increase in the August and September volumes (and a corresponding decrease in the January through June volumes). The daily range for flows is about midway between the ranges from Alternatives C and E.

The experimental and adaptive options for Alternative D include all the elements considered in the any of the alternatives, except for hydropower improvement flows (table 3). The experimental implementation calls for early testing of TMFs in the first 2–5 years without having to meet the condition-dependent triggers and delayed consideration of spring HFEs until the third year of implementation.

5.5.1 Alternative Long-Term Strategies

Four long-term strategies (D1, D2, D3, and D4) were developed to capture the range of possible outcomes from adaptive implementation of Alternative D (table 3). The long-term strategies in this set look more similar than in the sets for Alternatives C and E because they were created after an initial analysis of the other six alternatives and, thus, reflect insights from that analysis. For instance, long-term strategies D1 through D4 are all similar with regard to implementation of HFEs because the initial analysis suggested that the benefits of HFEs outweighed the costs, even in the face of the uncertainties tested. There remain, however, other long-term strategies implicit in Alternative D; for example, if spring, proactive, or extended HFEs are determined to have very strong negative effects on resources of importance that cannot be mitigated by other actions, they could be removed from long-term implementation. The four long-term strategies for Alternative D, however, are thought to capture the most important differences that might arise in long-term implementation.

Long-term strategy D4 might be considered the base strategy under Alternative D because all action elements except low summer flows and bug flows are in operation (table 3). Long-term strategy D1 adds low summer flows. Long-term strategy D2 adds implementation of bug flows and would be supported if early experimental tests of bug flows determined they had the intended effects in restoring important native benthic invertebrate communities without having adverse effects on other resources. Under this long-term strategy, low summer flows would only be implemented in the second 10 years. Long-term strategy D3 is similar to D1 but removes TMFs.

The motivations for the different long-term strategies in Alternative D are the same critical uncertainties that motivate the long-term strategies in Alternative C, with a specific focus on the effectiveness of TMFs, the influence of temperature on juvenile HBC growth and survival, and the effect of bug flows on other resources.

5.6 Alternative E

Alternative E was developed by representatives of the seven states in the Colorado River Basin to provide for recovery of HBC while protecting other important resources, including sediment, the RBT fishery at Lees Ferry, aquatic food base, and hydropower resources. Called the "resource-targeted condition-dependent" strategy in interim public documents during the preparation of the EIS (Bureau of Reclamation and National Park Service, 2014), Alternative E has information-dependent and condition-dependent triggers, seeks to test critical hypotheses, and contains explicit instructions for how new insights will affect subsequent implementation of action elements.

The base operations for Alternative E seek greater value of hydropower production than Alternatives C and D (table 2). The monthly volumes largely follow hydropower demand and are proportional to the contract rate of delivery but with a reduction in August through October volumes to conserve sediment during the monsoon period. The daily range is large compared to the other alternatives. The ramp rates are the same as in Alternative C and D.

Alternative E includes a number of condition-dependent (triggered) elements; among them are fall HFEs, spring HFEs, TMFs, low summer flows, load-following curtailment

(before but not after HFEs), and mechanical removal of trout (table 3). Implementation of spring HFEs is delayed until the second 10 years to allow testing of TMFs in the early years (with long-term implementation of spring HFEs conditional on TMFs being an effective tool). An important experimental element of Alternative E is early testing of the response of RBT populations to TMFs and fall HFEs in a 2x2 factorial design, replicated two to three times (in hopes of experiencing both cold and warm water temperatures). The specific details of the triggers for these events are found in chapter 2 of the EIS. Most of these elements are experimental, and so there are information-dependent triggers as well; that is, monitoring and evaluation of all these elements would be completed, and elements would be dropped or retained depending on if the evidence supported their retention.

5.6.1 Alternative Long-Term Strategies

Six long-term strategies (E1, E2, E3, E4, E5, and E6) were developed to capture the range of possible outcomes from adaptive implementation of Alternative E (table 3). The motivation for the creation of these long-term strategies was the recognition that there are critical uncertainties that impede identification of the best long-term strategy. The key questions concerned the following: the magnitude of increase in RBT production in the Glen Canyon reach caused by fall HFEs, the relative effects of temperature and trout density on survival and growth of juvenile HBC at the Little Colorado River, the effectiveness of TMFs in reducing RBT production, and the effect of high flows on sediment retention.

Long-term strategy E1 uses spring and fall HFEs when triggered, along with TMFs to manage the trout populations; this long-term strategy would be favored, for example, if HFEs are determined to be beneficial to sediment conservation and TMFs are effective in controlling trout populations. Long-term strategy E2 also uses spring and fall HFEs but uses low summer flows instead of TMFs; this strategy might be favored if temperature is a more important factor in HBC survival than trout predation and TMFs are ineffective. Long-term strategy E3 does not allow HFEs, TMFs, or low summer flows and uses mechanical removal to manage trout density at the Little Colorado River when needed; such a strategy might be favored if HFEs greatly increase production of trout, TMFs are ineffective in managing trout populations, HBC are strongly affected by trout predation, and low summer flows do not provide enough advantage to HBC to warrant use. Long-term strategy E4 allows fall HFEs but not spring HFEs and relies on mechanical removal to manage trout at the Little Colorado River. Long-term strategy E5 is like E3 in not allowing HFEs but uses low summer flows rather than mechanical removal to support HBC population growth. Long-term strategy E6 also does not use HFEs and uses TMFs when needed to manage trout. As with Alternatives C and D, these long-term strategies are not meant to be a comprehensive set of the possible permutations of Alternative E that might arise from adaptive implementation but, rather, are meant to represent a broad range of possible outcomes, effectively bracketing the strategies that might arise.

As with Alternative C and D, whether or not the resolution of the critical uncertainties actually matters to the ranking of the long-term strategies is one of the central questions in section 8.3, “Expected Value of Information.”

5.7 Alternative F

Alternative F was designed to follow a more natural pattern of flows, limiting sediment transport and providing warmer temperatures in the summer months. The base operations provide higher release volumes in April–June (to mimic spring runoff), including a May 1 high-flow spike of 45,000 ft^3/s (essentially an untriggered HFE) and lower volumes the remainder of the year. The daily flows are steady with no daily fluctuations (no hydropeaking). The only modification to base operations would be sediment-triggered HFEs (fall and spring). In keeping with the desire to have this alternative better match predam conditions than the other alternatives, it does not use TMFs or mechanical removal.

5.8 Alternative G

Alternative G was designed to maximize the conservation of sediment by providing year-round steady flows. The base operations provide equal monthly volumes and steady daily flows. In practice, the monthly volumes would have to be adjusted as the forecasts for annual volume change through the year, but the intent is to keep flows quite steady. This alternative does allow all forms of HFEs to be used to maximize sandbar building and sediment conservation.

6 Quantitative Methods

The 19 long-term strategies were evaluated against the 18 performance metrics and 5 sources of uncertainty: the hydrology during the 20-year LTEMP period of performance, the sediment inputs during the 20-year LTEMP period of performance, the relative effects of temperature and trout predation on juvenile HBC survival and growth, the effectiveness of trout management flows, and the effect of fall HFEs on trout recruitment. A total of 10 modeling teams built a linked set of analyses to simulate the performance of the long-term strategies; the performance metrics were calculated from the simulation outputs. This section describes the methods used to complete these analyses.

6.1 Modeling Overview

The basis of the analysis of the alternatives was a large, linked set of simulation models that were meant to represent the Colorado River ecosystem below Glen Canyon Dam (fig. 2).

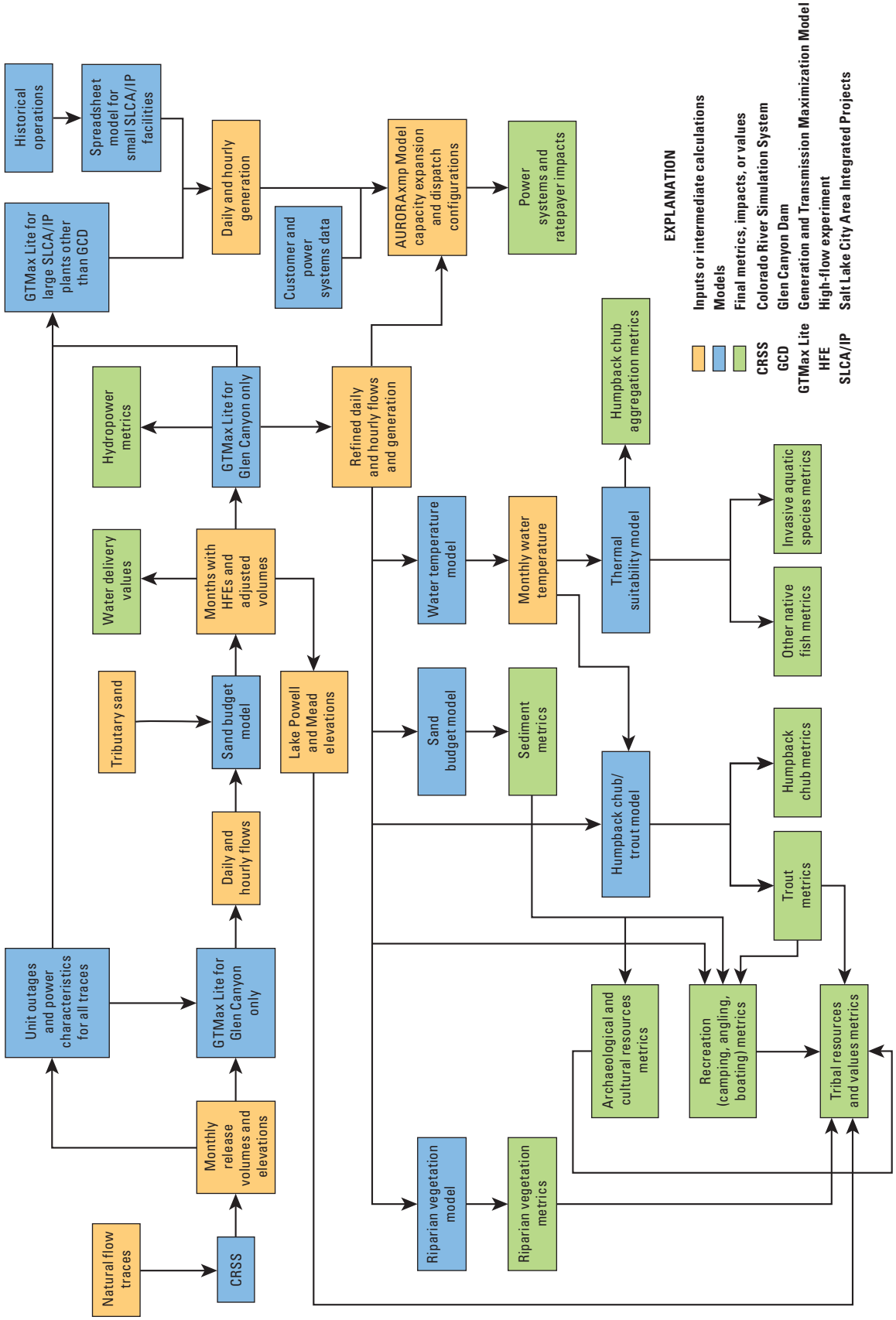

Figure 2. Model flow for the analysis of the Long-Term Experimental and Management Plan long-term strategies against the performance metrics.

Each long-term strategy encoded a set of rules that governed annual, monthly, daily, and hourly flow through the dam, as well as mechanical removal of nonnative fish from the Colorado River at its confluence with the Little Colorado River and vegetation treatments along the river corridor. The long-term strategy, coupled with 21 hydrological traces and 3 sediment traces (to represent environmental variation), determined the flows through the Glen Canyon Dam. The daily and hourly flows then were sent to models for vegetation, sediment, and temperature. The temperature and flow outputs then informed models for RBT, HBC, and other aquatic organisms. The outputs of all these models were collected and used to calculate performance metrics under all the resource goals. The details of all these modeling methods are provided in the technical appendixes to the LTEMP EIS; a synopsis is provided here.

6.2 Hydrology

The hydrological modeling requires three sets of input: a time series of hydrological flow into Lake Powell, a time series of sediment input into the Colorado River from the Paria River and the Little Colorado River, and the operational rules determined by a long-term strategy. The output of the hydrological modeling is the monthly, daily, and hourly flows through Glen Canyon Dam for the 20-year LTEMP period of performance. This requires three modeling systems. First, the Colorado River Simulation System (CRSS), built with the commercial software package RiverWare™ (Zagona and others, 2001), generates monthly volumes and lake elevations taking into account the operations of the 12 primary reservoirs on the Colorado River. Second, the Generation and Transmission Maximization model (GTMax-Lite) generates daily and hourly flows taking into account patterns of demand and supply of electric power in the Colorado River Storage Project (CRSP) region. Third, a sand budget model tracks sediment in Glen, Marble, and Grand Canyons; and is used to indicate when sediment conditions warrant high-flow experiments (if the long-term strategy in question allows them). After the HFEs are identified, a second pass through GTMax-Lite is required to refine the daily and hourly flows. Note that the effect of TMFs on hydrology were not modelled because this would have required a full coupling of the hydrology and fish models (with feedback from the fish models to the hydrology models), which was a computing task that was beyond the resources available.

6.2.1 Critical Uncertainty

To model uncertainty in future inflow, the indexed sequential method (Ouarda and others, 1997) was used to resample the historical record of natural flow in the Colorado River system during the 105-year period from 1906 through 2010. Every fifth trace was selected from this series to produce 21 hydrological traces; every long-term strategy was evaluated against all 21 hydrological traces.

To investigate the possible effects of climate change on the performance of the long-term strategies, CRSS was run with 112 natural flow traces developed from downscaled general circulation model projected hydrological traces (Bureau of Reclamation, 2012). These climate scenarios were based on 16 general circulation models from the Coupled Model Intercomparison Project Phase 3 (CMIP3) using three forcing scenarios (A2, high; A1b, medium; and B1, low) (Maurer and others, 2007). The LTEMP models were not run with the 112 hydrological traces; rather, the 112 hydrological traces from the climate-change scenarios were used to place weights on the 21 index sequential historical traces. The model results are compared using historical (equal) and climate-change weights on the 21 hydrological traces.

6.3 Sediment Dynamics

A sand budget model (Russell and Huang, 2010; Wright and others, 2010) was used to track sand storage and transport from Lees Ferry (RM 0) to Bright Angel Creek (RM 87) (fig. 1). The sand budget model takes as input hourly hydrographs at the reach boundaries (RM 30, RM 61, and RM 87) developed based on release schedules from Glen Canyon Dam and hourly sand delivery from the Paria and Little Colorado Rivers. The model tracks sand storage and movement through three reaches (Upper Marble Canyon, RM 0 to 30; Lower Marble Canyon, RM 30 to 61; and Eastern Grand Canyon, RM 61 to 87) using empirically-based rating curves formulated on a particle-size-specific basis. The outputs of the model include hourly time series of the sand transported at the downstream border of each reach, and the sand budget for each reach. From these outputs a variety of performance metrics, including the SLI (performance metric 15), can be calculated.

6.3.1 Critical Uncertainty

Sediment input to the Colorado River between Lees Ferry and Bright Angel Creek comes primarily from the Paria River and the Little Colorado River (fig. 1). Variation in sediment input is driven by spatial and temporal variation in precipitation. To capture uncertainty about the time series of future sediment input, three 20-year traces of sediment input were created from historical records using an index sequential method. For Paria River input, 49 reconstructed historical traces were available (index years 1964–2012). For Little Colorado River input, 18 reconstructed historical traces were available (index years 1995–2012). The cumulative 20-year sediment delivery for each trace was calculated; and the traces corresponding to the 10th, 50th, and 90th quantiles of cumulative sediment delivery were selected to represent the range of possible uncertainty. The traces from corresponding quantiles for the Paria River and Little Colorado River delivery were coupled in the simulations. Weights were placed on the three sediment traces so that the weighted mean and standard deviation of the 20-year Paria River sediment delivery for the three

traces matched the mean and standard deviation for the full set of index sequential Paria River traces.

6.4 Temperature

The average monthly water temperatures along the river corridor from Glen Canyon Dam to Lake Mead were forecast using the monthly flow and air temperatures forecasts. The release temperature from Glen Canyon Dam was simulated with the CE–QUAL–W2 model (Cole and Wells, 2006). This served as an input to a river temperature model that calculated the gains and losses of heat as the water moved downstream (Wright and others, 2009). For the purposes of the decision analysis, water temperature was an intermediate variable used as input to the fish models but not used directly as a performance metric.

6.5 Coupled Rainbow Trout-Humpback Chub Dynamics

A coupled RBT–HBC model was used to simulate the population dynamics of RBT in the Glen Canyon reach, movement of RBT from Lees Ferry to the Little Colorado River confluence, and the population dynamics of HBC in the Little Colorado River reach. The RBT population dynamics were simulated with an age-structured population model that accounted for the effects of water flow on recruitment, survival, growth, and downstream emigration (Korman and others, 2012). The RBT performance metrics are calculated from this model. The RBT catch rate (performance metric 3) was calculated from the age-specific abundances, age-specific vulnerabilities, and a catchability coefficient. The abundance of RBT greater than 16 inches (considered high-quality RBT; performance metric 5) was calculated from the age-specific abundances and size-at-age characteristics. The annual emigrants (performance metric 4) were computed as a fraction of the recruitment.

The RBT movement model predicts the monthly abundance of RBT in each 1-mile segment of the Colorado River from RM 0 to RM 150 taking into account movement rates, natural mortality, and implementation of mechanical removal. Movement and survival were density independent and were not affected by flow or temperature.

A size- and location-structured population model was used to predict the adult population size of HBC at monthly intervals (Yackulic and others, 2014). The HBC population size in two locations, the Colorado River and the Little Colorado River (a tributary of the Colorado River), was accounted for in the model. Survival of juvenile HBC in the Colorado River depended on the abundance of RBT in the Little Colorado River reach of the Colorado River; their growth depended on RBT abundance and temperature. Growth rates in other size classes in the Colorado River depended on water temperature. From this model, the minimum number of adult HBC during each 20-year trace was calculated, and the expected minimum value (performance metric 1) was calculated by taking the mean across traces.

6.5.1 Critical Uncertainties

A number of critical uncertainties concerned parameters in the RBT and HBC models. Each of these uncertainties was expressed as alternative sets of model parameters. All long-term strategies, with all sediment and hydrology traces, were run separately against the combinations of model parameters. The alternative sets of model parameters were assigned weights to represent their empirical support, and weighted averages of the performance metrics were calculated across them.

Uncertainty about the effect of fall HFEs on recruitment of RBT in the Glen Canyon reach was expressed as two hypotheses: one that there is no effect on recruitment, and another that proposed recruitment would increase at the same rate as seen with spring HFEs (Korman and others, 2011) but for only 1 year instead of 2 years. An expert panel consisting of four fish biologists who were familiar with RBT dynamics in the Colorado River was convened in March 2014. A modified Delphi process with four-point elicitation (Speirs-Bridge and others, 2010) was used to estimate the likelihood of the two hypotheses; the resulting individual estimates were aggregated by simple averaging.

Uncertainty about the effect of TMFs in reducing RBT recruitment in the Glen Canyon reach was expressed as two hypotheses by the expert panel: TMFs reduce recruitment by 10 percent, and TMFs reduce recruitment by 50 percent. The two levels of effectiveness were chosen to represent equally plausible extremes.

The final area of uncertainty concerned the effects of RBT abundance and temperature on the growth and survival of juvenile HBC in the Little Colorado River reach of the main stem Colorado River. Four hypotheses were generated (fig. 3*A* and 3*B*): a strong effect of temperature on growth and a strong effect of RBT on growth and survival (f1), a weak effect of temperature on growth and a weak effect of RBT on growth and survival (f2), a weak effect of temperature and a strong effect of RBT (g1), and a strong effect of temperature and a weak effect of RBT (g2). The parameter values for the four hypotheses were chosen from the ends of diameters on the 90-percent confidence ellipsoid for the joint parameter likelihood (Yackulic and others, 2014) and, thus, were equally weighted.

6.6 Fish Habitat Suitability

Temperature suitability for HBC and other native and nonnative fish at a number of sites between Lees Ferry (RM 0) and Diamond Creek (RM 225) (fig. 1) was evaluated with species-specific models for the effect of temperature on survival, reproduction, and growth (Valdez and Speas, 2007). The details of all these methods and results are in the LTEMP EIS.

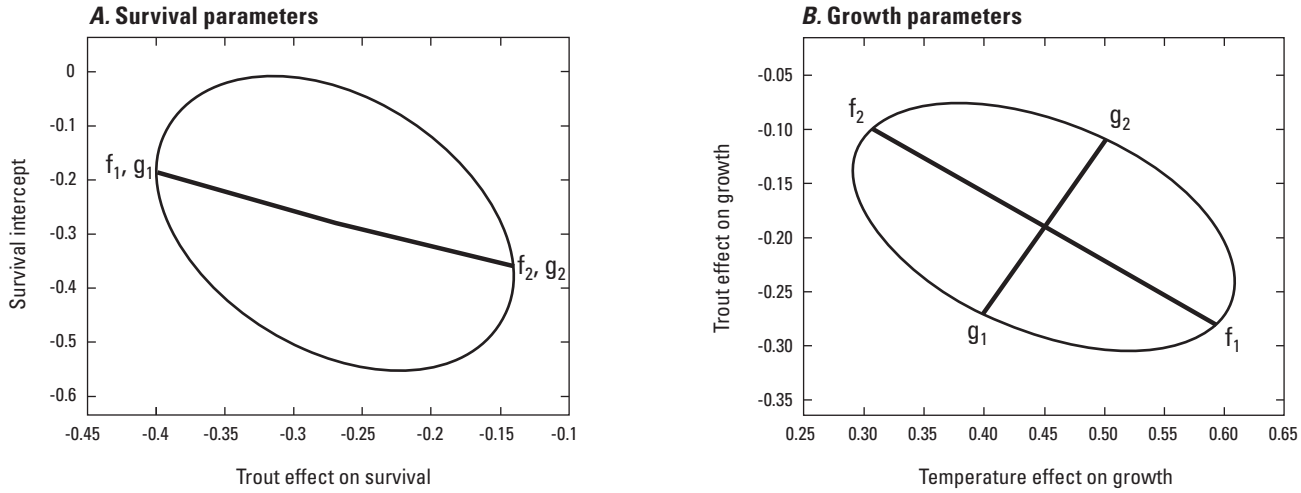

Figure 3. Uncertainty in the humpback chub population dynamics as represented by four alternative sets of parameters. *A*, survival parameters; and, *B*, growth parameters

The only one of those metrics that was retained for the decision analysis was the average temperature suitability for HBC at Havasu Creek (RM 157) and Pumpkin Spring (RM 213) because most of the other metrics exhibited very little difference across alternatives. Monthly water temperatures in the main stem Colorado River at the various sites under each long-term strategy were used to calculate the suitability for spawning, incubation, and growth during critical periods of the annual cycle. The overall temperature suitability at a site was the product of the suitability for the three component processes during the course of the year and could theoretically vary between 0 and 1 (performance metric 2).

6.7 Archaeological and Cultural Resources

The performance metrics associated with archaeological and cultural resources (performance metrics 6–8; table 1) did not require separate models but, rather, were calculated from intermediate sediment and flow variables.

6.8 Hydropower

As noted above in the "Hydrology" section (section 6.2), CRSS, the sand budget model, and GTMax-Lite are used in combination to simulate the water release and, therefore, hydropower generation on an hourly basis for each long-term strategy (fig. 2). The GTMax-Lite optimized the economic value of hourly energy produced at Glen Canyon Dam. This model determined an hour-by-hour pattern of generation (in megawatt hours) and water releases (in cubic feet per second) that satisfied the operating constraints imposed by each alternative, such as upramp and downramp rates, maximum change in the release during a rolling 24-hour period, maximum hourly release, and others. Hourly electricity market prices during the 20-year LTEMP period were determined using the AURORAxmp (Aurora) model to simulate the operation of the Western Interconnection of which Glen Canyon Dam is one of several thousand generating plants. Hourly prices determined by Aurora for 2013 were benchmarked against 2013 day-ahead market prices published by the Intercontinental Exchange. Prices forecast by Aurora for 2013 were compared against historical Intercontinental Exchange prices, and future electricity prices were adjusted accordingly.

For a given long-term strategy, the value of hydropower generation (performance metric 9) was calculated by combining the forecasts of the hourly generation profile and electricity market price. The net present value (NPV) of this 20-year time series was calculated assuming a 3.375 percent discount rate, and then divided by 20 to present the results on an annualized scale.

Hydropower capacity from Glen Canyon Dam is also marketed in the form of long-term firm contracts to provide power up to a given level. Energy demand is highest in August, so to calculate the marketable capacity (in megawatts), the peak daily generation was tabulated for each day in August across the 20 years of a trace (for each long-term strategy). From these 620 daily values (20 years x 31 days in August), the 90-percent exceedance value (10th quantile) was calculated, representing the marketable capacity for that trace. In 90 percent of August days (and much more often in other months), WAPA can be confident of being able to deliver that amount of power without having to purchase it. The net present value of that capacity (performance metric 10) was calculated by multiplying by the levelized cost of capacity plus fixed annual operating and maintenance (O&M) expenses of a thermal power plant constructed to replace capacity lost at Glen Canyon Dam. The selection of the replacement technology was based on insights obtained from the power systems economic analysis. The Aurora model runs made for this analysis determined that a natural gas combustion turbine would be the type of generating unit most likely constructed

as a replacement for lost Glen Canyon Dam capacity. The cost to construct that type of unit, spread over its book life, was determined to be $50,100/MW-year, including capital investment costs, allowance for funds during construction, and fixed O&M costs. The source of cost data for replacement power plant capacity was U.S. Energy Information Administration (2014). In the analysis in the LTEMP EIS (chapter 4 and appendix K), the daily August generation values for all traces were combined before the exceedance value was calculated; this results in some slight differences in the median values presented but not systematic bias.

6.9 Recreation

The performance metrics associated with recreation (performance metrics 11–13; table 1) did not require separate models but, rather, were calculated from intermediate sediment and flow variables.

6.10 Riparian Vegetation

The effects of the long-term strategies on riparian vegetation were simulated with a state-and-transition model for Colorado River riparian vegetation downstream from Glen Canyon Dam (Ralston and others, 2014). The model tracks seven vegetation communities (bare sand, marsh, shrub wetland, tamarisk, cottonwood-willow, arrowweed, and mesquite) on channel margins and sandbars in the New High Water Zone and Fluctuation Zone as affected by the depth, timing, and duration of inundation. Six geomorphic submodels are included: lower separation bar, upper separation bar, lower reattachment bar, upper reattachment bar, lower channel margin, and upper channel margin; only four of these are unique (the parameters for the upper separation bar, upper reattachment bar, and upper channel margin are all equal). The model starts in 1 of 25 possible states (the 7 vegetation communities crossed with the 6 geomorphic submodels; not all of the 42 combinations are possible) and then tracks the vegetation state in each subsequent year as affected by the alternative-specific flows. The output is the number of years spent in each vegetation state during the 20-year LTEMP period of performance. These results are summed across the 25 starting states and then compared to the results that would have happened if the starting state was maintained for the 20-year period. In comparing the native to nonnative states, and in calculating the native diversity, the results are weighted by the current estimated area of each vegetation state.

Four component ratios are calculated as intermediate results: the ratio of cumulative to initial native vegetation cover, the ratio of cumulative to initial vegetation state diversity, the ratio of cumulative to initial native to nonnative dominant vegetation state, and the ratio of initial to cumulative cover of arrowweed. The final value (riparian native states and diversity index; performance metric 14) is the sum of the four component ratios; thus, an index value of 4.0 indicates an unchanged vegetation condition, values greater than 4.0 indicate improved vegetation conditions, and values less than 4.0 indicate degraded vegetation conditions.

7 Consequence Analysis Results

In this section, the results for the individual performance metrics are presented. In most cases, these results are reported as means over all sources of uncertainty with boxplots used to show the variance induced by uncertainty. Unless otherwise noted, the historical weighting of hydrological traces was used; the sensitivity of the results to climate change (as captured by weighting of the hydrological traces) is discussed in section 8.4, “Effects of Climate Change.”

7.1 Humpback Chub Results

Across alternatives, the expected (mean) minimum number of adult HBC during the 20-year LTEMP period of performance differed by about 500 from Alternative A (fig. 4, bottom panel). The variation across hydrological traces within an alternative was greater than the magnitude of variation across alternatives. Many of the long-term strategies were demonstrably better than Alternative A; the biggest exceptions (C2 and F) were long-term strategies that increased RBT recruitment (through HFEs) without tools to manage RBT populations (TMFs and mechanical removal). The best-performing long-term strategy (E6) did not allow HFEs of any type and included triggered use of TMFs if needed. The benefit of low summer flows to HBC (compare D1 to D4) is not discernible, likely because of their infrequent use.

The set of 16 scenarios that captured critical uncertainty did not affect the dominance of long-term strategy E6 (table 4); that is, if the only desired outcome is to maximize the HBC metric, the best long-term strategy is E6 regardless of the effect of fall HFEs or TMFs on RBT recruitment or the relative effects of temperature and RBT on juvenile HBC growth and survival. For the purpose of the HBC objective, therefore, the expected value of information across the critical uncertainties that were articulated is 0.

Across the uncertainty represented by the hydrological traces, there is a small value of information (table 5). For most hydrological traces, the best long-term strategy for HBC was E6; but long-term strategies B2, C3, D1, and E5 were also favored in some traces. In the face of uncertainty, the best strategy is E6 with an expected (mean) minimum adult population size of 5,708. If the hydrological trace could be known in advance of choosing an action, the appropriate strategy (B2, C3, D1, E5, or E6) would be chosen; the expected minimum adult population size would be 5,725, which is an increase of 0.30 percent. Of course, the hydrological trace cannot be known in advance of choosing an action because it represents environmental variation during the next 20 years, but the inclusion of these results is helpful in understanding the value

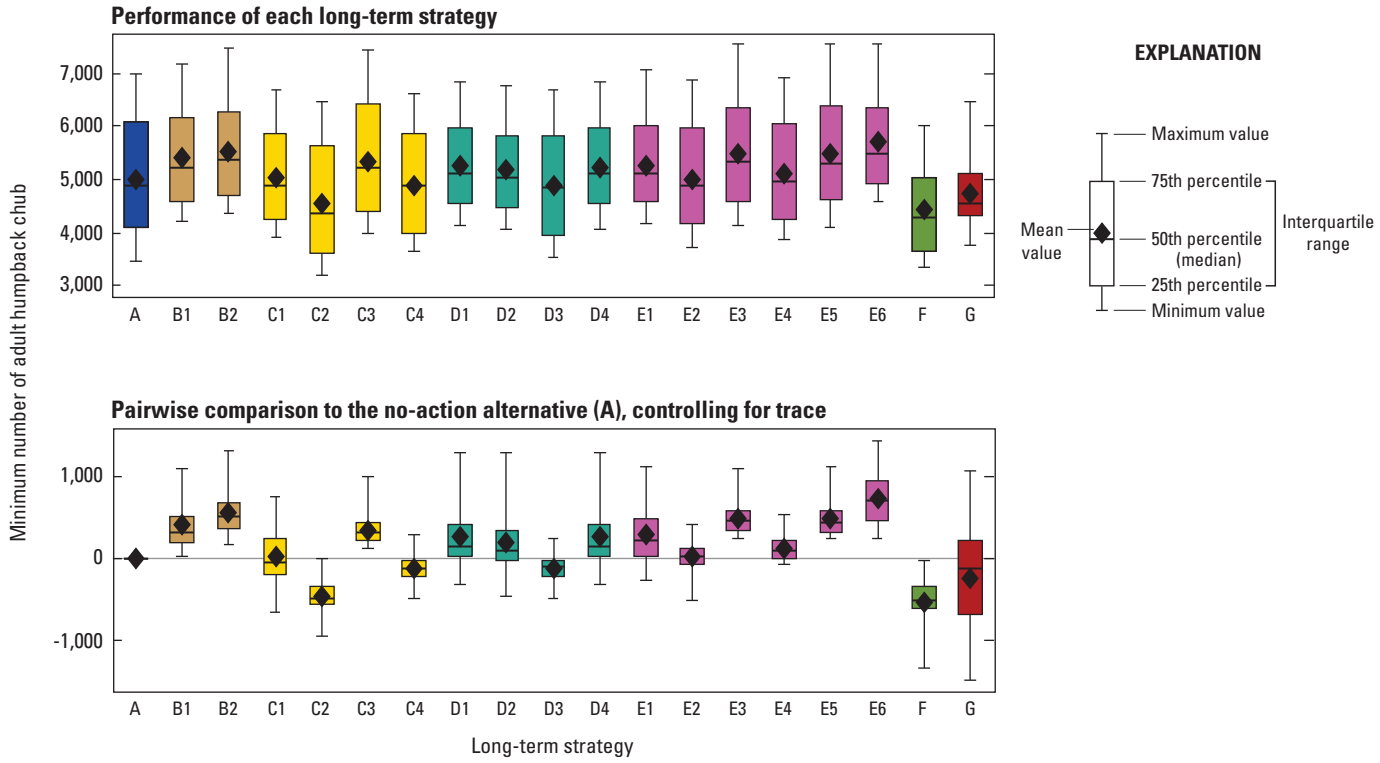

Figure 4. Minimum number of adult humpback chub (performance metric 1) forecast for 19 long-term strategies with equal weighting of traces.

of information for resolvable uncertainty (the 16 scenarios) relative to the value of information for background environmental variation.

The value of information depends on the set of long-term strategies evaluated. The calculations just described assume the decision maker is choosing from the entire set of 19 long-term strategies. In practice, it is more likely that one of the alternatives would be chosen, and the long-term strategy would be chosen from within the set associated with that alternative. The value of information in resolving the critical uncertainties is 0 for all alternatives except Alternative C, which has a value of information of 8.5 adult HBC (table 6).

Temperature suitability for HBC was forecast at a number of locations in the main stem Colorado River, and in most cases the suitability was low (less than 0.03 on a scale of 0 to 1). At the two locations farthest downstream (Havasu Creek, RM 157; Pumpkin Spring, RM 213; fig. 1), the average suitability was around 0.1 (on a scale of 0 to 1). The temperature suitability for HBC was affected more by hydrology than by the long-term strategy; only Alternative F stood out from the other alternatives (fig. 5). Alternative G, with its year-round steady flows, provided the best suitability (mean 0.102); its ranking above the other long-term strategies was not affected by any of the critical uncertainties (table 6). There was a small effect of the hydrological trace on the ranking of alternatives based on temperature suitability (EVXI; 0.77 percent; table 6).

7.2 Rainbow Trout Fishery Results

The RBT performance metrics differed substantially across long-term strategies (figs. 6–8). The RBT catch rate (performance metric 3) and RBT emigration rate (performance metric 4) were highly correlated with one another because both were driven by the RBT population size. Catch rate and emigration rate were highest for those long-term strategies that implemented many HFEs but did not allow TMFs (C2, C4, D3, E2, and F) or that provided steady flows that supported RBT recruitment (G) (figs. 6–7). The abundance of high-quality RBT (greater than 16 inches in length, performance metric 5) was negatively correlated with RBT population size; the best long-term strategies were those that restricted or did not allow HFEs (B1, B2, C3, E3, E5, E6) (fig. 8).

Apart from the HBC metric when only the strategies under Alternative C were considered, the RBT performance metrics were the only ones affected by the critical uncertainties; the fall HFE hypothesis had an EVXI of 0.26 percent, 3.50 percent, and 0.98 percent for the three performance metrics, respectively (table 6). Across all performance metrics and all uncertainties, the strongest effect was the effect of the combined hydrological/sediment trace on the RBT catch rate with an EVXI of 7.53 percent (table 6). The uncertainty about the effectiveness of TMFs did not affect the top ranked long-term strategy for any of the trout or other performance metrics (table 6).

Table 4. Effect of critical uncertainty on minimum adult humpback chub population size (performance metric 1).

[The cell entries show the expected minimum humpback chub population size for each long-term strategy in each combination of hypotheses. The hypotheses are if high-flow experiments increase rainbow trout recruitment (N, no; Y, yes), how effective rainbow trout management flows are (H, high effectiveness; L, low effectiveness), and the relative effects of temperature and rainbow trout on juvenile humpback chub survival and growth (f1, f2, g1, and g2). A solid dot (●) indicates the result is averaged over this uncertainty. The highlighted long-term strategy is the best performing alternative in each row. HFE, high-flow experiments; TMF, trout management flow; RBT, rainbow trout]

Fall HFE	TMF	Model	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
N	H	f1	5,204	5,712	5,858	5,463	4,766	5,408	5,402	5,655	5,576	5,174	5,645	5,839	5,500	5,580	5,574	5,572	5,900	4,409	5,082
N	H	f2	5,116	5,413	5,520	5,268	4,772	5,253	5,246	5,324	5,275	5,050	5,318	5,482	5,298	5,357	5,352	5,351	5,521	4,545	5,028
N	H	g1	5,195	5,774	5,941	5,430	4,632	5,377	5,372	5,655	5,556	5,116	5,646	5,874	5,500	5,597	5,593	5,582	5,947	4,184	5,042
N	H	g2	5,135	5,396	5,486	5,324	4,901	5,303	5,295	5,368	5,329	5,125	5,359	5,493	5,327	5,375	5,369	5,376	5,527	4,773	5,078
N	L	f1	5,204	5,653	5,799	5,251	4,766	5,408	5,402	5,439	5,367	5,003	5,432	5,790	5,500	5,580	5,574	5,572	5,857	4,409	4,803
N	L	f2	5,116	5,382	5,487	5,132	4,772	5,253	5,246	5,214	5,168	4,959	5,209	5,457	5,298	5,357	5,352	5,351	5,500	4,545	4,855
N	L	g1	5,195	5,710	5,877	5,189	4,632	5,377	5,372	5,420	5,332	4,931	5,415	5,822	5,500	5,597	5,593	5,582	5,902	4,184	4,739
N	L	g2	5,135	5,367	5,457	5,206	4,901	5,303	5,295	5,265	5,228	5,036	5,257	5,470	5,327	5,375	5,369	5,376	5,507	4,773	4,922
Y	H	f1	4,803	5,340	5,538	4,824	4,210	5,408	4,365	5,266	5,179	4,781	5,258	4,936	4,608	5,580	4,727	5,572	5,900	4,352	4,603
Y	H	f2	4,870	5,193	5,327	4,878	4,412	5,253	4,559	5,104	5,051	4,820	5,100	4,948	4,715	5,357	4,808	5,351	5,521	4,494	4,709
Y	H	g1	4,748	5,349	5,578	4,720	4,038	5,377	4,232	5,214	5,111	4,680	5,208	4,861	4,496	5,597	4,643	5,582	5,947	4,126	4,549
Y	H	g2	4,916	5,201	5,317	4,974	4,571	5,303	4,679	5,168	5,124	4,914	5,161	5,019	4,814	5,375	4,886	5,376	5,527	4,726	4,762
Y	L	f1	4,803	5,280	5,475	4,639	4,210	5,408	4,365	5,015	4,939	4,575	5,010	4,880	4,608	5,580	4,727	5,572	5,857	4,352	4,364
Y	L	f2	4,870	5,159	5,291	4,755	4,412	5,253	4,559	4,972	4,924	4,702	4,969	4,913	4,715	5,357	4,808	5,351	5,500	4,494	4,557
Y	L	g1	4,748	5,282	5,509	4,521	4,038	5,377	4,232	4,950	4,860	4,472	4,947	4,801	4,496	5,597	4,643	5,582	5,902	4,126	4,292
Y	L	g2	4,916	5,170	5,285	4,864	4,571	5,303	4,679	5,042	5,001	4,793	5,036	4,988	4,814	5,375	4,886	5,376	5,507	4,726	4,621
Grand mean																					
●	●	●	4,991	5,392	5,541	5,016	4,527	5,335	4,874	5,247	5,181	4,876	5,241	5,269	5,015	5,477	5,103	5,470	5,708	4,450	4,741
Effect of fall HFE hypotheses																					
N	●	●	5,162	5,551	5,678	5,283	4,768	5,335	5,328	5,417	5,354	5,049	5,410	5,653	5,406	5,477	5,472	5,470	5,708	4,478	4,943
Y	●	●	4,835	5,247	5,415	4,772	4,308	5,335	4,459	5,091	5,024	4,717	5,086	4,918	4,658	5,477	4,766	5,470	5,708	4,424	4,557
Effect of TMF hypotheses																					
●	H	●	4,991	5,415	5,565	5,098	4,527	5,335	4,874	5,337	5,268	4,950	5,330	5,290	5,015	5,477	5,103	5,470	5,724	4,450	4,847
●	L	●	4,991	5,368	5,516	4,933	4,527	5,335	4,874	5,157	5,094	4,801	5,152	5,248	5,015	5,477	5,103	5,470	5,691	4,450	4,636
Effect of temperature and RBT hypotheses																					
●	●	f1	4,995	5,488	5,660	5,030	4,475	5,408	4,859	5,334	5,256	4,874	5,327	5,340	5,034	5,580	5,131	5,572	5,878	4,379	4,702
●	●	f2	4,987	5,281	5,402	5,000	4,584	5,253	4,887	5,148	5,099	4,877	5,144	5,188	4,993	5,357	5,067	5,351	5,510	4,518	4,780
●	●	g1	4,961	5,519	5,718	4,949	4,322	5,377	4,776	5,299	5,204	4,789	5,293	5,316	4,975	5,597	5,096	5,582	5,925	4,154	4,645
●	●	g2	5,021	5,279	5,382	5,084	4,728	5,303	4,972	5,206	5,166	4,962	5,199	5,232	5,059	5,375	5,117	5,376	5,517	4,748	4,839

Table 5. Effect of hydrological trace on minimum adult humpback chub population size (performance metric 1).

[The cell entries show the expected minimum adult humpback chub population size for each long-term strategy, under each hydrological trace, averaged over the sediment traces and critical uncertainties. The bottom row shows the mean over the hydrological traces. The highlighted long-term strategy is the best performing alternative in each row. The best strategy in the face of uncertainty has an expected minimum population size of 5,708; the expected minimum population size if the hydrological trace could be known before the strategy was selected is 5,725 (average of the highlighted cells). Thus, the expected value of information, for resolving uncertainty about the future hydrology, is an increase of 17 adults in the minimum humpback chub population.]

Trace	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
h00	3,680	4,570	4,575	4,258	3,286	4,113	3,772	4,616	4,574	3,732	4,617	4,615	3,875	4,252	3,986	4,182	4,887	3,419	4,326
h01	3,789	4,804	4,812	4,279	3,284	4,050	3,670	4,692	4,613	3,740	4,692	4,708	3,779	4,182	3,892	4,136	5,038	3,357	4,519
h02	3,742	4,403	4,406	3,991	3,304	3,964	3,656	4,372	4,325	3,609	4,370	4,344	3,820	4,131	3,936	4,085	4,592	3,391	4,155
h03	4,035	4,325	4,434	4,007	3,476	4,307	3,959	4,306	4,206	3,909	4,287	4,402	4,197	4,576	4,266	4,610	4,837	3,493	4,208
h04	5,047	5,443	5,591	4978	4,401	5,345	4,892	5,083	5,026	4,930	5,071	5,147	4,944	5,455	5,076	5,450	5,639	4,430	4,674
h05	6,386	6,619	6,901	6,166	5,940	6,873	6,164	6,234	6,152	6,126	6,236	6,318	6,335	6,998	6,433	7,008	6,998	5,767	5,226
h06	4,200	4,497	4,794	4,048	3,726	4,563	4,102	4,324	4,258	4,097	4,292	4,242	4,240	4,735	4,330	4,739	4,735	3,664	3,918
h07	4,206	4,386	4,555	4,274	3,972	4,618	4,207	4,445	4,347	4,245	4,445	4,535	4,448	4,857	4,518	4,857	4,918	3,765	4,421
h08	5,176	5,303	5,378	4,988	4,733	5,364	5,064	5,317	5,278	5,165	5,323	5,262	5,274	5,523	5,304	5,543	5,523	4,364	4,831
h09	5,435	5,561	5,726	5,297	5,193	5,580	5,269	5,746	5,704	5,528	5,730	5,486	5,414	5,714	5,453	5,703	5,713	4,864	4,953
h10	6,053	6,160	6,258	6,036	5,913	6,413	6,049	6,035	5,970	5,900	6,030	5,984	5,976	6,362	6,048	6,377	6,362	5,792	5,433
h11	6,788	7,118	7,349	6,630	6,365	7,433	6,577	6,710	6,646	6,551	6,735	6,792	6,802	7,544	6,867	7,553	7,544	6,003	5,526
h12	6,310	6,560	6,677	5,854	5,580	6,628	5,879	6,048	5,930	5,906	6,040	6,242	6,200	6,967	6,314	6,998	6,970	5,035	5,052
h13	4,511	4,965	5,111	4,567	4,005	4,868	4,372	4,657	4,614	4,350	4,673	4,791	4,565	5,080	4,643	5,071	5,340	4,026	4,107
h14	4,120	5,185	5,313	4,644	3,663	4,391	4,045	5,029	4,986	3,931	4,991	4,828	4,151	4,513	4,236	4,479	5,166	3,713	4,436
h15	4,130	4,543	4,715	4,097	3,601	4,368	3,981	4,256	4,160	4,024	4,186	4,342	4,011	4,458	4,124	4,442	4,745	3,668	4,202
h16	5,013	5,313	5,674	5,172	4,716	5,772	5,186	5,229	5,159	4,966	5,218	5,292	5,135	5,682	5,201	5,679	5838	4,761	4,568
h17	4,994	5,213	5,375	4,948	4,615	5,210	4,942	5,347	5,281	5,079	5,347	5,221	5,036	5,317	5,099	5,309	5,471	4,638	4,938
h18	6,419	6,586	6,692	6,192	5,814	6,653	6,201	6,476	6,432	6,328	6,489	6,503	6,457	6,803	6,505	6,818	6,857	5,905	6,009
h19	6,678	7,055	7,339	6,506	5,895	7,076	6,354	6,540	6,468	6,242	6,555	6,880	6,511	7,210	6,674	7,202	7,570	5,832	5,801
h20	4,098	4,617	4,678	4,395	3,590	4,450	4,004	4,721	4,675	4,027	4,725	4,710	4,150	4,659	4,254	4,629	5,117	3,559	4,267
Mean	**4,991**	**5,392**	**5,541**	**5,016**	**4,527**	**5,335**	**4,874**	**5,247**	**5,181**	**4,876**	**5,241**	**5,269**	**5,015**	**5,477**	**5,103**	**5,470**	**5,708**	**4,450**	**4,741**

Table 6. Expected value of information, by performance metric, for resolving critical uncertainty.

[See table 1 for a list of performance metrics. The best performance is the expected value of the performance metric across all uncertainties for the long-term strategy that maximized or minimized the performance metric. The value of perfectly resolving uncertainty across the 16 formal hypotheses about critical parameters is shown when all 19 long-term strategies are considered; only the two long-term strategies of alternative B are considered; and only the four, four, or six long-term strategies of alternatives C, D, and E are considered, respectively. Partial values of information are shown for resolving only the uncertainty about the effects of fall high-flow experiments on rainbow trout recruitment, efficacy of trout management flows, and effects of temperature and rainbow trout on humpback chub. Finally, the partial values of information are shown for resolving uncertainty about the combined hydrological-sediment trace, just the sediment trace, and just the hydrological trace. For the performance metrics not shown, all values of information were 0. min, minimum; HBC, humpback chub; TempSuit, temperature suitability index; Qual, quality; RBT, rainbow trout; WTSI, wind transport of sediment index; GC flow, Glen Canyon flow index; TOR, time-off-river index; CAI, camping area index; Veg, riparian vegetation index; SLI, sand load index; max, maximum; EVPI, expected value of perfect information; EVXI, expected value of partial information; HFE, high-flow experiment; TMF, trout management flow; ~, value less than 0.01 percent]

Performance metric	1	2	3	4	5	6	7	8	9	11	14	15	16
	minHBC	TempSuit	RBT Catch	Emigrate	Qual RBT	WTSI	GC flow	TOR	Power	CAI	Veg	SLI	Marsh
Desired direction	max	max	max	min	max	max	min	max	max	max	max	max	max
Best performance	5,708	0.102	3.367	22,415	956	0.465	18.4	0.840	150.41	0.451	3.954	0.576	1.101
Best action	E6	G	F	E6	E6	G	E3	G	B2	G	D4	G	E6
EVPI (16, all)	0.0	0.000	0.009	785	9.3	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVPI (16, B)	0.0	0.000	0.000	0	0.0	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVPI (16, C)	8.5	0.000	0.000	237	0.8	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVPI (16, D)	0.0	0.000	0.000	0	0.0	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVPI (16, E)	0.0	0.000	0.000	0	0.0	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVXI (fall HFE)	0.0	0.000	0.009	785	9.3	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVXI (TMF)	0.0	0.000	0.000	0	0.0	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVXI (HBC)	0.0	0.000	0.000	0	0.0	0.000	0.0	0.000	0.00	0.000	0.000	0.000	0.000
EVXI (traces)	19.0	0.001	0.254	1,033	8.4	0.003	0.9	0.001	0.35	0.007	0.224	0.021	0.035
EVXI (sediment)	0.0	0.000	0.000	37	0.0	0.000	0.0	0.000	0.00	0.000	0.012	0.000	0.000
EVXI (hydrology)	17.0	0.001	0.198	636	5.5	0.002	0.9	0.001	0.35	0.004	0.212	0.015	0.032
As a percent of the best performance													
EVPI (16, all), in percent	~	~	0.26	3.50	0.98	~	~	~	~	~	~	~	~
EVPI (16, B)	~	~	~	~	~	~	~	~	~	~	~	~	~
EVPI (16, C), in percent	0.15	~	~	1.06	0.09	~	~	~	~	~	~	~	~
EVPI (16, D)	~	~	~	~	~	~	~	~	~	~	~	~	~
EVPI (16, E)	~	~	~	~	~	~	~	~	~	~	~	~	~
EVXI (fall HFE), in percent	~	~	0.26	3.50	0.98	~	~	~	~	~	~	~	~
EVXI (TMF)	~	~	~	~	~	~	~	~	~	~	~	~	~
EVXI (chub)	~	~	~	~	~	~	~	~	~	~	~	~	~
EVXI (traces), in percent	0.33	1.39	7.53	4.61	0.88	0.59	4.78	0.10	0.23	1.63	5.66	3.57	3.20
EVXI (sediment), in percent	~	~	~	0.17	~	~	~	0.03	~	~	0.30	~	~
EVXI (hydrology), in percent	0.30	0.77	5.89	2.84	0.58	0.44	4.77	0.08	0.23	0.96	5.36	2.58	2.91

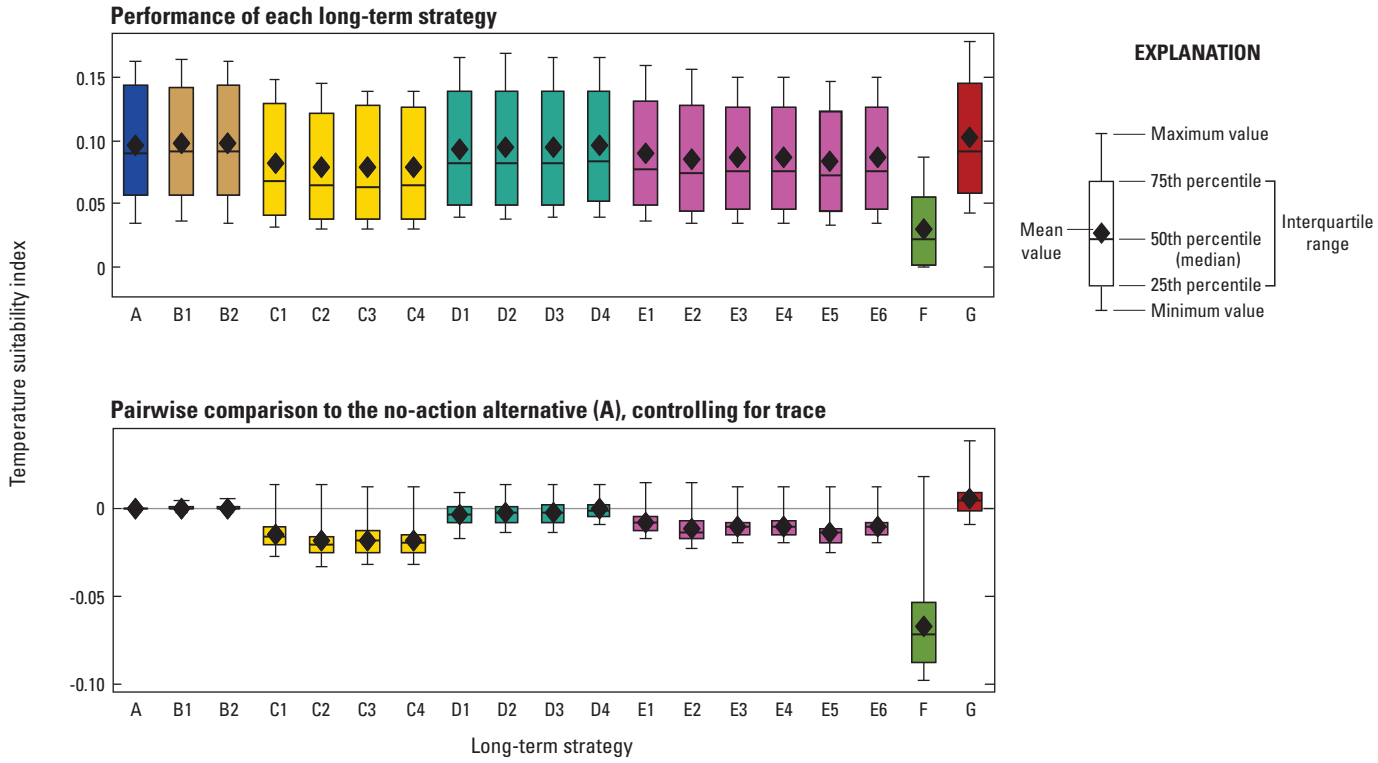

Figure 5. Temperature suitability index for humpback chub at river mile 157 and 213 (performance metric 2) forecast for 19 long-term strategies with equal weighting of traces.

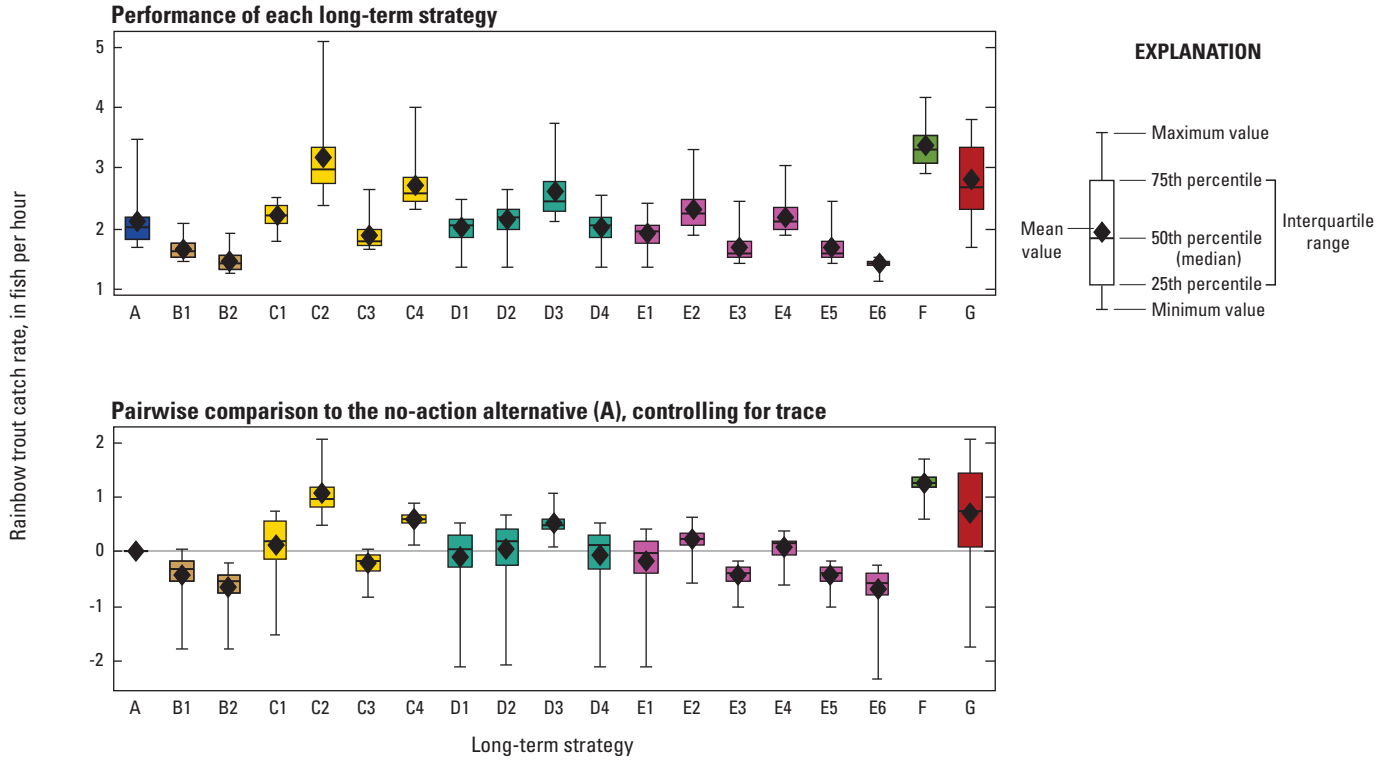

Figure 6. Rainbow trout catch rate (performance metric 3) forecast for 19 long-term strategies with equal weighting of traces.

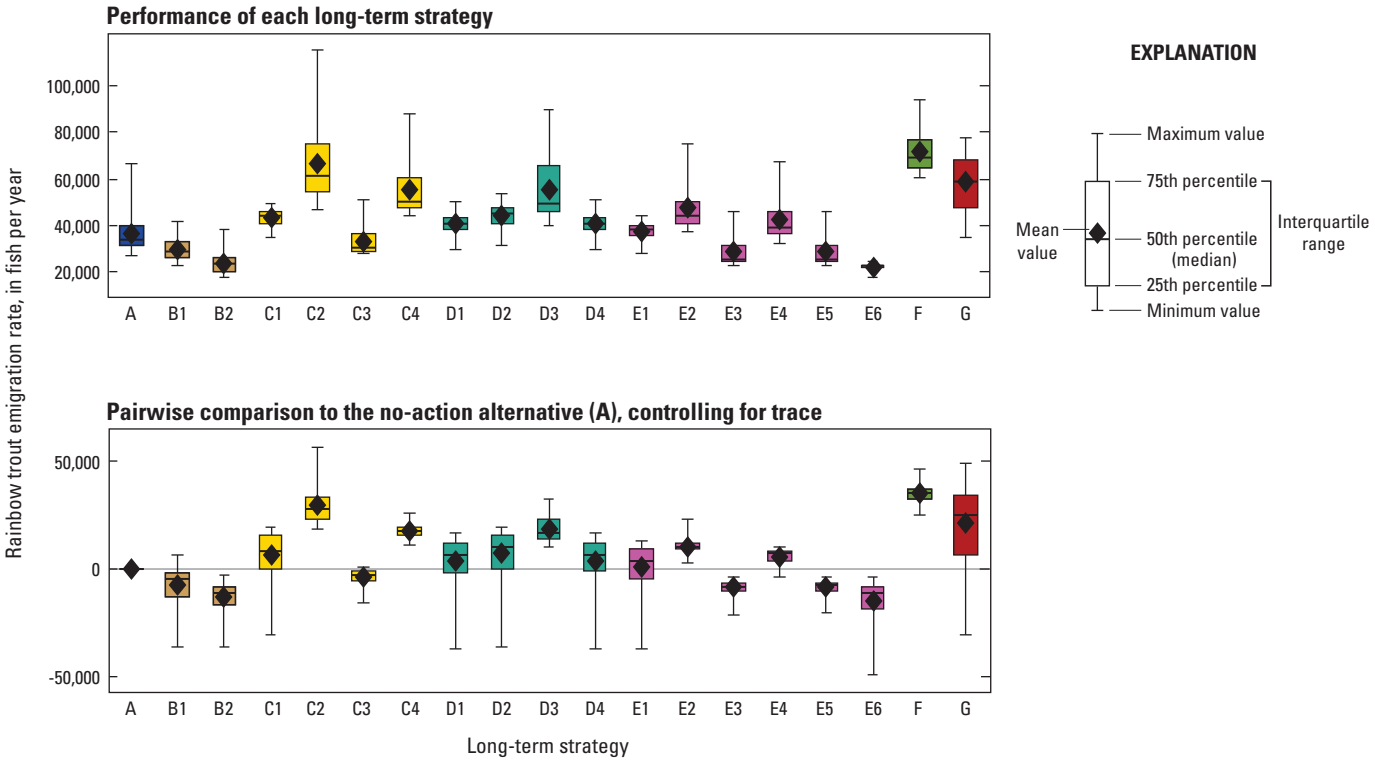

Figure 7. Rainbow trout emigration rate from Glen Canyon (performance metric 4) forecast for 19 long-term strategies with equal weighting of traces.

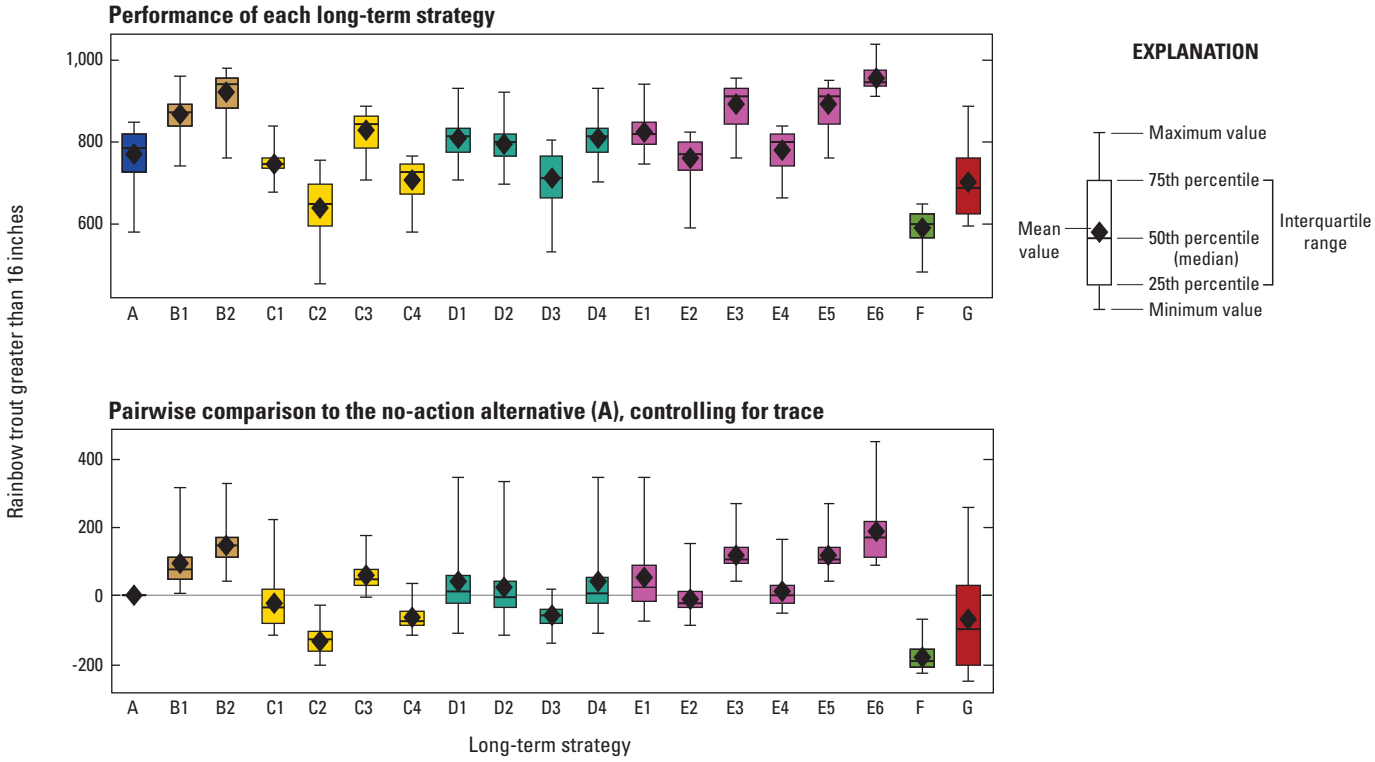

Figure 8. Abundance of high-quality rainbow trout (performance metric 5) forecast for 19 long-term strategies with equal weighting of traces.

7.3 Archeological and Cultural Resources Results

The protection of archeological and cultural resources was reflected in three performance metrics. The WTSI (performance metric 6) was largely driven by the SLI (performance metric 15) and was highest for those long-term strategies that implemented HFEs often (fig. 9). The best-performing alternative for WTSI was Alternative G (mean WTSI, 0.465); this ranking was not affected by any of the critical uncertainties or uncertainty in the sediment input (table 6). For some hydrological traces, long-term strategy C1 outperformed G, but the value of information related to hydrological uncertainty was small (0.44 percent).

The Glen Canyon flow index (performance metric 7) differed little among alternatives with a mean of around 20 days per year in which the flow exceeded 23,200 ft^3/s (fig. 10). Only Alternative F differed from the other long-term strategies (mean 36.8 days/year). The long-term strategies that did not allow HFEs (C3, E3, E5, and E6) had the best performance (smallest Glen Canyon flow index). The top ranking long-term strategy was not affected by critical uncertainty or sediment trace (table 6) but did vary depending on the hydrological trace (EVXI, 4.77 percent).

The time-off-river index (performance metric 8) was affected most strongly by the hydrological trace but was also weakly affected by the long-term strategy (fig. 11). Alternatives B and C were indistinguishable from Alternative A; Alternatives D, E, and G performed slightly better than Alternative A; and Alternative F performed noticeably worse because high flows during the peak rafting season allow quicker trips and more discretionary time at camping stops. Long-term strategies E1 and G were the best-performing strategies across hydrological and sediment traces, with only a small value of information associated with the trace uncertainty and no value of information associated with the critical uncertainties (table 6).

7.4 Hydropower Generation and Capacity Results

The best-performing long-term strategy for hydropower generation (performance metric 9) was B2, a long-term strategy designed to match power generation more closely to demand (fig. 12). For most of the long-term strategies, the annual value of hydropower generation is within $3 million of the value from Alternative A, except for Alternatives F and G for which annual generation is $6 million to $8 million less than Alternative A (fig. 12). The effect of hydrology on hydropower generation is much greater than the effect of the alternatives, with the average annual power generation over 20 years varying more than $60 million across hydrological traces (fig. 12). The dominance of B2 as the best long-term strategy for hydropower generation, however, is robust to uncertainty in hydrology with a value of information of only $350,000 per year (EVXI, 0.23 percent, table 6); for 4 out of 21 hydrological traces, long-term strategy E3 outranked B2.

The value of hydropower capacity (performance metric 10) was more sensitive to the choice of long-term strategy than hydropower generation with long-term strategies differing by nearly $20 million per year (fig. 13). Long-term strategy B2 was the best-performing strategy across all uncertainties, including hydrological trace. The long-term strategies in Alternative B outperformed Alternative A; all the remaining long-term strategies had a lower value of hydropower capacity than Alternative A (fig. 13). The value of capacity was somewhat sensitive to hydrological trace (the range of performance within a long-term strategy varied by $8 million to $17 million per year across hydrological traces), but the identification of the best-performing alternative was not (EVXI, 0).

7.5 Recreational Experience Results

The camping area index (performance metric 11), a metric composed from the SLI to represent beach formation and a flow factor to represent beach exposure, was highly correlated with the SLI (performance metric 18). The best-performing long-term strategies (especially C1, F, and G) include frequent implementation of HFEs; the worst-performing long-term strategies (for example, C3, E3, E5, and E6) do not permit HFEs (fig. 14). The identification of the top-ranked long-term strategy was affected by the combination of hydrological and sediment trace (EVXI, 1.96 percent) but not by any other uncertainties (table 6).

The fluctuation index (performance metric 12), which reflects the fraction of time the daily flow fluctuations are in a tolerable range for recreation, was highest for Alternatives F and G and lowest for Alternative B (fig. 15). Alternative D was comparable to Alternative A. The effect of the long-term strategies within an alternative was small compared to the effect of the base operations within each alternative. The fluctuation index was not strongly affected by any of the uncertainties, including hydrological trace.

The Glen Canyon rafting use metric (performance metric 13), which reflects the visitor-days lost per year because of HFEs, was best for those long-term strategies that did not permit HFEs (for example, C3, E3, E5, and E6) and worst for Alternative F (fig. 16). Under Alternative F, nearly 1,000 boat seats per year in Glen Canyon are expected to be lost because of HFEs. The rafting use metric showed variation as a result of hydrological trace, but the identification of the best-performing long-term strategies was not affected by any of the uncertainties.

7.6 Riparian Vegetation Results

The riparian vegetation index (performance metric 14) was the sum of four ratios that represented measures of different aspects of the vegetation community with a score of 4 indicating maintenance of current conditions.

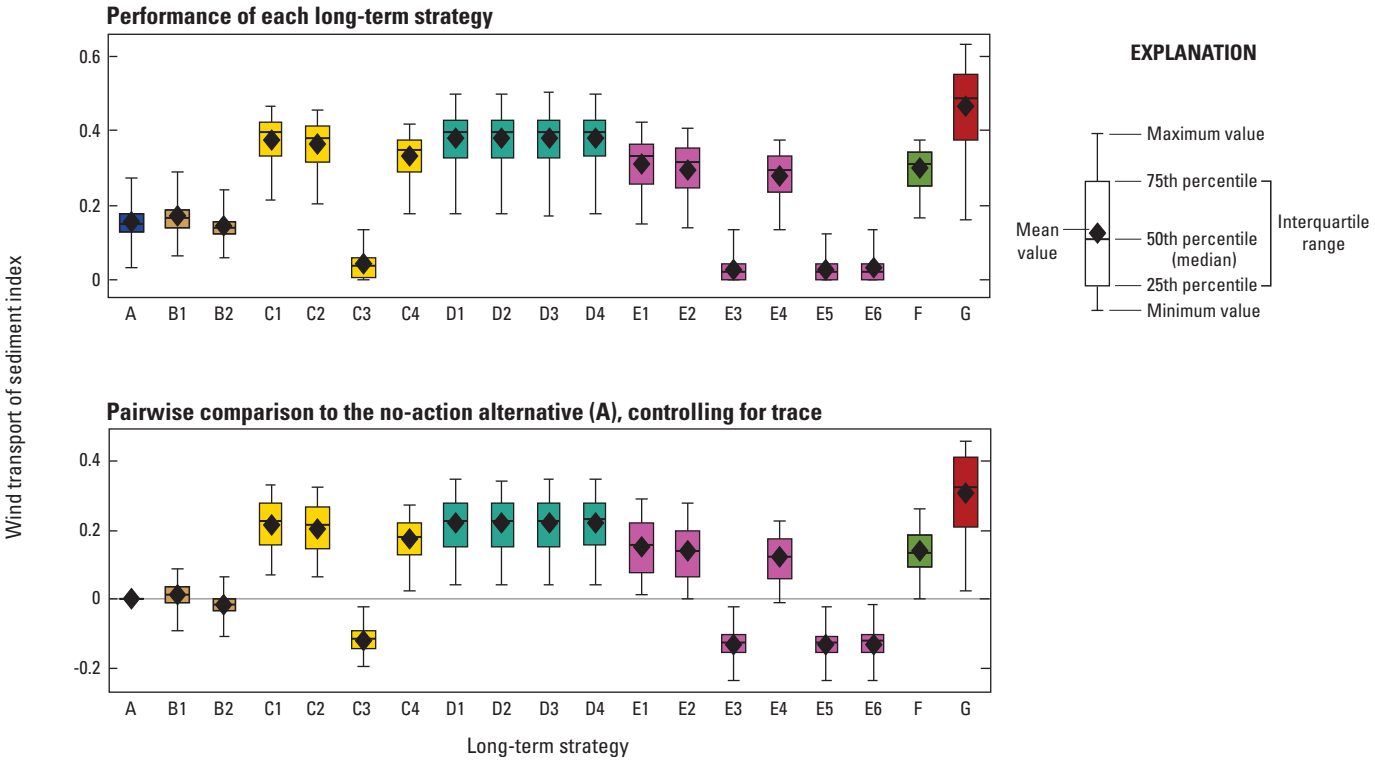

Figure 9. Wind transport of sediment index (performance metric 6) forecast for 19 long-term strategies with equal weighting of traces.

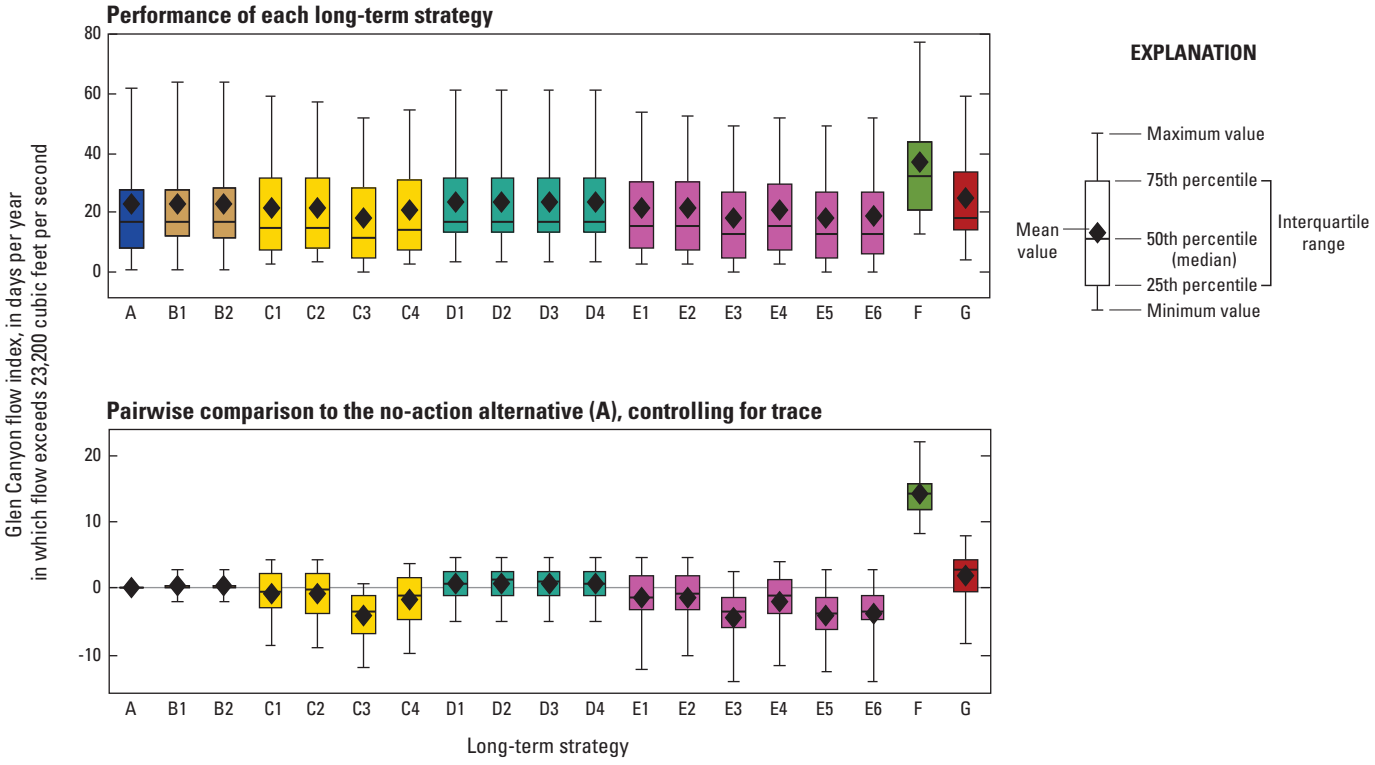

Figure 10. Glen Canyon flow index (performance metric 7) forecast for 19 long-term strategies with equal weighting of traces.

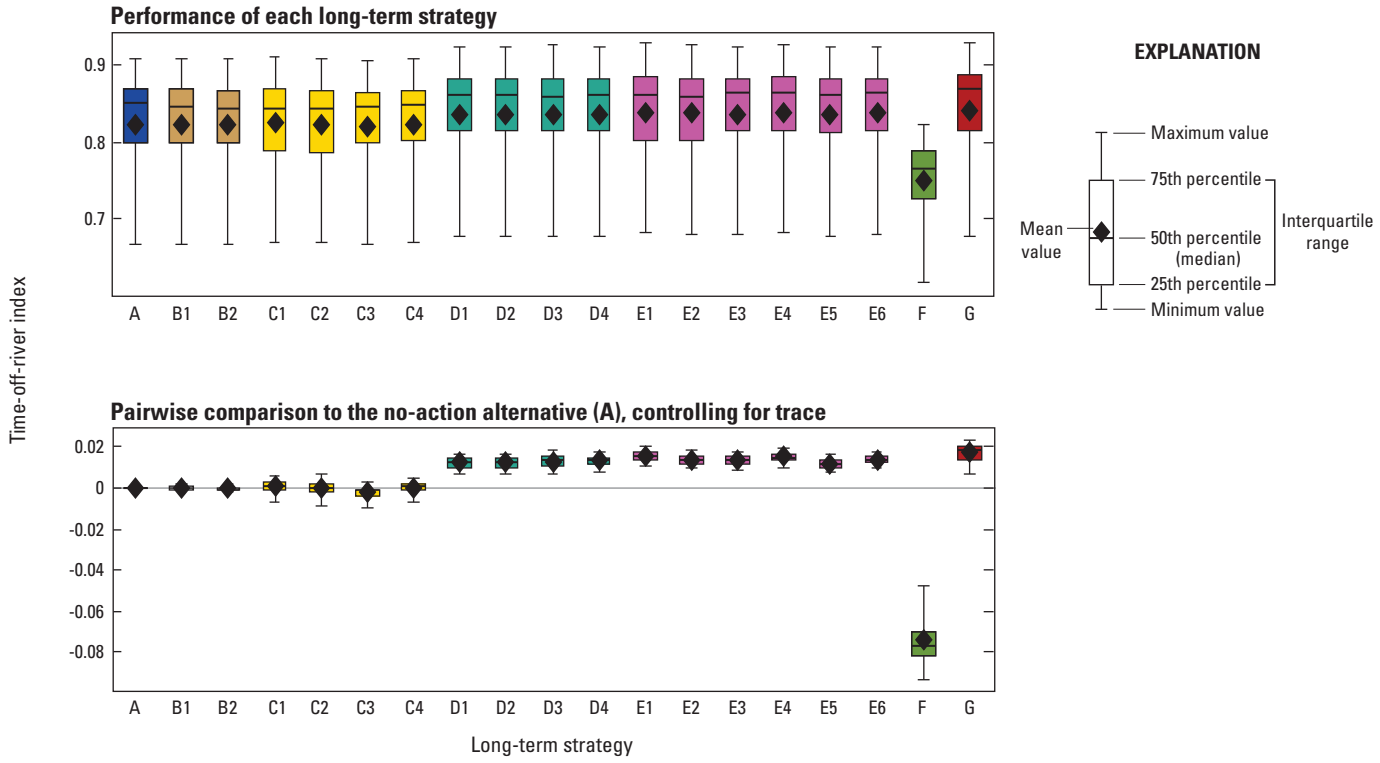

Figure 11. Cultural resources time-off-river index (performance metric 8) forecast for 19 long-term strategies with equal weighting of traces.

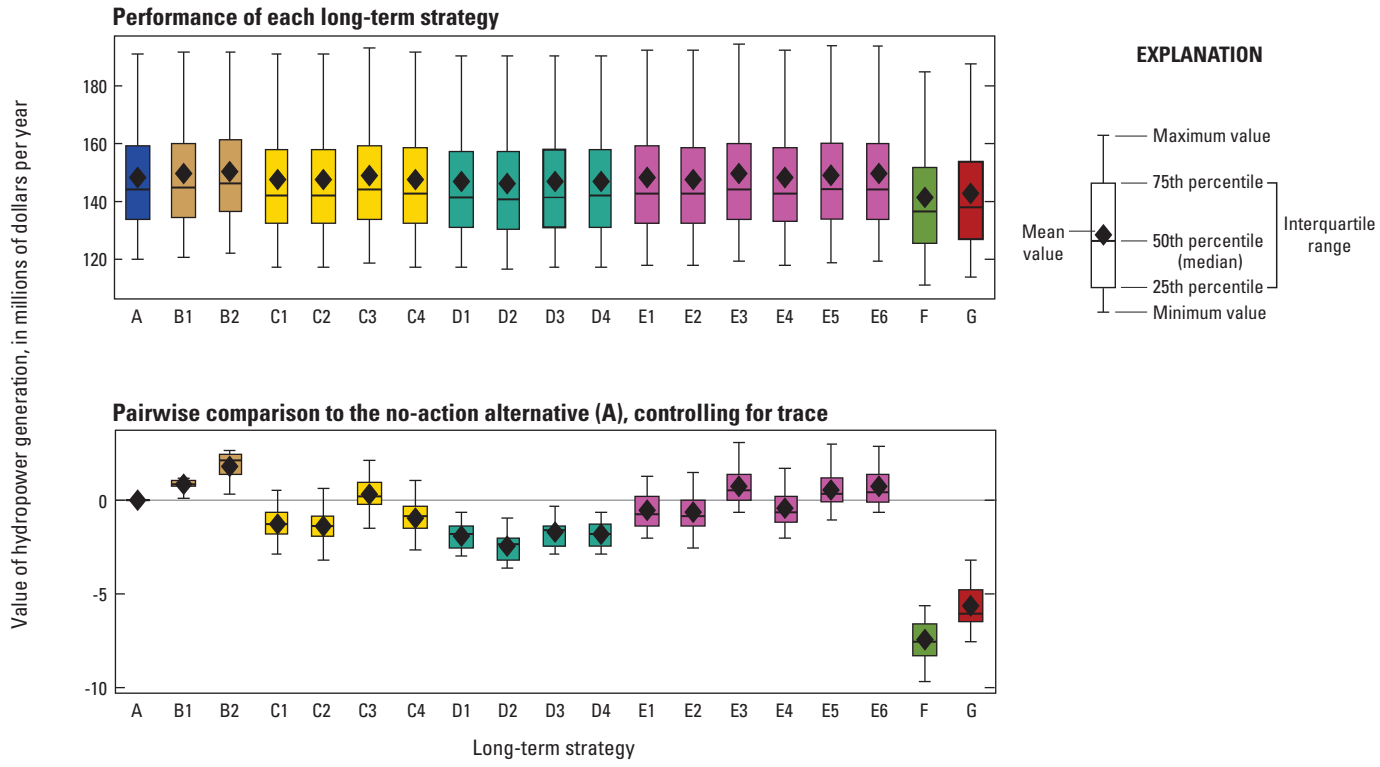

Figure 12. Annualized net present value of hydropower generation (performance metric 9) forecast for 19 long-term strategies with equal weighting of traces.

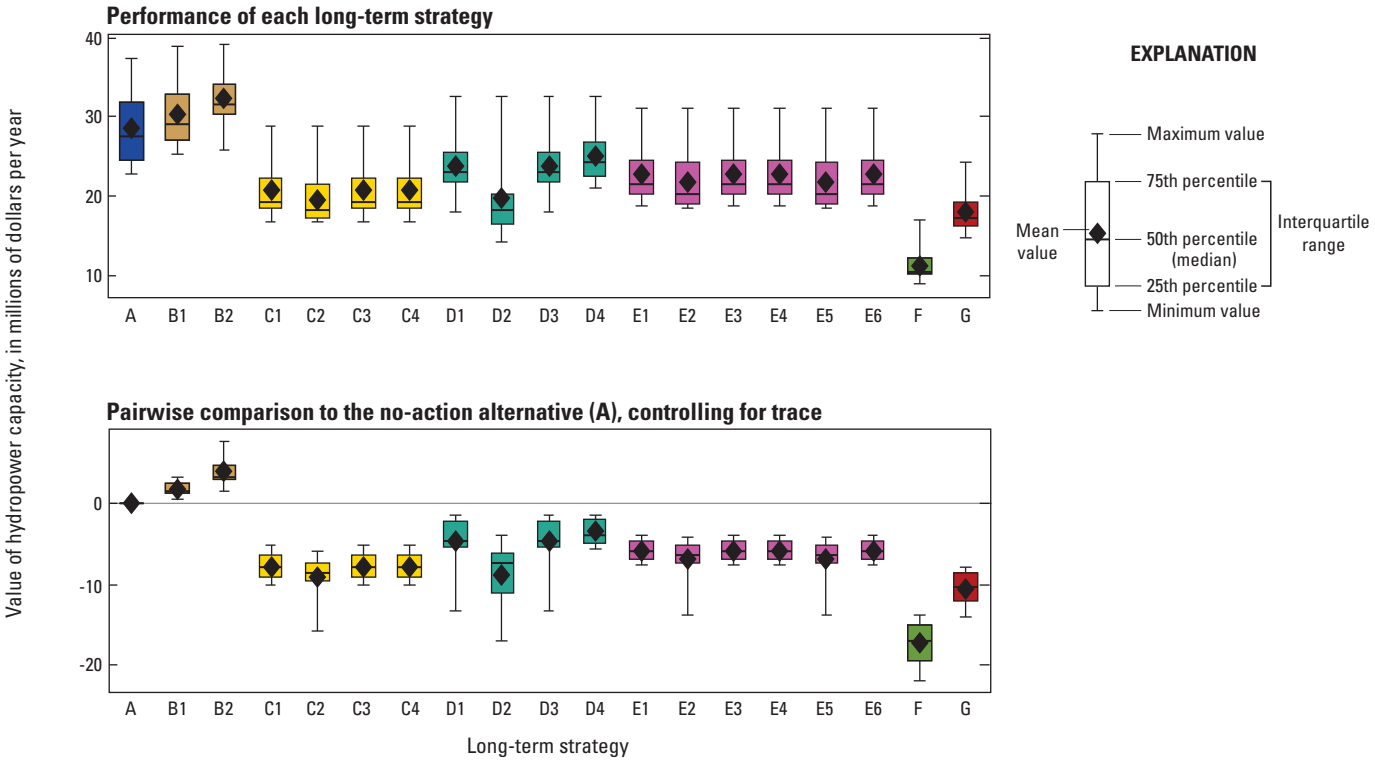

Figure 13. Annualized net present value of hydropower capacity (performance metric 10) forecast for 19 long-term strategies with equal weighting of traces.

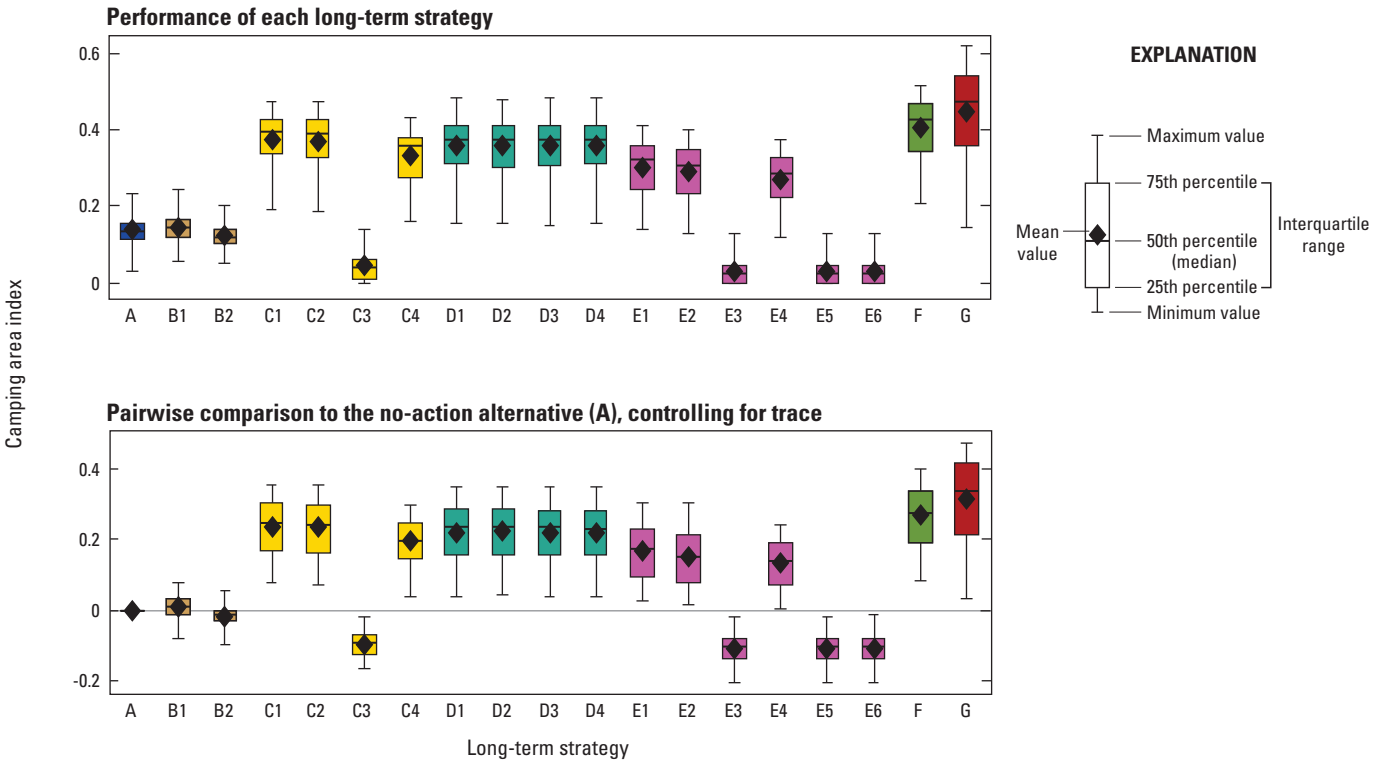

Figure 14. Camping area index (performance metric 11) forecast for 19 long-term strategies with equal weighting of traces.

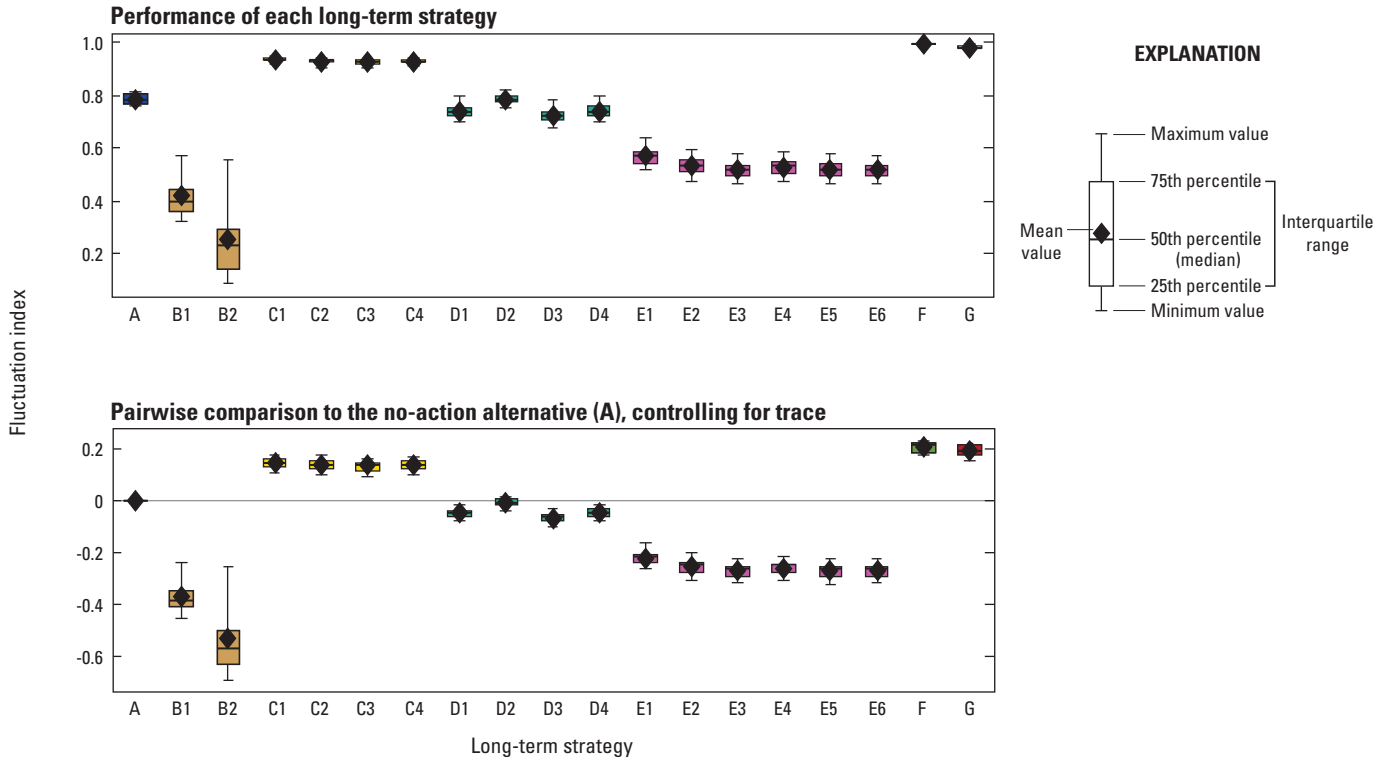

Figure 15. Fluctuation index (performance metric 12) forecast for 19 long-term strategies with equal weighting of traces.

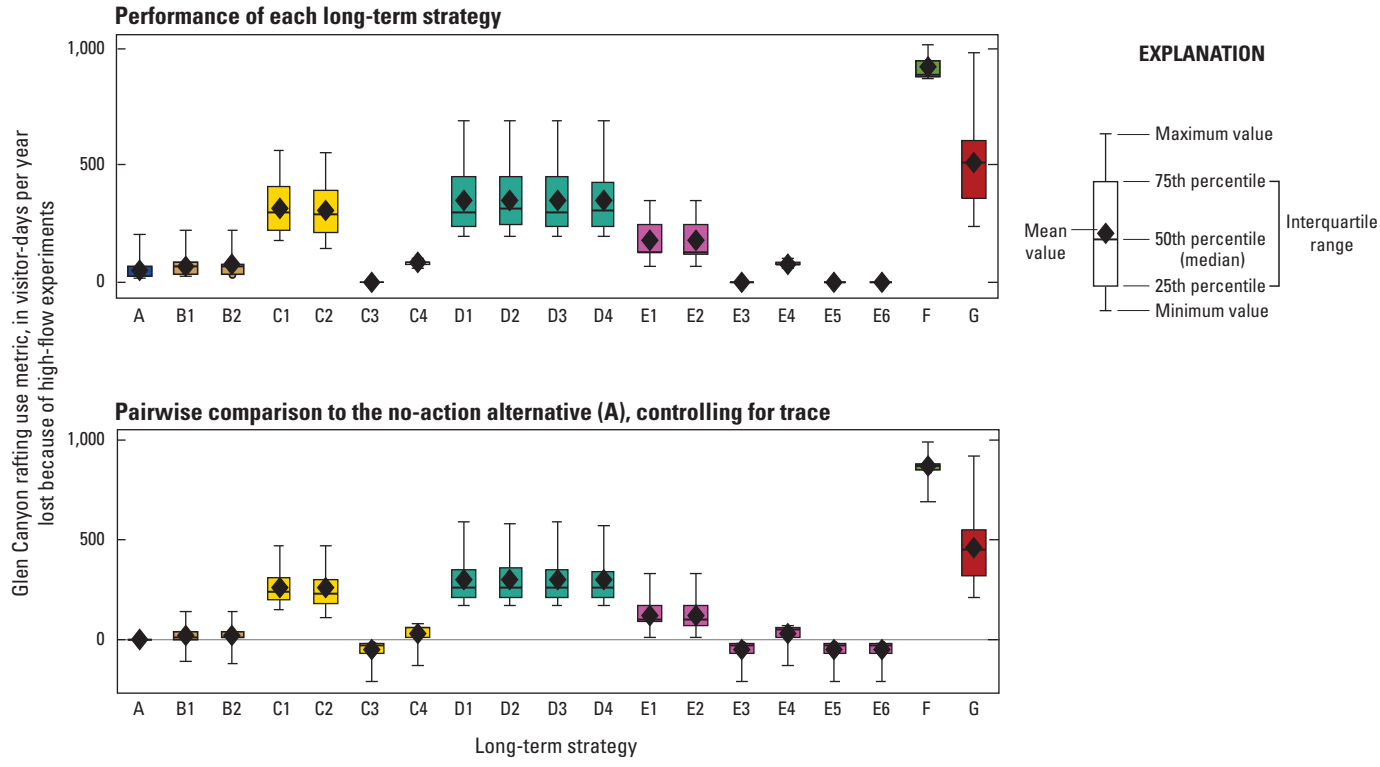

Figure 16. Glen Canyon rafting use metric (performance metric 13) forecast for 19 long-term strategies with equal weighting of traces.

The index ranged between 2 and 6 across alternatives and traces (fig. 17), indicating a 50-percent degradation or a 50-percent improvement in vegetation conditions, respectively. The highest mean vegetation index was associated with long-term strategy D4 (riparian vegetation index, 3.954), but 13 of the 19 long-term strategies were ranked first depending on the hydrological and sediment trace. The value of information for resolving uncertainty about the hydrological and sediment trace before committing to a long-term strategy was 0.224 (an improvement of 5.66 percent; table 6). The choice of the long-term strategy was not affected, however, by any of the critical uncertainties (table 6).

7.7 Sediment Results

The SLI (performance metric 15) measured the potential for sand bar formation by reporting the proportion of sand transported during flows greater than 31,500 ft^3/s. The SLI was most strongly affected by the frequency of HFEs; the long-term strategies with the highest SLI (especially C1, C2, D1, D2, F, and G) allowed frequent HFEs, and the long-term strategies with the lowest SLI (C3, E3, E5, and E6) did not permit HFEs (fig. 18). Uncertainty in the combination of hydrological and sediment trace did affect the ranking of the alternatives (EVXI, 3.57 percent; table 6) with 6 of the 19 long-term strategies favored in at least 1 trace.

7.8 Tribal Resources Results

Several performance metrics were developed to evaluate resources of specific importance from a tribal perspective. The marsh vegetation ratio (performance metric 16) forecast the preservation or expansion of the wetland vegetation communities along the Colorado River (fig. 19). For context, the current extent of marsh vegetation is 4.6 acres. The long-term strategy with the highest mean marsh vegetation ratio was E6 (mean marsh vegetation ratio, 1.101), representing about a 10-percent increase in marsh community area, but long-term strategy E3 was most commonly ranked first among the 63 traces. Alternatives C, F, and G exhibited consistent losses of marsh vegetation compared to Alternative A, whereas Alternatives D and E exhibited modest increases (fig. 19). The variance in the index induced by variation in hydrology was larger than the variance across alternatives (fig. 19). The value of information for resolving hydrological and sediment uncertainty before committing to a long-term strategy was 3.20 percent (table 6).

The frequency of mechanical removal (performance metric 17) was 0 for those long-term strategies that do not permit this management tool (C1, C2, E1, E2, E5, E6, and F) and varied between 0 and 6 years out of 20 for the other long-term strategies (fig. 20). For those long-term strategies that permitted mechanical removal, the frequency was influenced by the emigration rate of RBT from Glen Canyon (performance metric 4), which in turn was influenced by the frequency of HFEs. Because the long-term strategies with the lowest frequency were determined simply by whether mechanical removal was allowed or not, the identification of the top-ranked strategy was not influenced by any of the uncertainties.

The frequency of trout management flows (performance metric 18) was 0 for those long-term strategies that did not allow their use (10 out of the 19 long-term strategies) and varied between 0 and 20 years out of 20 for the remaining strategies (fig. 21). Under Alternative G, TMFs were triggered on average more than one-half of the years, and sometimes in all 20 years, depending on the hydrological trace. For the strategies that allowed TMFs, the frequency of their use was correlated with RBT abundance and, hence, with the RBT catch rate (performance metric 3) and emigration rate (performance metric 4). Again, because the long-term strategies with the lowest frequency of TMFs were determined by the admissible tools in the strategy, the value of information associated with the various uncertainties was 0.

7.9 Full Consequence Table

A summary of the performance of the 19 long-term strategies against the 18 performance metrics is represented in a consequence table (table 7). There is neither a single long-term strategy that performs best for all performance metrics (such a strategy would be shaded in yellow across the corresponding row), nor a single long-term strategy that performs worst for all performance metrics (such a strategy would be shaded dark blue across the row); furthermore, no long-term strategy is either consistently better or consistently worse than Alternative A across all performance metrics. Interestingly, the strategies that are worst for a number of performance metrics (for example, B2, C3, E5, F, and G) are also best for other performance metrics. Other long-term strategies are neither best nor worst on any performance metrics (for example, B1, C4, D1, D2). This pattern of performance indicates that there are important tradeoffs among the long-term strategies, and the best alternative cannot be identified without considering the relative value of the resource goals and performance metrics.

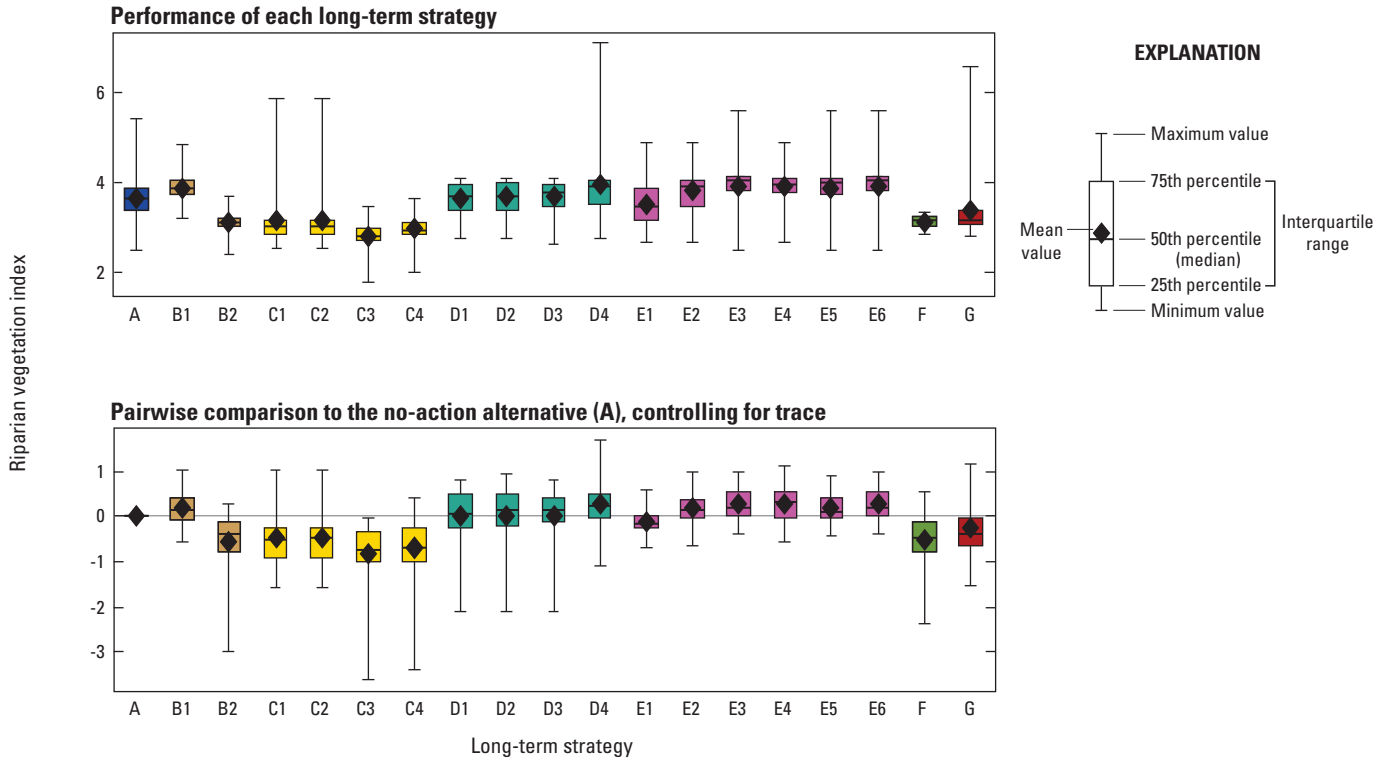

Figure 17. Riparian vegetation index (performance metric 14) forecast for 19 long-term strategies with equal weighting of traces.

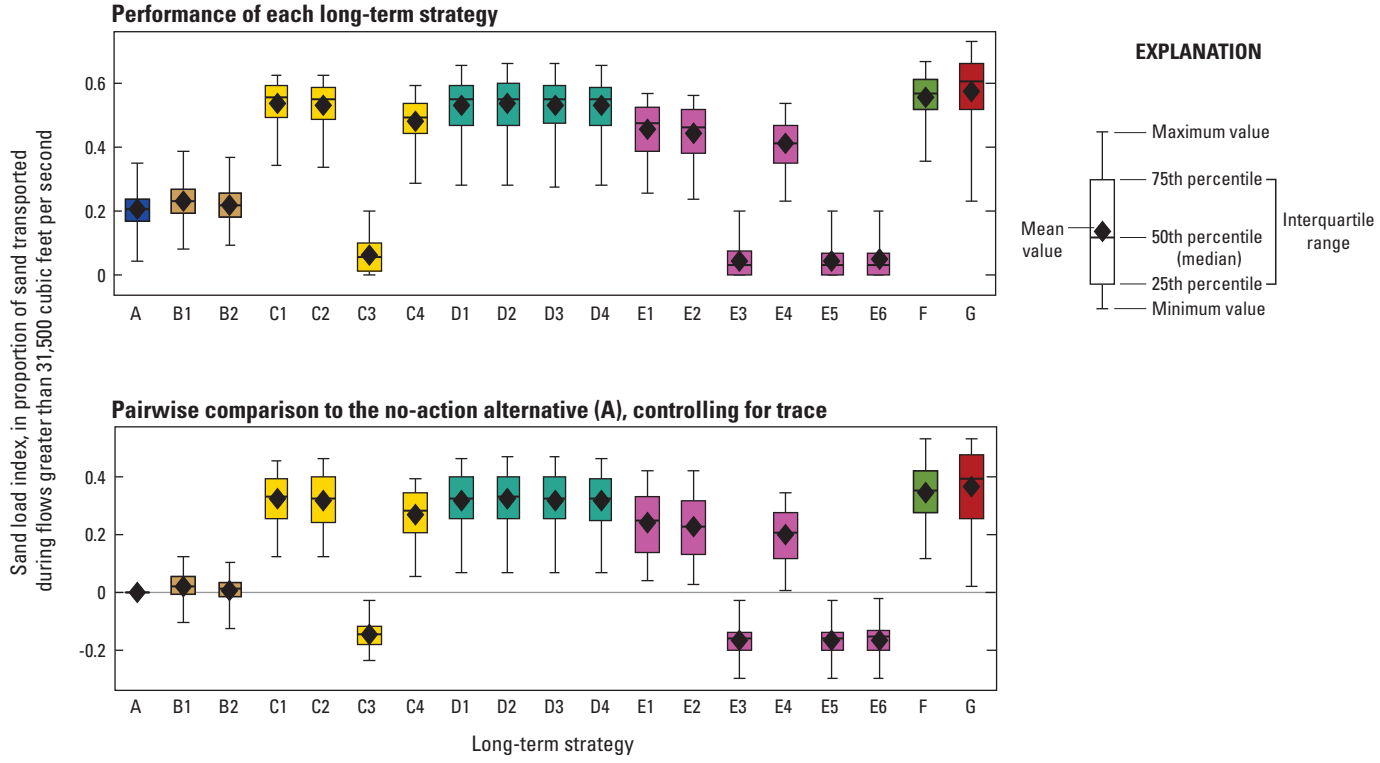

Figure 18. Sand load index (performance metric 15) forecast for 19 long-term strategies with equal weighting of traces.

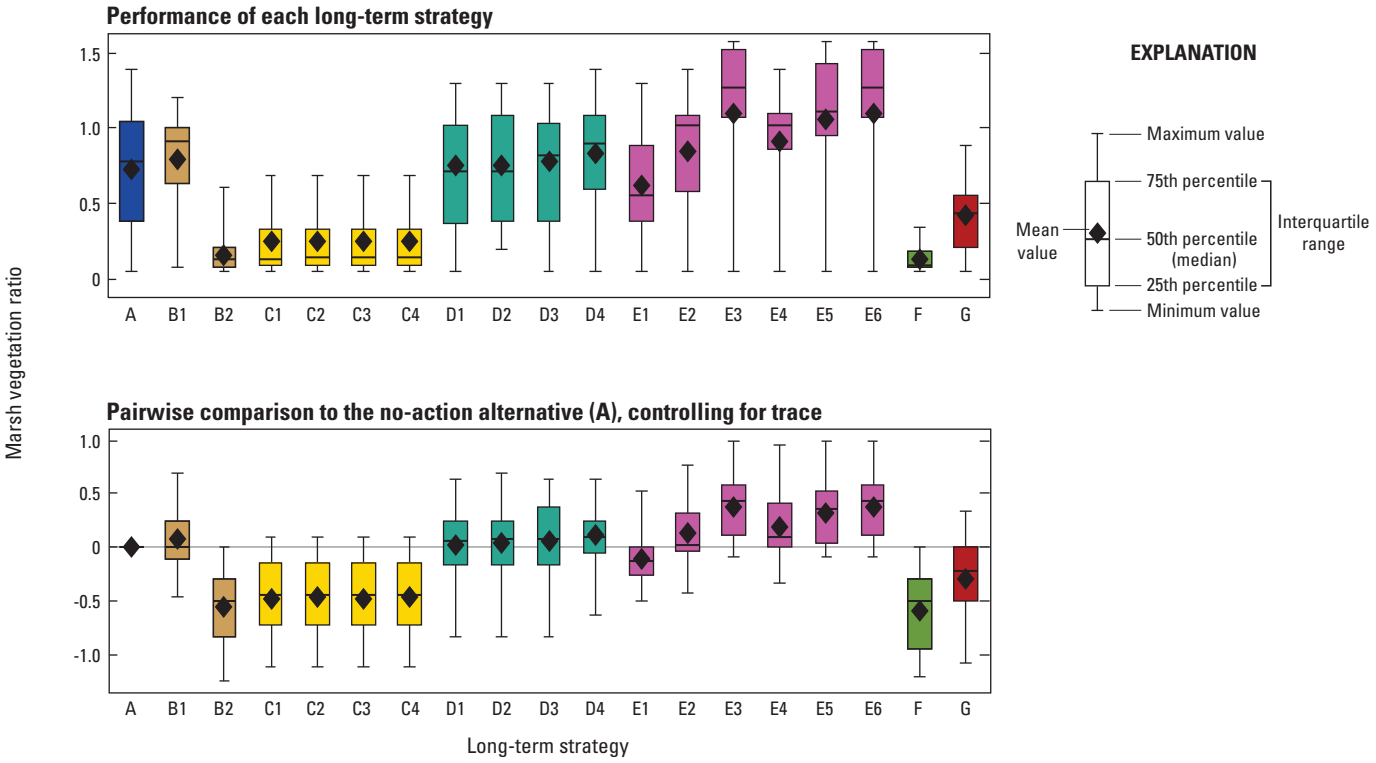

Figure 19. Marsh vegetation ratio (ratio of average marsh cover over 20-year period to current marsh cover, performance metric 16) forecast for 19 long-term strategies with equal weighting of traces.

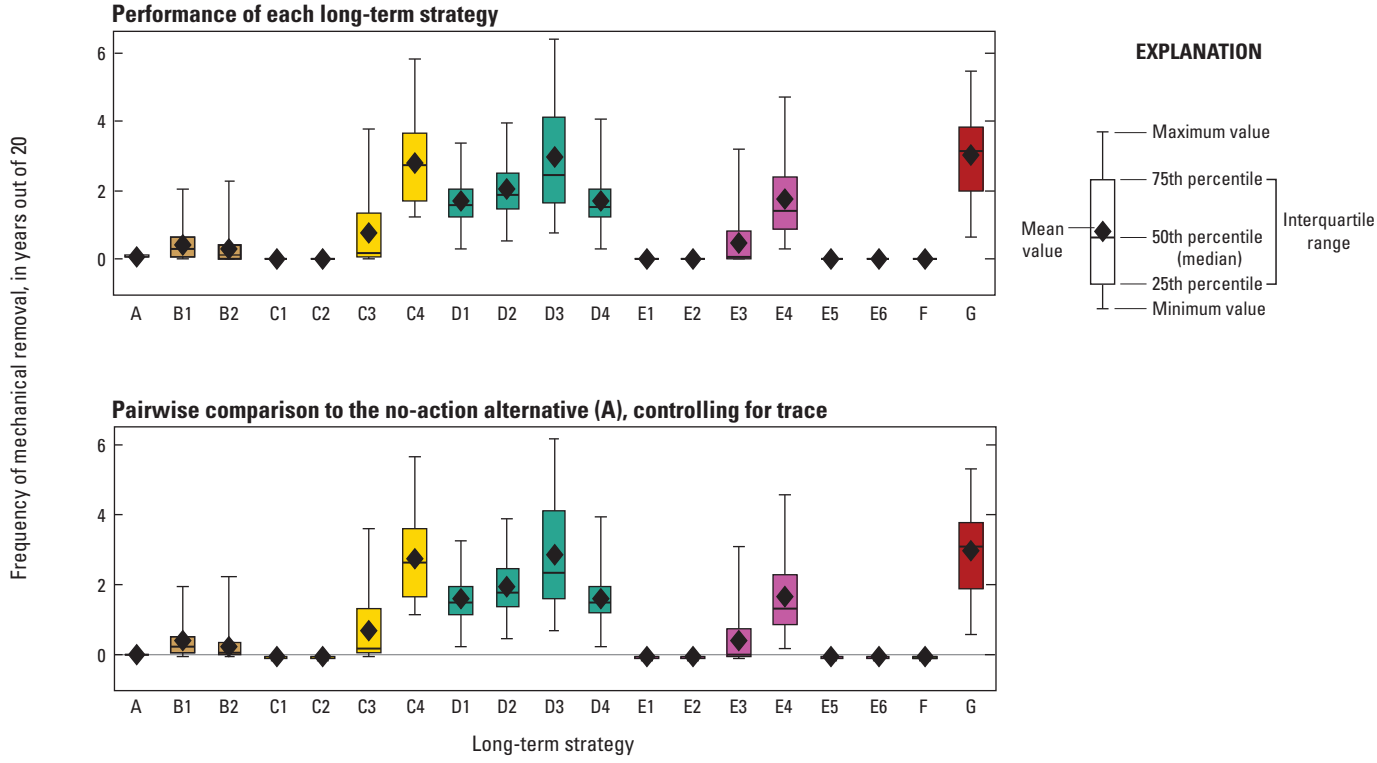

Figure 20. Frequency of mechanical removal (performance metric 17) forecast for 19 long-term strategies with equal weighting of traces.

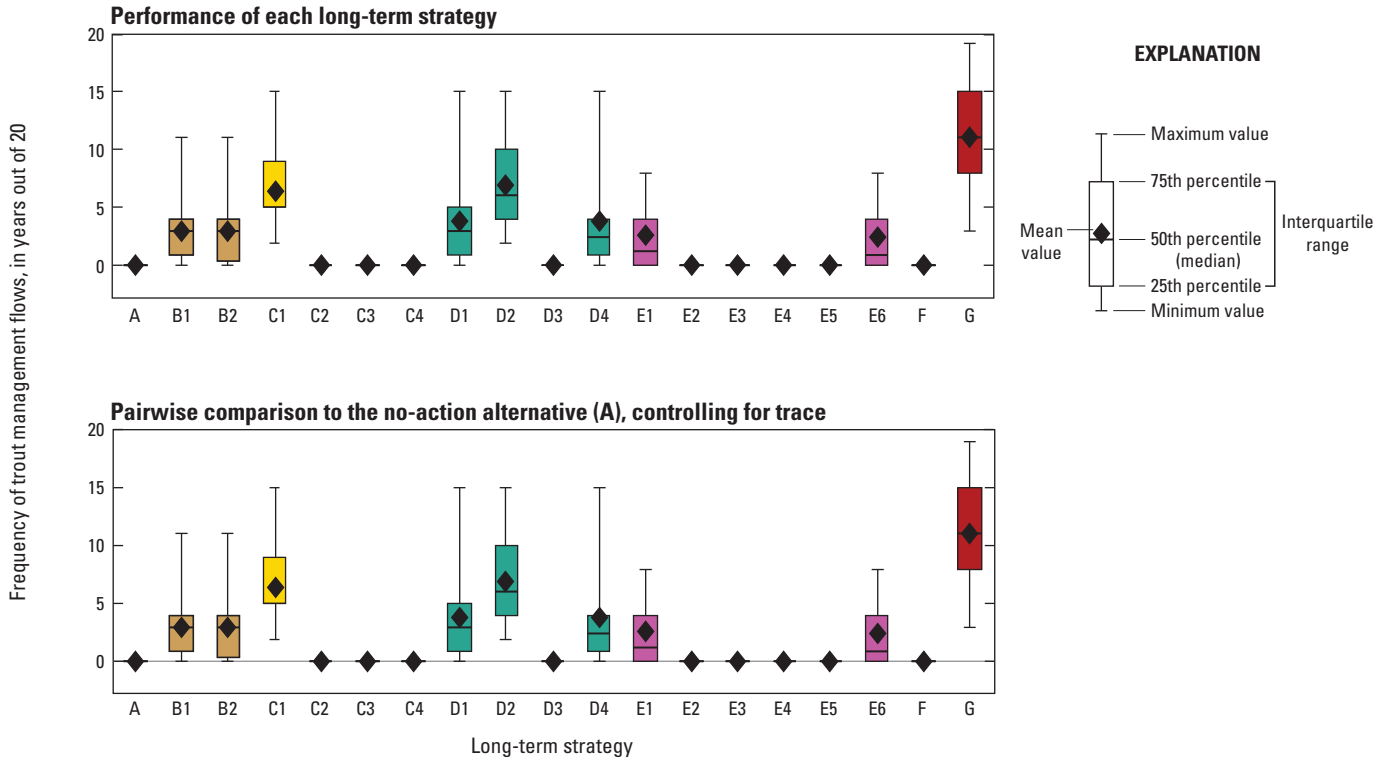

Figure 21. Frequency of trout management flows (performance metric 18) forecast for 19 long-term strategies with equal weighting of traces.

Table 7. Full consequence table showing the mean value of each performance metric for each long-term strategy.

[The columns are the performance metrics, numbered as in table 1. For most performance metrics, higher values are desired (yellow), but for five metrics, lower values are desired (pink). The rows are the long-term strategies. The values in each column are color-coded, with the best-performing long-term strategy shaded in yellow, the worst-performing long-term strategy shaded in dark blue, strategies that perform better than status quo (Alternative A) shaded in orange, and strategies that perform worse than status quo shaded in turquoise. HBC, humpback chub; TempSuit, temperature suitability index; RBT, rainbow trout; WTSI, wind transport of sediment index; GC flow, Glen Canyon flow index; TOR, time-off-river index; CAI, camping area index; FI, fluctuation index; GC raft, Glen Canyon rafting use metric; Veg, riparian vegetation index; SLI, sand load index; MR, mechanical removal; TMF, trout management flow]

Long-term strategy	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	HBC	Temp Suit	RBT Catch	RBT Emigrate	Quality RBT	WTSI	GC flow	TOR	Power	Cap.	CAI	FI	GC raft	Veg	SLI	Marsh	MR	TMF
	High	High	High	Low	High	High	Low	High	High	High	High	High	Low	High	High	High	Low	Low
A	4,991	0.097	2.11	36,699	769	0.159	22.7	0.823	148.5	28.5	0.139	0.786	49	3.66	0.211	0.72	0.07	0.0
B1	5,392	0.097	1.67	29,586	867	0.171	23.1	0.823	149.4	30.4	0.146	0.420	71	3.87	0.234	0.80	0.44	3.0
B2	5,541	0.097	1.46	24,172	920	0.144	23.1	0.823	150.4	32.4	0.122	0.256	72	3.12	0.222	0.17	0.30	3.1
C1	5,016	0.082	2.23	43,683	748	0.377	21.8	0.824	147.3	20.8	0.376	0.935	315	3.18	0.536	0.25	0.00	6.5
C2	4,527	0.079	3.18	66,890	640	0.365	21.8	0.823	147.2	19.5	0.371	0.929	307	3.18	0.534	0.25	0.00	0.0
C3	5,335	0.079	1.90	33,559	830	0.043	18.5	0.821	148.9	20.8	0.043	0.924	0	2.83	0.065	0.25	0.74	0.0
C4	4,874	0.079	2.72	55,076	707	0.334	21.0	0.823	147.6	20.8	0.335	0.928	83	2.98	0.483	0.25	2.80	0.0
D1	5,247	0.094	2.02	40,784	811	0.379	23.5	0.835	146.6	23.8	0.359	0.741	348	3.67	0.531	0.75	1.67	3.9
D2	5,181	0.095	2.15	43,981	796	0.378	23.6	0.835	146.1	19.6	0.360	0.784	351	3.69	0.535	0.76	2.02	6.9
D3	4,876	0.095	2.63	55,811	711	0.378	23.5	0.836	146.8	23.8	0.359	0.724	348	3.70	0.533	0.78	2.95	0.0
D4	5,241	0.097	2.03	40,936	810	0.380	23.5	0.836	146.7	25.1	0.358	0.741	348	3.95	0.529	0.84	1.69	3.8
E1	5,269	0.090	1.93	37,614	826	0.311	21.3	0.839	148.0	22.8	0.303	0.568	177	3.54	0.456	0.62	0.00	2.6
E2	5,015	0.086	2.33	47,450	761	0.297	21.3	0.837	147.9	21.8	0.292	0.534	174	3.84	0.443	0.85	0.00	0.0
E3	5,477	0.087	1.68	28,499	891	0.030	18.4	0.836	149.3	22.8	0.028	0.517	0	3.93	0.046	1.10	0.47	0.0
E4	5,103	0.087	2.19	42,806	781	0.281	20.9	0.838	148.1	22.8	0.272	0.529	79	3.93	0.415	0.91	1.73	0.0
E5	5,470	0.083	1.68	28,561	890	0.029	18.5	0.835	149.1	21.8	0.028	0.517	0	3.87	0.046	1.05	0.00	0.0
E6	5,708	0.087	1.42	22,415	956	0.032	18.8	0.837	149.3	22.8	0.030	0.518	0	3.93	0.049	1.10	0.00	2.4
F	4,450	0.030	3.37	71,869	592	0.299	36.8	0.749	141.0	11.2	0.406	0.997	919	3.14	0.558	0.14	0.00	0.0
G	4,741	0.102	2.81	58,533	702	0.465	24.7	0.840	142.9	18.0	0.451	0.981	512	3.40	0.576	0.42	3.05	11.0

8 Decision Analysis Results

The purposes of completing a formal decision analysis as a component of the evaluation in the LTEMP EIS was to explicitly examine the influence of the relative importance assigned to the resource goals on the ranking of the alternatives and long-term strategies, and to understand the effect of uncertainty on this same ranking. As described in section 3, "Decision Analysis," the two primary tools used to support this investigation were MCDA and the expected value of information.

8.1 Swing-Weighting Method and Results

The swing-weighting method (Winterfeldt and Edwards, 1986) was used to develop weights for the performance metrics, reflecting individual stakeholder expressions of the relative importance of those metrics. In April 2014, a 2-day workshop was held to present a preliminary analysis of the long-term strategies against the performance metrics to interested stakeholders. After discussion of the meaning and interpretation of each of the performance metrics, the stakeholders were given a swing-weighting response form with instructions (table 8) to complete within several weeks. The swing-weighting method asks a decision maker or stakeholder to consider each resource goal, the performance metric that reflects it, and the range over which the performance metric varies; and to compare the relative importance of the performance metrics by evaluating how valuable it would be to change the performance of an alternative from the worst score for a performance metric to the best score. The stakeholders were first asked to rank the performance metrics in this manner and then to assign a score between 0 and 100 to each metric to reflect a more nuanced interpretation of the ranking. Because it is difficult to evaluate 18 performance metrics simultaneously, and because there were natural groupings of the metrics, the swing-weighting exercise used a two-level structure. The 18 performance metrics were assigned to 8 higher-level groups (table 8). The stakeholders first ranked and scored the metrics within each group. Then, to rank and score the higher-level groups, the stakeholders were asked to think about the importance of changing the scores of all the metrics within a group for their worst levels to their best levels at the same time. While completing this exercise, the stakeholders had access to a preliminary consequence table (similar to table 7) and a spreadsheet that automatically calculated the weights on the performance metrics as the swing-weighting sheet was filled in.

A total of 27 Federal, State, tribal, and private agencies and organizations were invited to participate in the decision analysis by expressing their view of the relative importance of the performance metrics using the swing-weighting method (Winterfeldt and Edwards, 1986). The invitations were sent to agencies that were either members of AMWG or Cooperating Agencies for the LTEMP EIS; 14 agencies, including the 2 joint-lead agencies, elected to participate (table 9).

From the responses to the swing-weighting exercise, weights were calculated for the 18 performance metrics separately for each participating stakeholder. To compare these vectors of weights, principal components analysis was used to reduce the dimension of the comparison from 18 to 2. The first two principal components explained 52.6 percent of the variation in weights across stakeholders. The first principal component was positively correlated with the weight on the frequency of mechanical removal, SLI, WTSI, fluctuation index, and riparian vegetation index; and negatively correlated with hydropower generation and capacity (fig. 22*A*). The second principal component was positively correlated with HBC population size, Glen Canyon rafting use, and the camping area index; and negatively correlated with RBT emigration and the Glen Canyon flow index (fig. 22*A*). The differences among the participating stakeholders can then be plotted with these two components (fig. 22*B*). Representatives from the utility industry (CREDA, UAMPS, and SRP) tended to put more weight on the hydropower generation and capacity metrics than other stakeholders. The agencies concerned with management of the RBT fishery (International Federation of Fly Fishers [IFFF] and Arizona Game and Fish Department [AZGFD]) were in the middle of the spectrum on the first component but had strong positive values for the second component, reflecting an emphasis on HBC, high-quality RBT, and RBT catch rate. The FWS, Arizona Department of Water Resources (ADWR) and the Hopi, Hualapai, and Navajo Tribes placed relatively more emphasis on increasing vegetation and minimizing RBT emigration than other stakeholders. The principal components for two of the nongovernment organizations (Grand Canyon River Guides [GCRG] and National Parks Conservation Association [NPCA]) placed an emphasis on camping area index, SLI, and WTSI. Note that the joint-lead agencies (Reclamation and NPS) separately completed the swing-weighting exercise, and their separate weights were used as input to the principal components analysis, but they elected to average their weighting vectors for presentation and discussion. The joint-lead principal components fall near the center of the spectrum of stakeholders. Although some of these patterns compare well with the expressed views of the stakeholder agencies, others are harder to explain; it is important to note that the higher-order principal components still contained explanatory power, so not all the differences among agencies can be summarized with the first two components.

8.2 Multicriteria Decision Analysis

The weights on the performance metrics, unique to each agency, tribe, or organization, were combined with the consequence table to generate a weighted performance metric for each long-term strategy, allowing a comparison of the long-term strategies that integrates the differences in response across performance metrics and the relative value

Table 8. Swing-weighting response form.

[Stakeholder agencies were invited to share their perspectives on the relative importance of the resource goals and performance metrics using this swing-weighting exercise. The results were compiled to generate agency-specific weights on the performance metrics; GLCA, Glen Canyon National Recreation Area; GRCA, Grand Canyon National Park; min, minimum; M, million; B, billion; >, greater than; yr, year; hr, hour; #, number; TMF, trout management flow]

Agency:	
Participants:	

Goal	Performance metrics	Units	Desired direction	Worst case	Best case	Higher level		Sublevel	
						Rank	Score	Rank	Score
Humpback chub									
	Number of adult humpback chub (20-yr min)	# of adults	High	3,000	8,500				
	Temperature suitability index (river mile 157 and 213)	index (0–1)	High	0	0.20				
Rainbow trout fishery									
	Angler catch rate index	fish/angler-hr	High	1.0	5.0				
	Lees Ferry trout emigration estimate	trout/yr	Low	125,000	15,000				
	Number of trout > 16 inches total length	# fish	High	400	1,200				
Archaeological and cultural resources									
	Wind transport of sediment index (WTSI)	index (0–1)	High	0	0.50				
	GLCA flow effects of historic properties	days flow > 23.2k	Low	75	0				
	Time-off-river index (TOR)	index (0–1)	High	0.60	0.95				
Hydropower									
	Value of energy generation (mean annual)	Million $/yr Billion $/20-yr	High	120M/ 2.4B	200M/ 4B				
	Value of capacity (mean annual)	Million $/yr Billion $/20-yr	High	10M/ 0.2B	50M/ 1B				
Recreation									
	GRCA camping area index (average of 3)	index (0–1)	High	0	0.50				
	Fluctuation index	index (0–1)	High	0	1.0				
	GLCA rafting use index	boat seats lost/yr	Low	1,300	0				
Riparian vegetation									
	Vegetation index (sum of four ratios)	sum of ratios	High	2.0	6.0			1	100
Sediment									
	GRCA sand load index (sand transported > 31,500)	proportion	High	0	0.6			1	100
Tribal									
	Change in marsh vegetation	ratio	High	0	1.5				
	Mechanical removal (years out of 20)	yrs	Low	5	0				
	Frequency of TMF (years out of 20)	yrs	Low	20	0				

Table 9. Agencies participating in the swing-weighting exercise.

[Representatives from 27 Federal, State, tribal, and private agencies were invited to participate in the swing-weighting exercise. The set of invited agencies included the Adaptive Management Working Group and cooperating agencies for the Long-term Experimental and Management Plan Environmental Impact Statement. Of the 27 agencies invited, 14 participated. AMWG, Adaptive Management Working Group; CA, cooperating agency; NGO, non-governmental organization]

Agency	Affiliation	AMWG	CA	Participant
Bureau of Indian Affairs	Federal	Yes	Yes	No
National Park Service	Federal	Yes	Yes	Yes
Bureau of Reclamation	Federal	Yes	Yes	Yes
U.S. Fish and Wildlife Service	Federal	Yes	Yes	Yes
Western Area Power Administration	Federal	Yes	Yes	No
Havasupai Tribe	Tribe	No	Yes	No
Hopi Tribe	Tribe	Yes	Yes	Yes
Hualapai Tribe	Tribe	Yes	Yes	Yes
Navajo Nation	Tribe	Yes	Yes	Yes
Pueblo of Zuni	Tribe	Yes	Yes	No
Southern Paiute Consortium	Tribe	Yes	No	No
Fort Mojave Indian Tribe	Tribe	No	Yes	No
National Parks Conservation Association	NGO	Yes	No	Yes
International Federation of Fly Fishers	NGO	Yes	No	Yes
Grand Canyon River Guides	NGO	Yes	No	Yes
Arizona Department of Water Resources	State	Yes	No	Yes
Arizona Game and Fish Department	State	Yes	Yes	Yes
Colorado River Board of California	State	Yes	Yes	No
Colorado Water Conservation Board	State	Yes	No	No
Colorado River Commission of Nevada	State	Yes	Yes	No
New Mexico Interstate Stream Commission	State	Yes	No	No
Wyoming State Engineer's Office	State	Yes	No	No
Utah Division of Water Resources	State	Yes	No	No
Salt River Project	Public power utility	No	Yes	Yes
Upper Colorado River Commission	State and Federal	No	Yes	No
Colorado River Energy Distributors Association	Power purchase contractor	Yes	No	Yes
Utah Associated Municipal Power Systems	Power purchase contractor	Yes	Yes	Yes

the particular agency places on those performance metrics. For the joint-lead agencies, using their average set of weights, Alternative D (and specifically, long-term strategy D4) performed better than the other alternatives (fig. 23). Alternatives C, D, E, F, and G all substantially outperformed Alternative A (status quo), provided HFEs were implemented. The long-term strategies that did not implement HFEs (C3, E3, E5, and E6) were all demonstrably poorer than Alternative A, as measured by the weighted performance. The weighted performance of Alternative B was similar to that of Alternative A, with long-term strategy B1 slightly better than long-term strategy B2.

Alternative D was created after a preliminary analysis of the other alternatives. In the April 2014 preliminary analysis, the results of which were discussed by the joint-lead agencies and the Cooperating Agencies, Alternative C and E exhibited roughly equivalent performance with some differences in ranking across stakeholders. Alternative D was created as a hybrid between Alternative C and E, taking features of each that had contributed to positive performance in the preliminary analysis. One of the advantages of separating objective weighting from alternative evaluation in MCDA is that the weights only depend on the ranges of the performance metrics, not on the alternatives under consideration, so new alternatives can be evaluated without having to re-elicit the swing weights. Because Alternative D was created from the insights gained in the preliminary analysis of alternatives, it stands to reason that Alternative D outperformed Alternatives C and E. It is interesting, however, that the gain in performance is fairly small, suggesting that only marginal gains in performance remain with the management tools available, against the backdrop

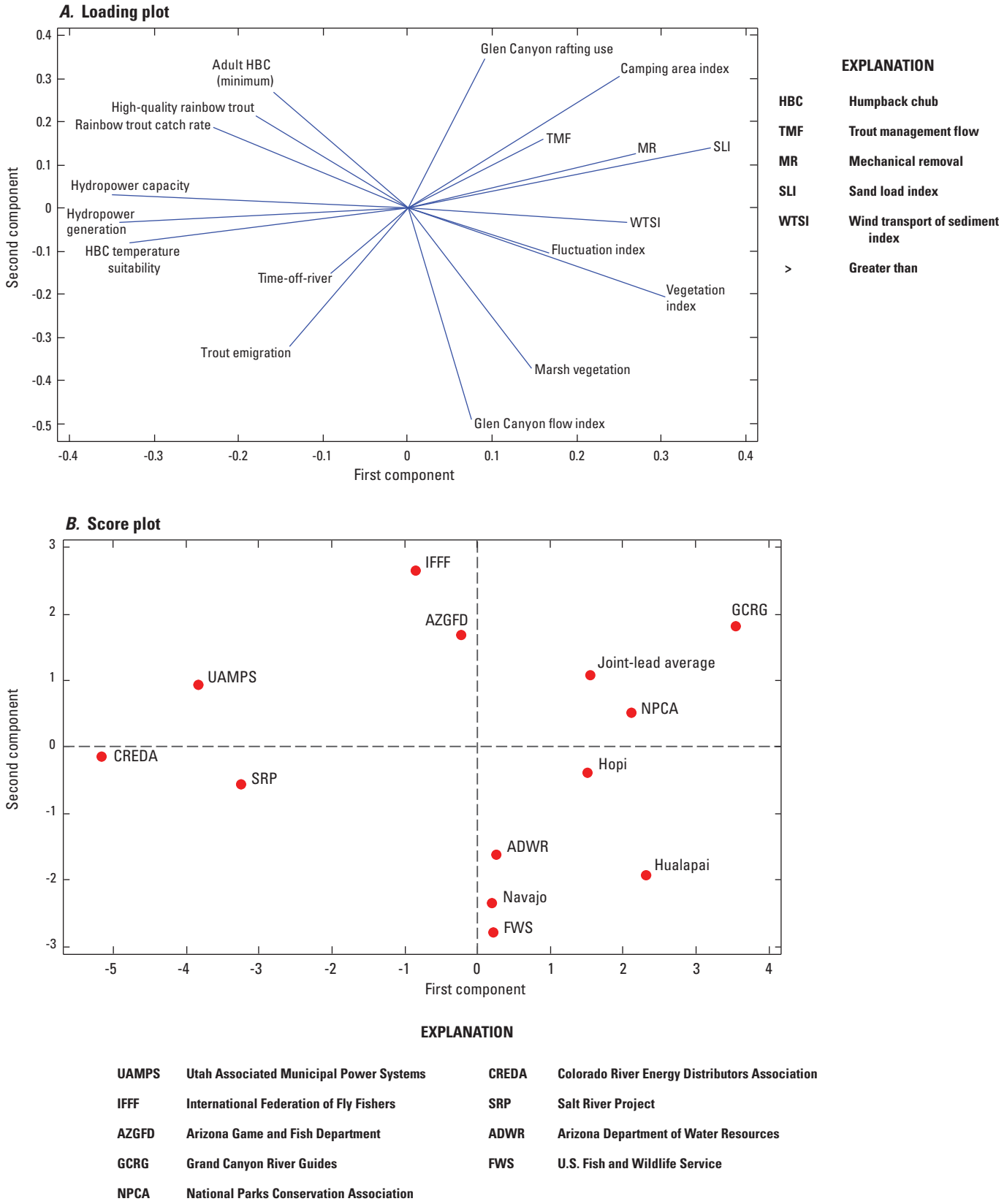

Figure 22. Principal components analysis of the weights on the performance metrics across stakeholder agencies. *A*, loading plot; and, *B*, score plot.

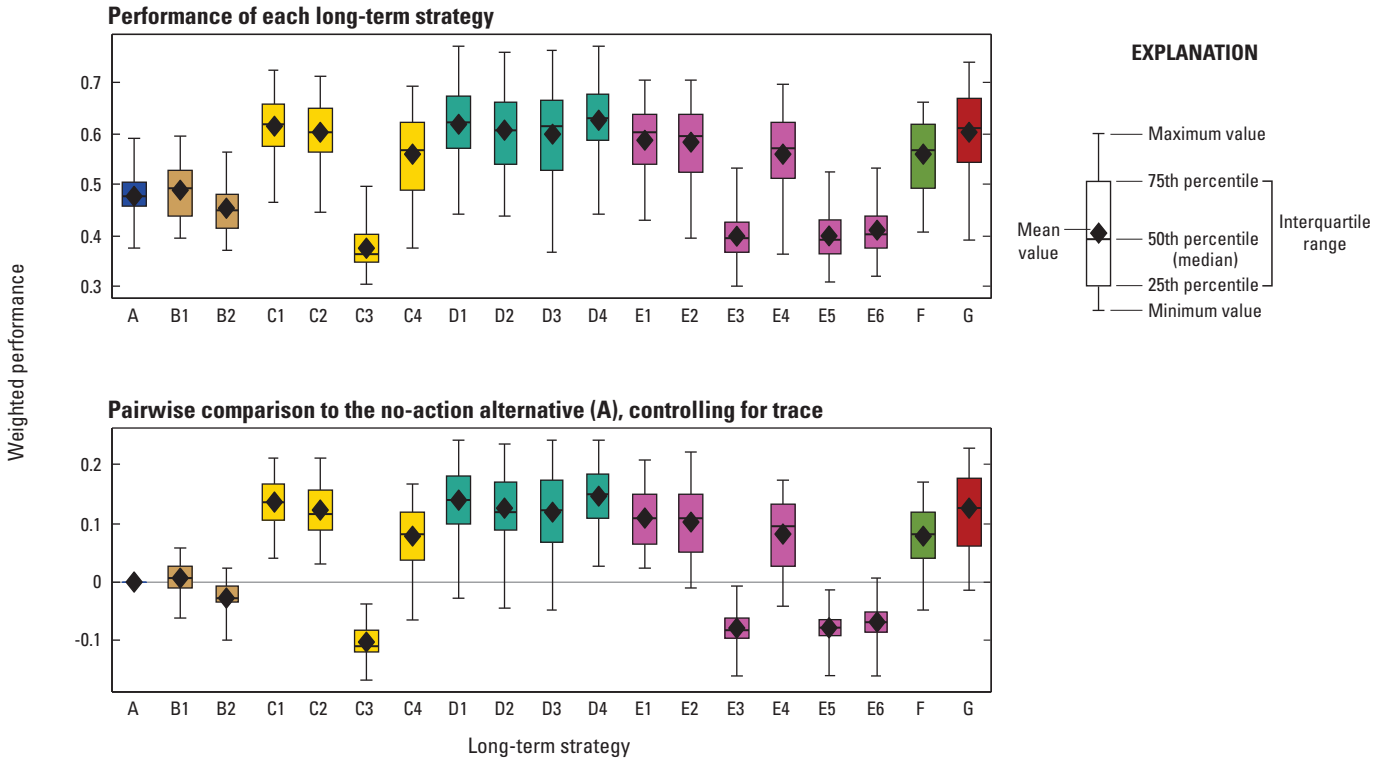

Figure 23. Joint-lead agency weighted performance across 18 metrics forecast for 19 long-term strategies using equal weighting of hydrological traces.

of uncertainty in hydrology and the complex set of tradeoffs among the resource goals.

One of the important motivations for MCDA was the opportunity to include and analyze differing viewpoints from stakeholder agencies regarding the importance of the various resource goals and their performance metrics. The agency-specific weightings did affect the ranking of alternatives (table 10). For most of the participating agencies, long-term strategy D4 had the highest mean-weighted performance (with the mean taken over hydrology and sediment traces and critical uncertainties). For two of the agencies (UAMPS, CREDA), long-term strategy B2 had the highest weighted score, and for one organization (GCRG), Alternative G had the highest weighted score. For all participating agencies except CREDA, long-term strategy D4 outperformed Alternative A. For all agencies, long-term strategy C3 performed worse than Alternative A, and for most of those agencies, it was the worst-performing long-term strategy. Alternative F was a polarizing strategy: for three agencies it was the worst-performing strategy, whereas for four others, it performed better than the status quo. Most of the differences across stakeholders in the MCDA ranking of the long-term strategies can be explained by the first principal component in the weighting (fig. 22). For those agencies that placed more weight on the performance metrics on the left side of the diagram (fig. 22*A*), Alternative B performed very well because it performs best for power generation and capacity; for those agencies that placed more weight on the performance metrics on the right side of the diagram (fig. 22*A*), Alternative B was outperformed by Alternative D. Across all participating stakeholders, the mean values for the long-term strategies in Alternative D were greater than those for Alternatives C and E, suggesting that the improvements made in crafting Alternative D are robust to the weights on the performance metrics.

Across stakeholders, the top-ranked long-term strategy was effectively tied with a number of other long-term strategies, against the backdrop of uncertainty induced by the hydrology and sediment traces; for example, using the joint-lead agency weights on the objectives, Alternative D4 had the highest mean performance, but the differences between D4 and next nine long-term strategies (D1, C1, D2, G, C2, D3, E1, E2, and E4) had ranges that included zero (fig. 24, bottom panel); that is, based on the results of the MCDA, alternatives C, D, E, and G were nearly indistinguishable using the joint-lead agency weights. This pattern held for the weights from most stakeholders as well (fig. 25), with between 2 and 11 long-term strategies effectively tied. For all stakeholders except CREDA, long-term strategies D4 and D1 were either the best-performing or effectively tied with the best-performing long-term strategy.

The differences among the long-term strategies within Alternative D are difficult to discern (fig. 23). The tradeoffs associated with using TMFs are marginal (compare D1 to D3). Similarly, the tradeoffs associated with “bug flows” do not

Table 10. Weighted performance for 19 long-term strategies using the weights on the performance metrics expressed by 14 participating agencies.

[The aggregate scores across performance metrics, weighted using the agency-specific swing-weighting results, are shown for each long-term strategy. For each participating agency, the best-performing long-term strategy is shaded in yellow, the worst-performing strategy is shaded in dark blue, strategies that perform better than Alternative A are shaded in orange, and strategies that perform worse than Alternative A are shaded in turquoise. The 21 hydrological traces were weighted equally. Thirteen additional stakeholder agencies were invited but declined to participate. JL, joint-lead agency average; FWS, U.S. Fish and Wildlife Service; ADWR, Arizona Department of Water Resources; AZGFD, Arizona Game and Fish Department; SRP, Salt River Project; UAMPS, Utah Associated Municipal Power Systems; CREDA, Colorado River Energy Distributors Association; IFFF, International Federation of Fly Fishers; NPCA, National Parks Conservation Association; GCRG, Grand Canyon River Guides]

	JL	FWS	ADWR	AZGFD	SRP	UAMPS	CREDA	Hopi	Hualapai	Navajo	IFFF	NPCA	GCRG
A	0.479	0.508	0.483	0.448	0.472	0.448	0.459	0.515	0.530	0.477	0.508	0.450	0.429
B1	0.488	0.504	0.511	0.450	0.493	0.485	0.474	0.512	0.538	0.495	0.511	0.474	0.443
B2	0.454	0.434	0.447	0.402	0.491	0.495	0.484	0.457	0.477	0.446	0.504	0.416	0.384
C1	0.615	0.539	0.484	0.508	0.458	0.410	0.410	0.574	0.599	0.521	0.544	0.604	0.637
C2	0.602	0.515	0.465	0.518	0.426	0.376	0.391	0.570	0.591	0.511	0.549	0.589	0.631
C3	0.376	0.433	0.378	0.369	0.418	0.400	0.412	0.411	0.410	0.374	0.445	0.315	0.280
C4	0.559	0.507	0.452	0.497	0.441	0.392	0.405	0.532	0.544	0.488	0.529	0.555	0.573
D1	0.619	0.573	0.542	0.540	0.489	0.450	0.436	0.596	0.630	0.559	0.553	0.634	0.648
D2	0.607	0.574	0.526	0.535	0.470	0.424	0.414	0.581	0.615	0.547	0.534	0.630	0.642
D3	0.599	0.557	0.526	0.540	0.472	0.425	0.428	0.584	0.614	0.550	0.544	0.621	0.637
D4	0.628	0.590	0.560	0.553	0.500	0.460	0.445	0.610	0.646	0.574	0.559	0.647	0.662
E1	0.589	0.535	0.522	0.506	0.475	0.447	0.430	0.572	0.607	0.535	0.550	0.587	0.592
E2	0.583	0.539	0.533	0.515	0.459	0.428	0.418	0.579	0.616	0.542	0.547	0.588	0.594
E3	0.400	0.488	0.482	0.411	0.450	0.445	0.434	0.463	0.483	0.445	0.461	0.373	0.319
E4	0.560	0.543	0.532	0.509	0.468	0.436	0.427	0.563	0.597	0.536	0.534	0.575	0.569
E5	0.401	0.482	0.476	0.407	0.442	0.438	0.426	0.461	0.482	0.440	0.461	0.370	0.318
E6	0.412	0.498	0.492	0.415	0.460	0.462	0.440	0.469	0.491	0.451	0.467	0.382	0.326
F	0.559	0.465	0.396	0.484	0.311	0.269	0.293	0.509	0.536	0.431	0.475	0.535	0.622
G	0.605	0.559	0.478	0.532	0.456	0.385	0.397	0.563	0.588	0.524	0.514	0.634	0.669

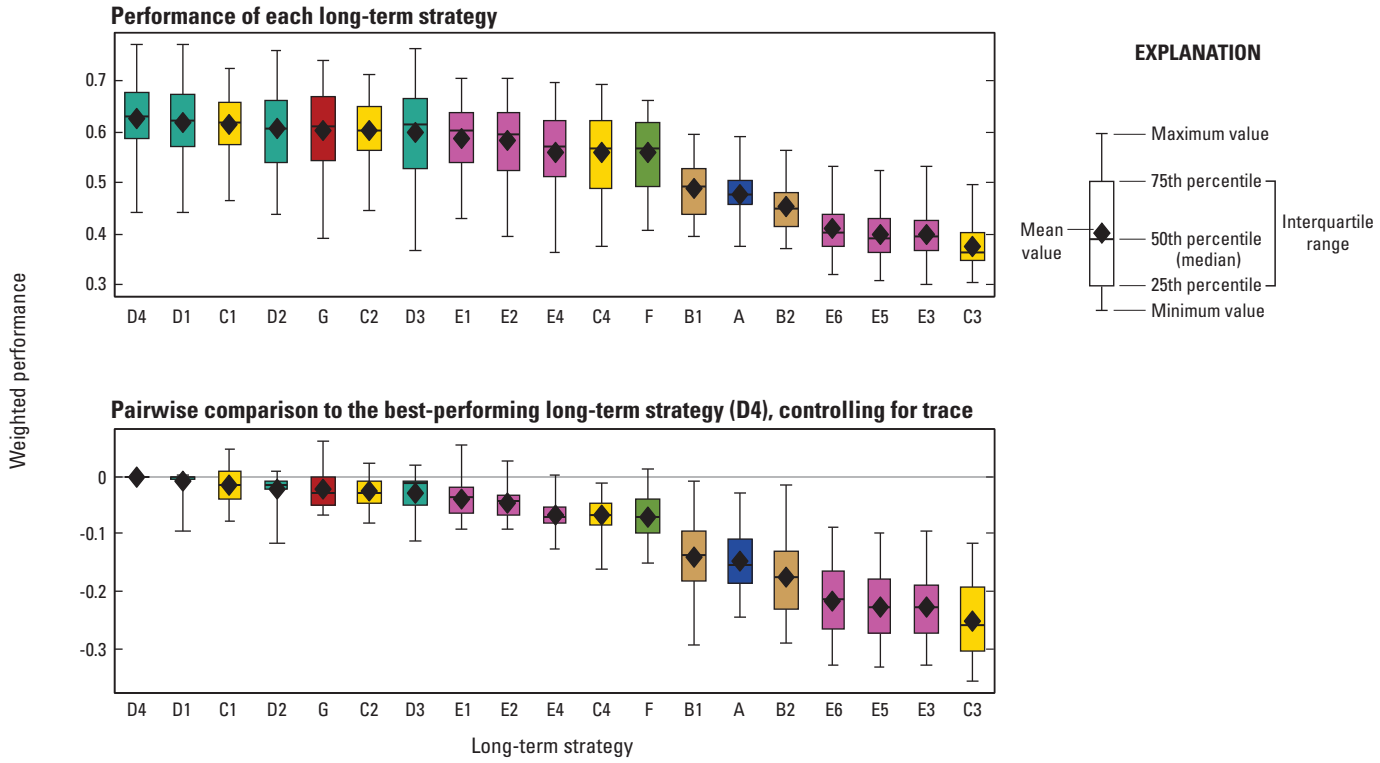

Figure 24. Joint-lead agency weighted performance across 18 metrics, sorted by mean performance, forecast for 19 long-term strategies using equal weighting of hydrological traces.

produce a clear favorite (compare D1 to D2). Finally, although there is the suggestion that the costs of low summer flows outweigh the benefits (compare D1 to D4), the difference is small against the backdrop of the variation driven by hydrology. The patterns within Alternative D are shown for the joint-lead agency weighting (figs. 23–24) but hold for the other stakeholder weightings as well (fig. 25).

8.3 Expected Value of Information

A second important purpose for the use of formal decision analysis tools was to examine the effect of uncertainty on the ranking of the alternatives. Although the effect of uncertainty on the ranking of alternatives based on single performance metrics was generally small (table 6), it is conceivable that the weighted performance could be more sensitive to uncertainty if the effects of the uncertainties affect the subtle balancing of tradeoffs. The analysis of the value of information on the weighted performance, however, revealed that the effect of the uncertainties was nearly 0 (table 11). For the joint-lead agency weighting and all but two of the participating stakeholders, the best-performing long-term strategy was the same across the 16 hypotheses that represented critical uncertainty (table 11); for example, long-term strategy D4 was preferred in the joint-lead agency weighting regardless of whether fall HFEs have an effect on RBT recruitment or not, regardless of whether TMFs are 10 or 50 percent effective in reducing RBT recruitment, and regardless of the relative influence of temperature and RBT on juvenile HBC survival and growth. For two stakeholders, there was a very small effect of the critical uncertainty: for IFFF, C2 was preferred more than D4 in 2 of the 16 hypotheses; and for GCRG, D4 was preferred more than G in 1 of the 16 hypotheses (table 11). Even in these two cases, however, the expected value of information for resolving the uncertainty represented by the 16 hypotheses was less than 0.1 percent.

At first glance, these results may seem puzzling. Many intense discussions within AMWG through the years have focused on concern that uncertainty about the response of the system to management prevents the identification of a best management strategy, and differences concerning recommendations for management have been explained as differences in interpretation of the scientific evidence. The uncertainties examined in this analysis (effect of fall HFEs, effectiveness of TMFs, and relative influence of temperature and RBT on juvenile HBC) have been central to previous discussions. But the results of this analysis do not support the conclusions that resolution of this uncertainty is important in choosing among the long-term strategies examined. There are several explanations for these results. First, there is less uncertainty than informal conversations imply. After several decades of intense study of the resources affected by the operation of Glen Canyon Dam, the AMWG partners have learned a great deal. Uncertainty remains, of course, but it is bounded; for

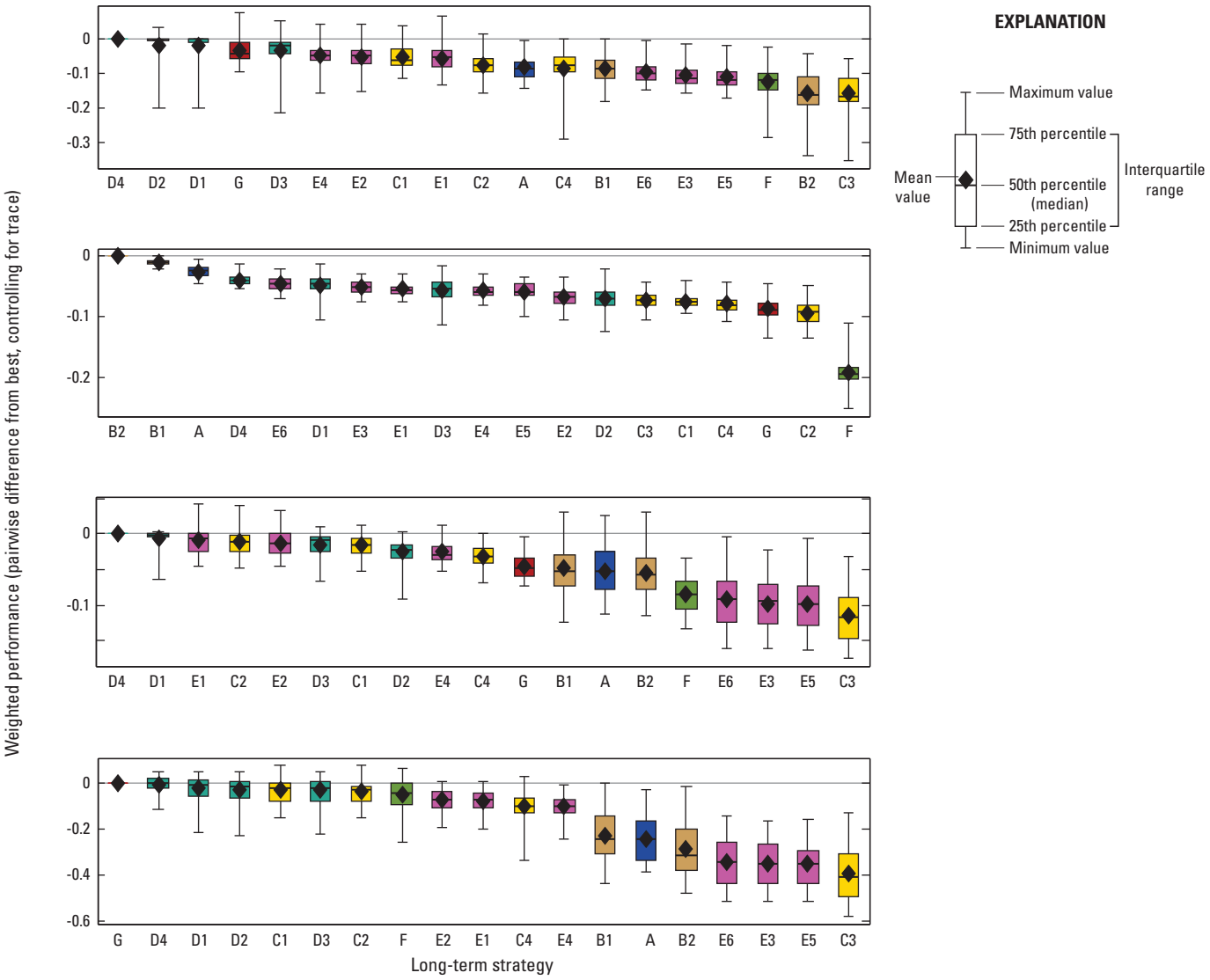

Figure 25. Weighted performance across 18 metrics, for four stakeholder agencies, sorted in descending order of mean performance. The four panels show the results for the stakeholders at the outer boundary of the score plot (fig. 22B; U.S. Fish and Wildlife Service, Colorado River Energy Distributors Association, International Federation of Fly Fishers, and Grand Canyon River Guides).

Table 11. Expected value of perfect information for resolving various uncertainties, as a function of the agency-specific weights.

[For each of the 16 combinations of hypotheses that describe the critical uncertainties, the best-performing long-term strategies are listed, using the agency-specific weights on the performance metrics. The shading of each cell is associated with the alternative from which the best-performing long-term strategy comes. See table 4 for a description of the critical uncertainties. The expected value of information for resolving critical uncertainty is zero for all the stakeholders except IFFF and GCRG. The expected value of partial information for resolving uncertainty about the combination of sediment and hydrology trace, sediment trace alone, and hydrology trace alone is shown. JL, joint-lead agency average; FWS, U.S. Fish and Wildlife Service; ADWR, Arizona Department of Water Resources; AZGFD, Arizona Game and Fish Department; SRP, Salt River Project; UAMPS, Utah Associated Municipal Power Systems; CREDA, Colorado River Energy Distributors Association; IFFF, International Federation of Fly Fishers; NPCA, National Parks Conservation Association; GCRG, Grand Canyon River Guides; HFE, high-flow experiment; TMF, trout management flow; EV, expected value; EVPI, expected value of perfect information; EVXI, expected value of partial information]

Critical uncertainties			Stakeholder											
Fall HFE	TMF	Temp trout	Federal		State					Tribe			NGO		
			JL	FWS	ADWR	AZGFD	SRP	UAMPS	CREDA	Hopi	Hualapai	Navajo	IFFF	NPCA	GCRG
No	High	f1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	High	f2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	High	g1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	High	g2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	Low	f1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	Low	f2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	Low	g1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
No	Low	g2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	High	f1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	High	f2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	High	g1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	High	g2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	Low	f1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
Yes	Low	f2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	C2	D4	G
Yes	Low	g1	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	D4
Yes	Low	g2	D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	C2	D4	G
Average best			D4	D4	D4	D4	D4	B2	B2	D4	D4	D4	D4	D4	G
EV			0.628	0.590	0.560	0.553	0.500	0.495	0.484	0.610	0.646	0.574	0.559	0.647	0.669
EVPI			0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	0.0000	0.0000
EVPI, in percent			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.01
EVXI (trace), in percent			1.50	1.39	1.54	1.84	0.89	0.10	0.00	1.06	1.32	1.00	1.23	1.87	2.50
EVXI (sediment), in percent			0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.14	0.00
EVXI (hydrology), in percent			1.10	0.93	1.27	1.58	0.75	0.09	0.00	0.87	1.12	0.80	0.91	1.53	1.89

example, the uncertainty in the effect of temperature and RBT on juvenile HBC is large, in the sense that the parameters governing those relations are uncertain by a factor of two (fig. 3*A* and 3*B*); the trout effect on survival could be as small as -0.15 or as large as -0.4. But, the decades of study of the interactions of RBT and HBC have indicated conclusively that there is an effect of RBT on juvenile HBC survival, and there are effects of both RBT and temperature on juvenile HBC growth. Second, the value of information is strongly affected by the set of alternatives considered. It only asks if the uncertainty impedes the choice of a best alternative from among the set evaluated. It does not ask if there could be another alternative, not yet identified, that would be sensitive to the uncertainty. So, for example, it was thought that the value of low summer flows would be sensitive to the effect of temperature on HBC growth; therefore, C2, for example, might be favored compared to C1 if model f1 holds, but C1 might be favored compared to C2 if model f2 holds. This presumes, though, that low summer flows are triggered in enough years and involve flows low enough to lead to substantial changes in the temperature in the Colorado River at the confluence with the Little Colorado River to produce a demonstrable difference between models f1 and f2; this was not the case. But, if there were another alternative that could produce large differences in temperature (for example, a temperature control device on Glen Canyon Dam), these uncertainties may have played a greater role. Third, in a multiple-objective decision, the influence of the weights on the objectives might override the effect of uncertainties; for example, the costs associated with low summer flows (on recreation and hydropower, for example) may override the potential benefits (to HBC) enough that the effect of the uncertainty does not matter.

8.4 Effects of Climate Change

Although the value of information associated with resolving critical uncertainty was small, there was an indication that the uncertainty associated with hydrological input had some influence on the ranking of the long-term strategies (table 11). For the joint-lead agency weighting, foreknowledge of the hydrological and sediment trace could lead to a 1.5 percent improvement in the weighted performance across objectives (table 11). Such knowledge is not possible because it would require accurate prediction of the monthly precipitation in the Colorado Basin over the next 20 years. But in demonstrating that hydrological input might be important in the selection of a long-term strategy, it raises the question about the potential influences of climate change.

The 21 reconstructed historical hydrological traces that were used in the LTEMP analysis represent possible 20-year sequences if the future is like the recent past (1906-2010). The 112 hydrological traces generated as part of the Basin Study (Bureau of Reclamation, 2012) represent the best current understanding of what might happen because of climate change. Mean annual inflow to Lake Powell is quite different under these two sets of traces (fig. 26). The median flow over the climate-change traces is lower than for the historical traces, although it is within the interquartile range of the historical traces. About 30 percent of the potential future distribution of flows, however, is not captured by the distribution of the historical traces. The historical 20-year trace with the lowest mean inflow has an annual flow of about 8.5 million acre-feet; 30 percent of the climate-change traces fall below this point, suggesting that the set of historical traces may not be representative of future conditions.

To examine part of the potential influence of climate change, a reweighting of the historical traces was calculated to better match the mean and variance of Lake Powell inflow seen in the climate-change traces. The climate-change weighing put about 18 percent of the weight on the single hydrology trace with the lowest input to Lake Powell. This reweighting of the hydrological traces was then used in all the MCDA calculations to examine the effect of those weights on the performance of the long-term strategies. For the joint-lead agency weights on the performance metrics, the weights on the hydrological traces had a small effect on the aggregate performance but did not change the rankings of alternatives (fig. 27). A similar pattern was seen for other stakeholder weightings. Although this result suggests the ranking of alternatives is robust to uncertainty about climate change, it is important to

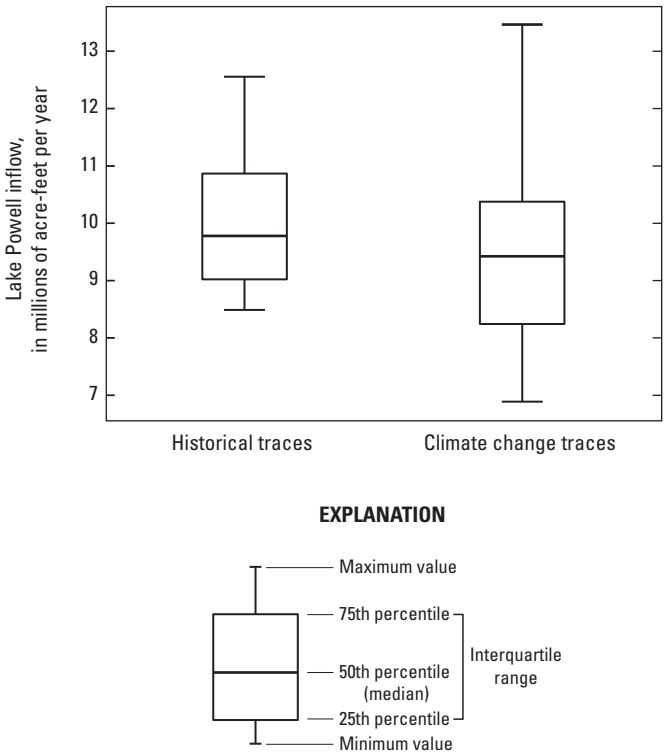

Figure 26. Mean annual inflow to Lake Powell during the 20-year period of the Long-Term Experimental and Management Plan for 21 historical hydrological traces and 112 climate-change-influenced hydrological traces.

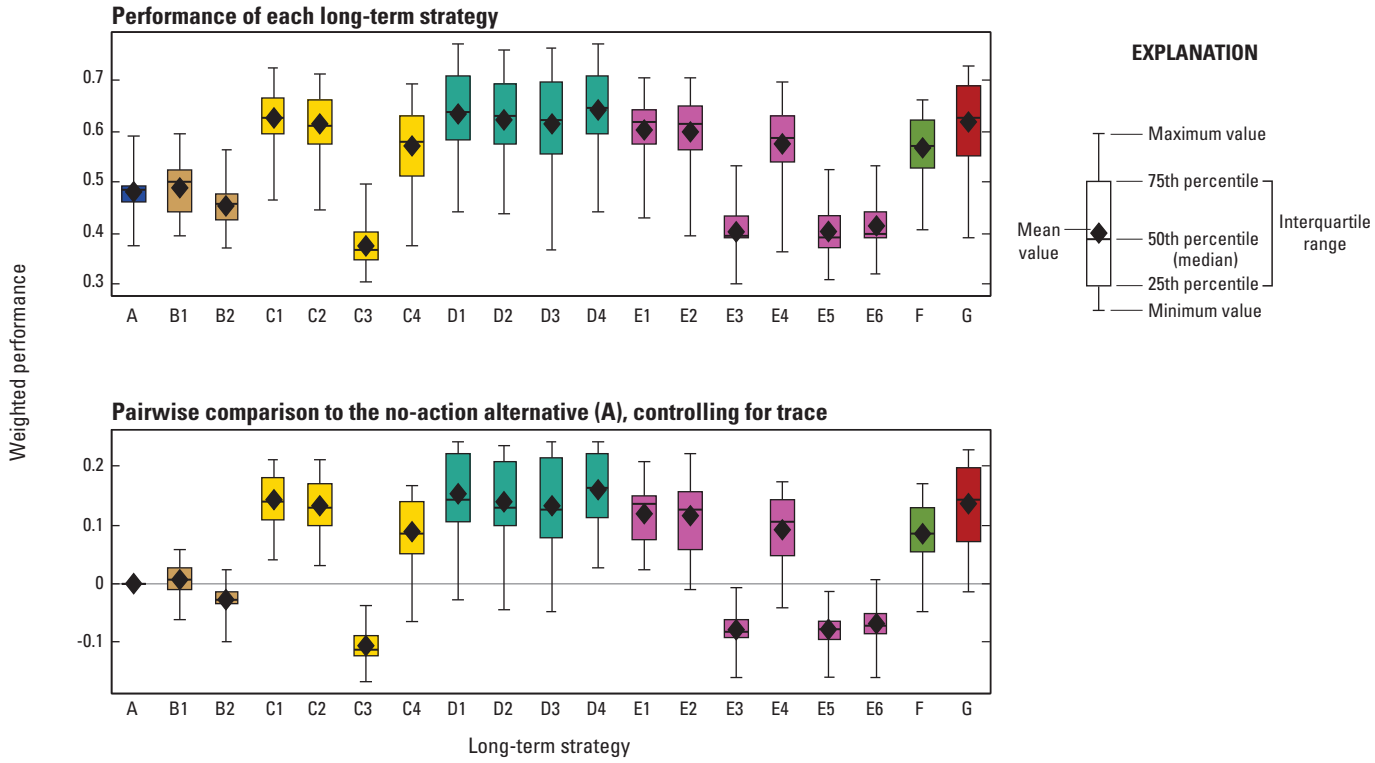

Figure 27. Joint-lead agency weighted performance across 18 metrics forecast for 19 long-term strategies using the climate-change weighting of hydrological traces.

keep in mind that the traces that were run through the modeling did not include plausible scenarios from the low end of the climate-change distribution.

9 Discussion

The analysis in this report is meant to add to the analysis in the LTEMP EIS itself. For those resource goals that could be evaluated with quantitative performance metrics, the tools of decision analysis allowed us to integrate the consequence analysis with the value judgments of stakeholders to formally evaluate the tradeoffs among the resource goals and to examine the influence of uncertainty on the performance of the long-term strategies. It is important to note, however, that not all the resource goals of importance could be evaluated quantitatively. The LTEMP EIS contains a narrative analysis of a greater number of resource goals than were included in the decision analysis, and this greater set of goals may be influential for the stakeholders and joint-lead agencies.

9.1 Evaluation of Alternatives

The alternatives examined in the LTEMP EIS and their long-term strategies differed in performance across the metrics considered. The full consequence table (table 7) shows strong tradeoffs: long-term strategies that perform well on any one performance metric may not perform well on others; thus, the choice of a preferred alternative will require the Secretary of Interior to weigh the importance of the various resource goals. The MCDA was designed as one way to provide input to the Secretary in her decision, by allowing the joint-lead agencies and stakeholders to express their interpretation of the importance of those resource goals and trace that interpretation through to the rankings of the alternatives. The best-performing long-term strategy did depend on the weights given to the performance metrics. Among the participating agencies, three alternatives rose to the top: Alternatives B, D, and G. Alternative B (especially long-term strategy B2) was favored by those agencies that emphasized the importance of the hydropower resource. Alternative G was the top- or second-ranked alternative for those agencies that emphasized restoration of natural processes, like beach building and native vegetation. For the remainder of the participating agencies, the analysis ranked Alternative D (especially long-term strategy D4) the highest. Alternative D was created after preliminary analysis revealed the strengths and weaknesses of the other alternatives and performs marginally better than the alternatives from which it was designed (C and E).

A number of other suggestions arise from the decision analysis regarding the long-term strategies. For most of the stakeholders, the benefits of HFEs seem to outweigh the costs, even in the face of uncertainty about their effects, at least as

measured by the performance metrics included in this analysis. The other modifications (for example, TMFs, mechanical removal, low summer flows, and bug flows) produce equivocal results; their inclusion is neither convincingly demonstrated nor precluded by the decision analysis.

Several caveats are warranted in interpreting this report. First, the performance metrics evaluated represent only a subset of the resource goals that might be influenced by the alternatives. The LTEMP EIS provides a fuller discussion of other goals, and the stakeholders and decision makers will need to judge if the formal decision analysis represents a sufficient degree of completeness. Second, not all stakeholders with an interest in the LTEMP EIS chose to participate in the decision analysis; thus, the array of viewpoints represented (for example, fig. 22 and table 10) may not capture the full range or appropriate distribution of viewpoints. Third, even for those stakeholders that participated, it may be difficult to express a nuanced set of values through the swing-weighting process. The set of MCDA methods used assumes the resource goals can be traded against each other in a linear, additive, and independent fashion. In fact, the value a stakeholder places on one objective might depend on how well an alternative is also performing on another objective; such dependencies require other decision analysis methods that were not used here. Fourth, some of the performance metrics may not have directly captured the resource goals they were meant to represent. For instance, the SLI is a proxy for sediment deposition and retention but not necessarily directly correlated with it. Fifth, some of the performance metrics (like hydropower generation) were expressed on natural scales that can be readily understood, but some of the performance metrics were expressed on proxy scales (for example, SLI) or constructed scales (for example, fluctuation index) that are difficult to understand; this mixture of scales makes the swing-weighting judgments challenging.

The structuring of objectives and the development of appropriate performance metrics are critical steps in MCDA and require diligence to meet the assumptions of a linear, additive value model (the form of MCDA used in this analysis). One of the concerns is the possible inclusion of means objectives, leading to possible double counting in the weighting process; for example, there was considerable discussion about the inclusion of the RBT emigration rate (performance metric 4)—was it fundamental or merely a means to conserving native fish populations? For some stakeholders, it was fundamental as an expression of the conservation of natural processes. But for other stakeholders, weight may have been placed on this objective as an expression of the effect of trout on native fish, thus, leading to possible double counting. Another concern is the possible inclusion of preferentially dependent objectives; for example, were RBT catch rate (performance metric 3) and abundance of high-quality RBT (performance metric 5) treated as independent in the swing-weighting exercise, or did the participants assume that if you had one, you would have the other and so assign weight based on simultaneous achievement? The two-stage swing-weighting may have helped reduce this concern, but with the large number of performance metrics being evaluated, cognitive mistakes in the swing-weighting exercise could still have happened. When applying decision theory to real problems, with all their subtleties and complexities, it is difficult to achieve perfect adherence to the assumptions of the analysis, but diligence toward those assumptions is needed.

All these caveats are fair, and the interpretation of the results should account for them. But the analysis also represents an effort to use the best available science to explicitly examine the ranking of alternatives as influenced by an analysis of consequences and the relative values placed on the resource goals.

9.2 Motivation for Adaptive Management

The purpose of doing the EVPI calculation was to understand the importance of resolving uncertainty (and the relative importance of resolving the different sources of uncertainty) before beginning experimental design. This puts the focus of uncertainty on its value to the decision maker, rather than its value as a point of scientific discovery. Although much has been written about the many scientific uncertainties about how the Colorado River ecosystem responds to management, less has been documented about how resolution of those uncertainties would explicitly affect and improve management decisions. The value of information analysis identifies the following: what long-term management alternative is best assuming each of the competing hypotheses, what long-term management alternative is best in the face of uncertainty (if uncertainty cannot be resolved), how much long-term management can improve through resolution of uncertainty, and which components of uncertainty contribute most to the value of information. Of course, what constitutes “best” depends on how the decision maker values the multiple resource goals within their statutory framework, so the analysis includes the sensitivity of the value of information to the weights on the objectives.

The results presented in this report (including the MCDA and EVPI analyses) provide valuable information for the construction of an experimental or adaptive design that is targeted to the most importance sources of uncertainty and has the best chance of resolving that uncertainty. The design of an adaptive strategy needs to consider three important elements: the value of the information being sought, the power of any experimental or adaptive design to resolve that uncertainty, and the short-term costs to the resource goals of pursuing the reduction of uncertainty. Although there are optimization algorithms to derive adaptive strategies taking these factors into account, for example, active adaptive stochastic dynamic programming (Williams, 1996), such tools are difficult to use in such a complex system.

Interestingly, the EVPI analysis suggests that there is not much advantage in an experimental approach because the resolution of the uncertainties articulated is not expected to alter the choice of long-term strategy. This suggestion, however,

hinges on the assumption that the uncertainties examined are a complete set. What about the "unknown unknowns," the uncertainties that we cannot yet articulate, but which we might nevertheless discover? We cannot analyze their importance, without being able to estimate their effect, and we also cannot design a monitoring system to detect them reliably. But, ongoing monitoring of the important resource goals, coupled with experimental implementation of the novel elements of any chosen alternative, is likely to reveal any surprises that would affect the achievement of the resource goals.

9.3 Decision Analysis and the National Environmental Policy Act

A typical analysis under the NEPA looks quite a bit like a formal decision analysis: resource goals (objectives) are articulated, alternatives are designed and described, and alternatives are evaluated against the individual resources of concern. These analyses are often qualitative, but a mix of qualitative and quantitative tools is also common. What is often missing from such analyses is a formal way to synthesize the results across the resources of concern. To the extent that NEPA is meant as a way to disclose to the public the environmental effects of the considered actions, such a synthesis is not needed. What decision analysis adds is a formal, quantitative way for the decision maker to consider and express the relative importance of the various resource goals in choosing a preferred alternative. In our view, then, decision analysis provides a useful companion to the analyses completed in an EIS.

The use of formal decision analysis in the context of a NEPA process was unfamiliar to a number of the Cooperating Agencies and other stakeholders, and several noted their discomfort with its use in comments to the joint-lead agencies. One-half of those stakeholders invited to participate in the swing-weighting exercise chose not to do so (table 9). They cited a number of concerns: skepticism that all the resources could be evaluated quantitatively, distrust of the methods of MCDA generally, a preference for providing input in a format they felt comfortable with, and a desire not to be forced to make an explicit value judgment on all the resource goals. Underlying the concerns was a stated fear that the decision analysis methods would be used to make the decision rather than just support an understanding of the alternatives. At all points, the joint-lead agencies and DOI leadership assured the stakeholders that the decision analysis was an effort to explore the performance of the proposed alternatives as deeply as possible with quantitative tools but was being used as only one of many sources of input in the transparent, deliberative process sought under NEPA. The effective use of decision analysis tools in the context of future NEPA processes will benefit from the insights of additional case studies, and from improved communication and training with regard to the theory, practice, justification, and benefits of decision analysis.

10 Summary

This report describes a formal decision analysis led by the U.S. Geological Survey, in cooperation with the Bureau of Reclamation, National Park Service, and Argonne National Laboratory, to support the development and evaluation of alternatives for the Glen Canyon Dam Long-Term Experimental and Management Plan. A set of 12 resource goals formed the basis of this evaluation, with 18 performance metrics used to provide quantitative measures of the resource goals. A total of 19 long-term strategies associated with 7 alternatives were evaluated against the performance metrics using a series of linked simulation models. Stakeholder input was elicited using the swing-weighting method, and this input was coupled with the quantitative evaluation of the alternatives in a multicriteria decision analysis. For 10 out of 13 stakeholder weightings presented, Alternative D (in particular, long-term strategy D4) outperformed the other alternatives. For the remaining stakeholder weightings, Alternatives B and G were the top performers. These rankings were robust to the uncertainties examined; the value of resolving uncertainty was never greater than 7.5 percent for any performance metric, and never greater than 2.5 percent for any stakeholder-weighted performance. This analysis is not a substitute for the full qualitative analysis found in the Long-Term Experimental and Management Plan Environmental Impact Statement, but does provide a transparent way to synthesize the analyses that could be quantified.

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12 Appendix 1. Disclaimers

In preparatory discussions with the Adaptive Management Working Group (AMWG) stakeholders and Cooperating Agencies, the joint-lead agencies and U.S. Department of the Interior (DOI) wanted to be clear about the role of the decision analysis in the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) process. The following disclaimer is to be included in the EIS when describing the use of formal decision analysis. (Note that during the discussions with the stakeholders, the term "structured decision analysis" was used as shorthand for the process being used. In this report, we follow the common practice in the literature and simply refer to the process as "decision analysis." The disclaimers below are reproduced verbatim, and so retain the use of the term "structured decision analysis"). A number of the participating stakeholders added disclaimers of their own when they submitted their swing-weighing results; these are also included below.

12.1 Standard Disclaimer

In an effort to provide multiple opportunities for interested stakeholders to provide input in the LTEMP process, the National Park Service (NPS) and Bureau of Reclamation (hereinafter referred to as "Reclamation") have decided to incorporate facilitated structured decision analysis (SDA) into the LTEMP EIS process. The SDA has been used previously for one aspect of the Glen Canyon Dam Adaptive Management Program (GCDAMP), the "Environmental Assessment for Non-Native Fish Control below Glen Canyon Dam." The use of SDA in the LTEMP process is not required by the National Environmental Policy Act (NEPA), nor does it replace the NEPA impact analysis.

Participation in the SDA process is a voluntary opportunity for stakeholder input. The NPS and Reclamation recognize that any input provided during the SDA effort does not replace the need and opportunities for formal public comment that are required steps in the NEPA process. Such formal comments on the Draft and Final EISs will be regarded as the formal and official positions of any commenting entity.

The use of SDA is an effort to cast a complex decision setting into a transparent, comprehensive but compressed form to help the decision makers and stakeholders see the essential elements; it may not, however, capture all nuances perfectly. The NPS and Reclamation recognize that the metrics for identified resource goals in the SDA do not necessarily reflect consensus or agreement among participants; moreover, the swing-weighting values to be applied to the metrics for identified resource goals may not reflect the broader policies or the importance of issues for any participant or agency. Stakeholders have had and will have formal opportunities to express their values through standard steps in the NEPA process, especially the submission of alternatives and public comments; for some stakeholders, these steps may allow them more flexibility to express their values in a familiar form than the decision analysis.

For these and other reasons, neither the co-leads nor the swing-weighting participants are bound by any outcomes or results of the SDA process. The NPS and Reclamation will use the results of the SDA process as one of multiple sources of information to inform the NEPA process, but the SDA process itself will not be used in isolation from other input to select the preferred alternative; rather, the NPS and Reclamation will choose a preferred alternative based on their statutory missions and responsibilities, giving consideration to legal, economic, environmental, technical, and other factors, as well as formal public input.

12.2 Arizona Department of Water Resources Disclaimer

The Arizona Department of Water Resources (ADWR) understands that the use of SDA in the LTEMP process is not required by NEPA, nor does it replace the NEPA impact analysis; furthermore, the ADWR recognizes that any input provided during the SDA effort does not replace the need and opportunity for formal public comment that are required steps in the NEPA process. Such formal comments on the Draft and Final EISs, in addition to the attached swing-weight exercise input, will be regarded as the formal and official positions of the ADWR.

The ADWR further recognizes that the swing-weighting values that have been applied to the metrics for identified resource goals do not reflect the broader policies or the importance of issues for the State of Arizona. The importance and priority of the values of ADWR are more accurately reflected within the "Resource Targeted Condition-Dependent" alternative, being necessarily incorporated during alternative creation. For these and other reasons, the ADWR is not bound by any outcomes or results of the SDA process.

Moreover, ADWR understands that the NPS and Reclamation will not solely rely on the results of the SDA process to select a preferred alternative; rather, the NPS and Reclamation will choose a preferred alternative based on their statutory missions and responsibilities, giving consideration to legal, economic, environmental, technical formal public input and other factors.

12.3 Arizona Game and Fish Department Disclaimer

The Arizona Game and Fish Department (AGFD) understands that the use of SDA in the LTEMP process is not required by NEPA, nor does it replace the NEPA impact analysis; furthermore, the AGFD recognizes that any input provided during the SDA effort does not replace the need and opportunity for formal public comment that are required steps in the NEPA process. Such formal comments on the Draft and Final EISs will be regarded as the formal and official positions of the AGFD, in addition to the attached swing-weight exercise.

The AGFD further submits that the swing-weighting values that we have provided for the metrics for identified resource goals do not reflect the broader policies or the importance of issues for the State of Arizona as a whole; rather, they represent AGFD values as they relate to our specific statutory authority and mission. For these and other reasons, the AGFD is not bound by any outcomes or results of the SDA process.

The AGFD understands and expects that the NPS and Reclamation will not solely rely on the results of the SDA process to select a preferred alternative; rather, the NPS and Reclamation will choose a preferred alternative based on their statutory missions and responsibilities, giving consideration to legal, economic, environmental, technical, formal public input and other factors.

12.4 Salt River Project Explanatory Letter

The Salt River Project (SRP) submits the attached swing-weighting exercise response under the following conditions:

- that this letter entitled "SRP's SDA Evaluation" remain attached to the SRP swing-weighting response table, and
- that the information submitted herein is not authorized for use, or attribution, beyond the purposes of this specific exercise in the current LTEMP EIS process.

1. *Hydropower (100).*—The SRP believes that the hydropower resource goal is the only one that represents both societal and environmental benefits. Greater quantities of hydropower provide cost effective service to people who value electricity to support many aspects of their lives. Greater quantities of this renewable, carbon-free resource also serve to avoid emissions and water use by other electric generating facilities. In the initial round of swing weighting, energy and capacity are valued equally.
    1. The energy metric does not appear to function in a consistent, intuitive manner; for example, a more flexible alternative with more energy production in higher-value months sometimes performs worse than a less flexible alternative with less energy production in higher-value months.
    2. While the capacity metric currently looks at July, SRP's peak demand requirement most often occurs in August, and our understanding from the Western Area Power Administration (WAPA) is that August is a better choice for peak planning purposes from their perspective as well. The SRP believes that utilizing August for peak demand planning would produce more credible capacity metric results.
2. *Humpback Chub (75).*—The SRP recognizes the environmental significance of the endangered humpback chub (HBC) (*Gila cypha*). The SRP supports the assembly of scientific evidence that establishes clear cause and effect relationships between flow regimes and a recovery of this endangered species. The "Number of Adult Humpback Chub" metric looks specifically at chub population, so the SRP places more emphasis on this metric than the "Temperature Suitability Index" metric.
3. *Archaeological and Cultural Resources (60).*—The Archeological and Cultural Resources goal represents an important societal benefit that the SRP supports; furthermore, SRP's perception is that, as presently crafted, the Archeological and Cultural Resources goal contains a more accurate representation of tribal interests than the "Tribal" resource goal. The SRP supports alternatives that science shows will preserve these resources.
    1. At the April Workshop, it was mentioned that the Time-off-river index was the issue that could lead to degradation of archeological and cultural resources; thus, this metric was scored highest.
    2. There has been some discussion about the wind transport of sediment index (WTSI). Specifically, some LTEMP representatives indicated that they would not want architectural and cultural sites buried by sand. This metric was, therefore, scored less highly.
    3. Based on new data from high-flow experiments (HFEs), it is unclear how HFEs and sediment affect downstream architectural and cultural sites. Because there are some winners and some losers, it is uncertain how the single "GLCA flow effects of historic properties (Ninemile)" metric can be representative of all sites; for example, science shows that HFEs will not increase sand bars before river mile (RM) 30 since there is no silt inflow. Even below RM 30, some sandbars cannot be built up to previous levels because even the maximum output of GCD cannot push sand high enough; thus, the SRP is not weighing this option as heavily as the others.
4. *Trout Fishery (40).*—The SRP recognizes the recreational value of the trout fishery and weighs the benefits against the environmental dangers of trout migration on downstream resources in the Grand Canyon ecosystem.

Since science appears to show that trout stay relatively close to Lees Ferry, SRP would not weigh "Lees Ferry trout emigration estimate" metric as heavily as if trout emigrated more through the canyon. As long as trout are not affecting downstream resources, the other metrics are also important to the trout fishery; thus, the "Angler Catch Rate Index" and "Number of trout > 16 inches total length" sublevel metrics are scored lower than the emigration metric but are still valued.

5. *Recreation (20).*—The SRP recognizes the societal value of recreation and believes Glen and Grand Canyons should be enjoyed by anyone who visits. While most visitors who visit the Grand Canyon do not raft down the canyon, the subset of people who do so should be considered.

    1. The "GRCA camping area index" is an important metric because people need safe areas to camp for the night. This is the highest rated metric.

    2. The fluctuation index is less highly rated because it does not take the time of day of the fluctuation into account.

    3. The GLCA rafting use index does not appear to have enough swing from low to high values to be rated highly. The swing of 600 people per year that could not take a trip down the river is not the same scale of an impact as a 1,000 fish population increase for HBC or a $9 million per year increase in hydropower energy value.

6. *Riparian Vegetation (20).*—The SRP recognizes the effect of riparian vegetation on the ecosystem of the Grand Canyon and believes it is has valuable environmental impacts. The aggregation of all metrics into this single metric hides some of the complexities; for example, CDAS and SASF perform worst for native/nonnative ratio but best for arrowweed. These are not able to be considered separately, which makes specific value judgments difficult.

7. *Sediment (0).*—The SRP observes that the effects of sediment are accounted for in the HBC, Archaeological & Cultural, Recreation, and Riparian Vegetation metrics. The SRP's perception is that sediment is a means to an end. We believe that a separate sediment metric does not make sense in the same manner that a separate temperature or HFE metric does not make sense.

8. *Tribal (0).*—The SRP believes that tribal interests should be recognized as a valued dimension of the LTEMP EIS process; however, as presented assembled and stated, the Tribal Resource goal does not appear to effectively represent tribal interests. The results for "Change in Marsh Vegetation" were questioned at the April Workshop and were not changed before this swing weighting. Trout should only be removed when they are endangering HBC, and the decision of how to remove them would preferably comply with tribal interests.

12.5 Utah Associated Municipal Power Systems Explanatory Letter

Utah Associated Municipal Power Systems (UAMPS) representing over 30 UAMPS members contracting for power generating output of Glen Canyon Dam is pleased to submit our response to the swing-weight exercise related to the LTEMP EIS process. The UAMPS is both an LTEMP EIS Cooperating Agency, a member of Glen Canyon Dam Adaptive Management Workgroup, and has been involved with most activities related to the operation of Glen Canyon Dam since environmental studies began in the mid-1980s. The UAMPS is grateful for the opportunity to participate in the EIS process as a member of the AMWG and as a Cooperating Agency contributor. We are appreciative of the great amount of work performed by both Federal government employees and contractors performing studies and assembling vast amounts of reporting documents, as well of those interested parties who have been following this LTEMP process.

We continue to be concerned with the valuation of the electric generation from Glen Canyon Dam and the reduction of power capacity and see this loss will be required to be replaced by resources using fossil fuels emitting carbon dioxide, which create other environmental problems and considerations. Thus far, we have not seen any expression of impacts of capacity switching except for some costs of capacity data for natural gas generation. In that regard, we wish to support the comment submitted by the Colorado River Energy Distributors Association (CREDA) that the cost estimates for natural gas combined-cycle generation in today's costs included in the performance metrics are way undervalued and should be corrected. We also hope additional cost analysis will eventually be included to address the lost power generating flexibility at Glen Canyon Dam needed for the western power grid. The flexibility provided by this hydropower is not free and will need to be made-up by some other power generating resource paid for by all utilities connected to the WECC power grid. Thus far, this loss of generating flexibly and the environmental impacts resulting from the shift to fossil fuels has only been casually addressed. We see the environmental objectives in this EIS seem to have priority over the far reaching climate change impacts that the electric industry in the west faces more and more as it struggles meet electric demands.

12.6 Colorado River Energy Distributors Association Submittal Letter

This letter [dated April 18, 2014] is an integral part of CREDA's SDA swing-weighting exercise submittal. CREDA members are all non-profit wholesale customers of the Salt

Lake City Area Integrated Projects (SLCA/IP) firm electric and transmission resources, of which Glen Canyon Dams is the largest generating facility. Although all members are non-profit entities, CREDA membership is diverse. Therefore, responses provided on the attached exercise cannot be ascribed to any individual CREDA member, as individual members did not have the ability to participate in the 5 days of workshop nor complete the exercise individually. Further, the responses are submitted with the understanding that the results will be reported with participant attribution and included in the draft/final Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). Further, it is not clear to CREDA in what other forums this submittal is intended for use or attribution. Given those assumptions, CREDA submits its SDA swing-weighting response under the conditions that a) this letter shall remain attached to the SDA swing-weighting response table, and 2) the information submitted herein is not authorized for use or attribution beyond purposes of this specific exercise in the LTEMP EIS processes and documents.

SDA AND LTEMP: Having participate fully in the August and March-April SDA workshops, it has become clear to CREDA this this process may not lend itself readily to a system and resources as complex and interdependent as we see in the resources of interest in the LTEMP. As the performance metrics and models have been developed and evolved, CREDA still has concerns about some of the underlying Resource Goals, and their inconsistency with the AMWG-approved Desired Future Conditions. Although many comments and concerns have been expressed on some of the Goals in various forums and through various medium, the Goals have remained unchanged since LTEMP scoping, As we were advised on April 1, if a participant still has concerns with a Resource Goal, or if the participant believes the elements of a metric are contradictory, inappropriately "linked" to a Resource Goal, or a create a potential legal or policy conflict, the participant should value the metric with a very low or 0 value. We appreciate the time and effort involved in developing and facilitating the SDA process, but suggest that it may be more applicable and useful for either determining stakeholder values of individual attributes of a resource, or analyzing a reduced number of alternatives (particularly when many of the LTEMP alternatives were "split up" for this exercise). We commend the stakeholders who devoted a significant amount of time and effort to the August 2013 and this year's process.

SDA, HYDROPOWER ANALYSIS AND LTEMP: As you are aware, CREDA is participating in this process as a member of the Glen Canyon Dam Adaptive Management Work Group (AMWG), representing "contractors for the purchase of Federal power produced at Glen Canyon Dam". As such representative, CREDA's submittal of the Balanced Resource Alternative represents the value we ascribe to the hydropower resource, notwithstanding we have some outstanding questions about how this alternative was ultimately modeled for the SDA process. Participants in the April workshop were advised that the hydropower performance metric was incomplete, and that a key component of the metric, capacity, had to be developed by Argonne in an inordinately short period of time (April 1–8), further, that the "ratepayer analysis" portion of the hydropower analysis was noted as "still under discussion" in the Performance Metrics document provided to the workshop participants. CREDA offers detailed comment herein on the energy, capacity and ratepayer analysis components of the hydropower resource, as we were invited to do as soon as possible after the April 1 workshop. We understand and expect that the electric resource flexibility component of the metric will be assessed as part of the draft/full EIS process, and that air quality impacts, such as carbon offsets will also be a part of the overall hydropower analysis. We offer the following comments and suggestions for use in assessing hydropower resources going forward in the LTEMP process.

ENERGY: The information provided to the SDA workshop participants on April 1 has results that are unintuitive. For example, one can compare RTCD4 with BR1. Both have Fall HFEs. BR1 has an average output of 14,500 cfs during July and August, while RTCD4 has an average output of 12,000 cfs and 11,000 cfs respectively. Furthermore, BR1 has an average fluctuation range that is 140% of MLFF, while RTCD4 has an average fluctuation range that is 114% of MLFF. Based on common knowledge, BR1 should perform better for energy than RTCD4. However, based on modeling results, RTCD4 performed better. This example, along with others discussed during the April 4 meeting, call the energy results into question. *We urge the LTEMP co-leads to utilize the expertise of the cooperating agency utility experts in energy analysis. We would also like to see more detailed energy results, as was agreed in the April 4 conference call.*

CAPACITY: The information provided to the SDA workshop participants on April 10 indicates that the capacity metric uses July as its peak month. CREDA reaffirms its suggestion on March 31 that August be used as the peak month to reflect actual utility peak demand experience, both past and as projected for the period of the LTEMP EIS. Also included in the April 10 information is a capacity value of $65,000/MW-yr to be used in the swing-weighting process, based upon the following factors:

- 620-MW natural gas combined cycle plant
- Capital cost of $917/kW
- Fixed operation and maintenance cost of $13.17/kW
- 30-year lifetime
- Discount rate of 3.8%

CREDA believes, based on discussion with its utility members who are also cooperating agencies in the LTEMP, that a more accurate estimate of the capacity value for a large, natural gas combined cycle facility is in the range of $82,000/MW-yr–$132,000/MW-yr.

As a consulting service to the electric utility industry, the Electric Power Research Institute (EPRI) regularly

prepares estimates of the costs associated with developing various types of energy resources, including gas-fired combined cycle facilities. EPRI's publicly available Generation Technology Options Report (published 2/19/2013) can be accessed at the linked site. EPRI information provided below can be found in Table 1-2 of their report.

Having worked with EPRI for a number of years with respect to resource characteristics and cost information for various electric resource technologies, a CREDA member's experience suggests that EPRI's valuations often do not fully account for the generally higher elevations and harsher ambient conditions that exist in CREDA member service regions relative to the assumptions used in EPRI's technology assessment efforts. Consequently, the CREDA member's internal cost estimates are higher. A comparison of key factors is provided below.

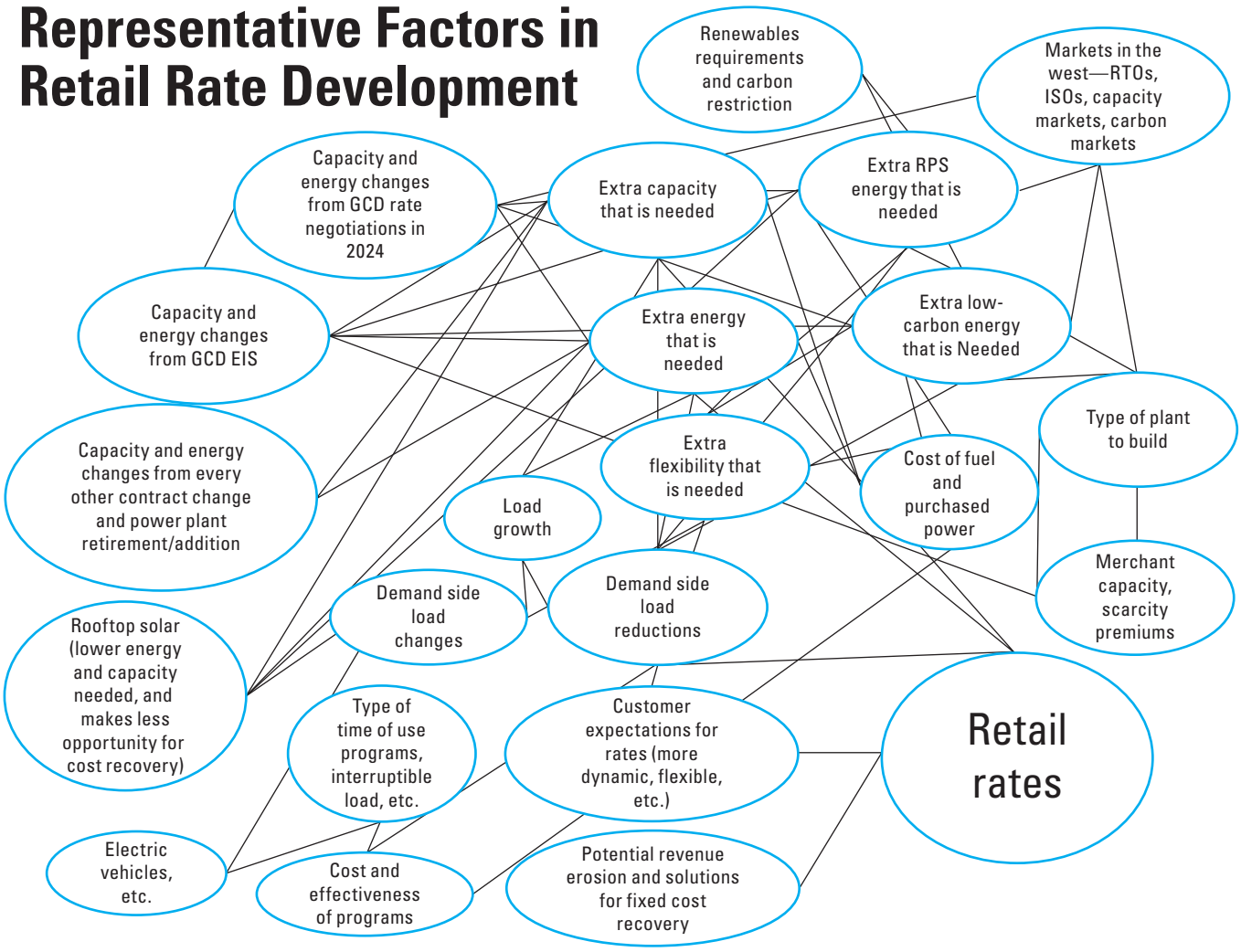
In summary, CREDA believes that the currently proposed values for LTEMP capacity valuation result in an understatement of Glen Canyon hydropower capacity value on the basis of a credible, publicly available, industry standard source for such information (EPRI) as well as on the basis of utility specific information and experience. *We urge the LTEMP co-leads to utilize the expertise of the cooperating agency utility experts in capacity analysis.*

RATEPAYER ANALYSIS: As was recently communicated to Ass't. Secretary Castle, CREDA and its electric utility members believe that this analysis must be based on and reflect impacts to the product/resource produced through the operation of Glen Canyon Dam, which is *wholesale* electric power and energy. On 4/1/14, we again objected to an attempt to develop and include a *retail* rate analysis, which is not required by NEPA, and which will likely be incorrect and misleading because it will not be possible to obtain sufficient and credible data given the time constraints and budget dollars associated with the LTEMP process. The chart below provides some perspective about the complexities involved in electric utility retail rate development. *Consistent with the scope of federal agency responsibility, to the extent any ratepayer analysis is required (which we don't believe is the case under NEPA), we urge the LTEMP co-leads to focus on the wholesale level, and consider utilizing cooperating agency utility expertise.*

Finally, CREDA recognizes the time and effort spent by all the SDA participants and believes that a key outcome from the workshops and exercises is the opportunity afforded the AMWG stakeholders, LTEMP co-leads, Argonne National Labs and GCMRC personnel and contractors to learn more about and appreciate the complexities and interdependencies of the resources addressed through the Adaptive Management Program, as well as the challenges faced by the Secretary of the Interior in balancing the resources associated with the operation of Glen Canyon Dam. It has also become clear through the model development and results supporting the SDA process that the resources of concern are "performing well" under the current operational and management parameters. The LTEMP co-lead and cooperating agencies should strongly consider this information.

	Factor	LTEMP	EPRI	CREDA
1	Capital Cost	$917/kw	$1,025/kw–1,325/kw	$1,130/kw–$1,426/kw
2	Fixed O&M Cost	$13.17/kw-yr	$15/kw-yr	$23/kw-yr–$25/kw-yr
3	Discount Rate (1)	3.8%	5%	Higher than 5%
4	Resulting Capacity Cost (2)	$65,000/MW-yr	$82,000/MW-yr–$101,000/MW-yr	$108,000/MW-yr–$132,000/MW-yr

(1) The discount rates of CREDA members are proprietary and confidential information.
(2) Lower cost represents wet cooling, higher cost represents dry cooling.



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ISSN 2328-0328 (online)
http://dx.doi.org/10.3133/sir20155176

APPENDIX D:

HYDROLOGY TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX D:

HYDROLOGY TECHNICAL INFORMATION AND ANALYSIS

D.1 ANALYSIS METHODS

The Colorado River Simulation System (CRSS) is the modeling tool used to assess the effects of the Long-Term Experimental and Management Plan (LTEMP) alternatives on water resources and to provide relevant information for other models used to assess other resources. This section provides a background on CRSS, all relevant modeling assumptions used in CRSS, and a description of any changes made to CRSS, specifically for the LTEMP modeling.

D.1.1 Background

CRSS, the Bureau of Reclamation's (Reclamation's) long-term planning model that covers the Colorado River Basin from the natural inflow points in the Upper Basin (see Figure D-3) to Imperial Dam, was the first model used in the LTEMP Environmental Impact Statement (EIS) analysis process. CRSS simulates future system conditions based on different hydrologic inflow scenarios and assumed reservoir operations for the evaluation period (2013–2033). The model framework used for this process is a commercial river-modeling software called RiverWare™ (Zagona et al. 2001), a generalized river-basin-modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation and the Tennessee Valley Authority. CRSS was originally developed by Reclamation in the early 1970s and was implemented in RiverWare in 1996.

CRSS simulates the operation of the major reservoirs on the Colorado River and provides information on the projected future state of the system on a monthly basis in terms of output variables, including the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and the diversions to and return flows from the water users throughout the system. The basis of the simulation is a mass balance (or water budget) calculation that accounts for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, evaporation), and water moving through the system (i.e., either stored in reservoirs or flowing in river reaches). The model was used to project the future conditions of the Colorado River system on a monthly time-step for the period 2013–2033.

The input data for the model include monthly natural inflows,[1] various physical process parameters such as the evaporation rates for each reservoir, initial reservoir conditions on January 1, 2013, and the future diversion and depletion schedules for entities in the Basin States and for the United Mexican States (Mexico). These future schedules were based on the current

[1] Calculated as gaged flow corrected for the effects of upstream reservoirs and depletions. Natural flow data and supporting documentation are available at http://www.usbr.gov/lc/region/g4000/NaturalFlow/index.html.

projected demand scenario (Schedule A) from the Colorado River Basin Water Supply and Demand Study (Reclamation 2012b).

The rules of operation of the Colorado River mainstream reservoirs including Lake Powell and Lake Mead are also provided as input to the model. This set of operating rules describes how water is released and delivered under various hydrologic conditions and aims to reflect actual operations. However, limitations inherently exist in the model's ability to reflect actual operations, particularly when responding to changing hydrological conditions and other operational constraints such as dam maintenance.

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-yr period from 1906 through 2010 and the "Downscaled GCM Projected" water supply scenario from the Basin Study (Reclamation 2012a). For the climate change analysis presented in Section 4.16.1.2 of the EIS, the 21 hydrologic traces used in the analysis were weighted according to their frequency of occurrence (based on mean annual inflow to Lake Powell) in the Basin Study's 112 simulations. Each sequence is input as natural flow at 29 individual inflow points (or nodes) on the system. The future hydrology is merely a projection of what future conditions might be based upon the 105-yr record and is not a prediction of the likelihood of these future hydrologic conditions occurring.

The following sections describe the CRSS modeling assumptions and configuration associated with the modeling undertaken for the LTEMP EIS process. The version of CRSS used for the LTEMP modeling started from the version of CRSS used for the Basin Study and was updated with more recent initial conditions and other changes necessary to reflect the different alternatives, as described below.

D.1.2 Initial Conditions

The model was initialized with the observed 2012 end-of-calendar-year (EOCY) reservoir conditions shown in Table D-1.

D.1.3 Reservoir Operations

D.1.3.1 Upper Basin Reservoirs above Lake Powell

The Taylor Park, Fontenelle, and Starvation reservoirs are operated in accordance with their existing rule curves (Reclamation 2007), although Fontenelle's operating rules in CRSS have been updated since the 2007 Interim Guidelines (DOI 2007). Aspinall Unit operations do not reflect the *Record of Decision* (ROD) *for the Aspinall Unit Operations Final Environmental Impact Statement* (Reclamation 2012c) because the modeling for the LTEMP EIS began before the latest Aspinall ROD could be reflected in CRSS. Instead, the Aspinall Unit is also operated in accordance with its previous rule curves as documented in the *Colorado River Interim*

TABLE D-1 Initial Reservoir Conditions
(2012 Observed End-of-Calendar-Year Values)

Reservoir	Elevation (ft AMSL)	Storage (ac-ft)
Fontenelle	6,485.19	196,963
Flaming Gorge	6,020.63	3,001,912
Starvation	5,734.92	255,000
Taylor Park	9,301.09	56,647
Blue Mesa	7,452.65	327,537
Morrow Point	7,146.50	106,381
Crystal	6,749.11	15,830
Navajo	6,024.73	956,630
Powell	3,609.82	12,712,205
Mead	1,120.36	13,636,479
Mohave	638.30	1,572,110
Havasu	446.41	550,689

Guidelines for Lower Basin Shortages and Coordinated Operations of Lake Powell and Lake Mead Final Environmental Impact Statement (2007 Interim Guidelines Final EIS [Reclamation 2007]).

Navajo and Flaming Gorge operations reflect the recent RODs (Reclamation 2006a,b, respectively). In general, both RODs contain downstream flow targets that the reservoirs attempt to meet according to the rules within the RODs. In summary, Flaming Gorge operations are governed by the April–July unregulated inflow into the reservoir, which determines the downstream flow targets that should be met; for example, in a wet year (larger inflow into the reservoir), higher downstream flows are targeted. The flow targets are specified at the sub-monthly time-step, which historically could not be reflected within CRSS. In order to capture the sub-monthly component of the flow targets, and thus Flaming Gorge's operations, the model was programmed to determine typical daily operations before summing to a monthly release (Butler 2011).

Similarly, Navajo's ROD contains multiple downstream flow targets, specified at sub-monthly time intervals. In this case, a September 30 storage target guides Navajo's operations. A release pattern is selected to bring Navajo as close as possible to the September 30 storage target while helping meet the downstream flow targets stated in the ROD (Butler 2011).

D.1.3.2 Lake Powell and Lake Mead

For 2013–2026, Lake Powell and Lake Mead would be operated according to the 2007 Interim Guidelines (DOI 2007). For modeling purposes, after the expiration of the 2007 Interim Guidelines in 2026, operations are assumed to conform to those specified in the

No-Action Alternative from the 2007 Interim Guidelines Final EIS (Reclamation 2007). Both operations are briefly described below.

Lake Mead flood control procedures are in effect for the entire simulation period. In addition, if Lake Mead elevation falls below 1,000 feet above mean sea level (AMSL), deliveries to the Southern Nevada Water Authority (SNWA) are assumed to continue.

If Lake Mead is sufficiently low such that after the maximum shortage (per the 2007 Interim Guidelines or No-Action Alternative post 2026) is applied and water is still unavailable to meet the remaining deliveries, the remaining deliveries are shorted hydrologically with respect to their physical location on the river.

Operations during the Interim Guidelines (2013–2026)

Operations of Lake Powell and Lake Mead are coordinated as specified in the 2007 Interim Guidelines (DOI 2007). Figure D-1 summarizes the different operating tiers at both reservoirs. Based on rules programmed in the model, CRSS determines which tier Lake Powell is operating in and simulates releases consistent with the selected tier. Similarly, CRSS is configured to simulate normal, shortage, and surplus deliveries in the Lower Basin, consistent with the Interim Guidelines.

Operations after the Interim Guidelines Expire (2027–2033)

The operating rules reverted to the rules of the 2007 Interim Guidelines Final EIS No-Action Alternative for simulations starting in 2027 and continuing through 2033. The No-Action Alternative assumed the following for shortage, surplus, and coordinated operations. There was no intentionally created surplus (ICS) assumed in the No-Action Alternative, however; consistent with the 2007 Interim Guidelines, ICS deliveries would be permissible through 2036. See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for additional details regarding the No-Action Alternative.

Three factors that affect Lake Powell's release are (1) the minimum objective release of 8.23 maf, (2) equalization, and (3) spill avoidance. For equalization to occur, the 602(a) storage requirement must be met.[2]

Stage 1 shortage is triggered to prevent Lake Mead from declining below 1,050 feet AMSL. Stage 1 shortages range in volume from approximately 350 to 500 kaf. If Lake Mead's elevation continues to decline, a Stage 2 shortage is imposed to keep Lake Mead above 1,000 feet AMSL. Stage 2 shortages can be up to 3.0 maf.

2 See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for the full 602(a) storage requirement computation.

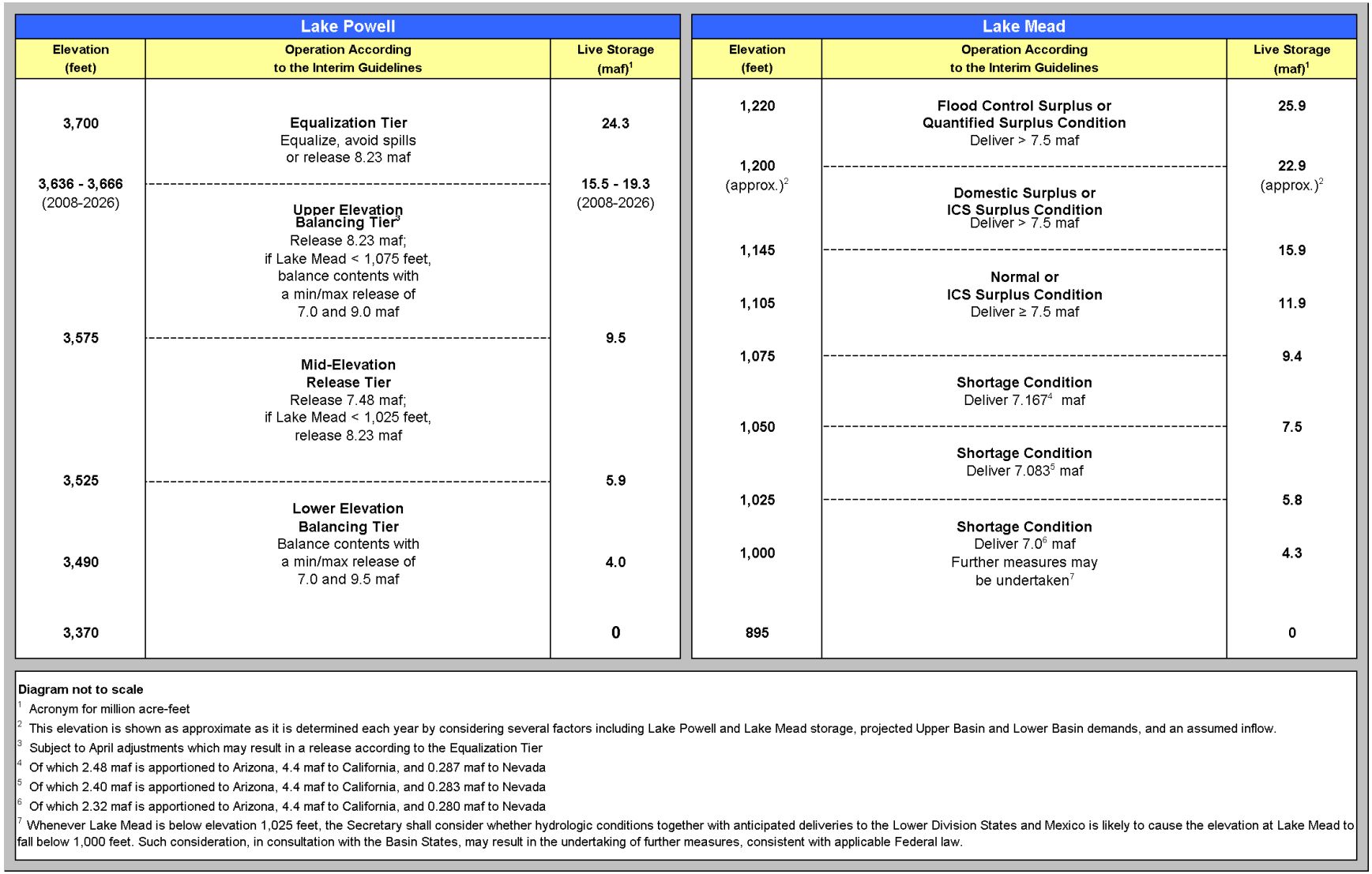

Diagram not to scale

[1] Acronym for million acre-feet

[2] This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

[3] Subject to April adjustments which may result in a release according to the Equalization Tier

[4] Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada

[5] Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada

[6] Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada

[7] Whenever Lake Mead is below elevation 1,025 feet, the Secretary shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consistent with applicable Federal law.

FIGURE D-1 Operating Tiers as Specified by the 2007 Interim Guidelines (DOI 2007) for the Operations of Lake Powell and Lake Mead

Surplus determinations are per flood control surplus conditions or the 70R Strategy.[3]

Modeling Assumptions for Annual Releases Extending beyond the Water Year

Modeling assumptions for equalization operations need to be performed for a full analysis of monthly and annual operations in this EIS. These assumptions are for analytical purposes only and do not, and cannot, modify the Secretary's approach to operations of equalization releases that are made pursuant to the Colorado River Basin Project Act of 1968. Modeled equalization release volumes can be affected by the annual pattern of monthly volumes. Alternatives that have higher releases earlier in the water year are able to release more water in years when the maximum release through the powerplant becomes a potential limiting factor to equalizing within the water year, which is consistent with the objectives of the Law of the River. A limitation of the current modeling assumptions is that they cannot fully mimic or predict operator judgment or actions to achieve full equalization within the relevant timeframe. Reclamation will continue to operate Glen Canyon Dam to achieve equalization releases in a manner fully consistent with the Law of the River and in consultation with the Colorado River Basin States.

For LTEMP modeling, logic was added to CRSS to handle instances in which Lake Powell could not meet annual release requirements by the end of the water year. If the computed remaining release in September is greater than Lake Powell's powerplant capacity, then the volume above powerplant capacity necessary to meet annual release requirements is released in the subsequent months. Releases, beginning in October, are increased above the normal release requirements (e.g., 600 kaf in an 8.23-maf release year of Alternative A, the No-Action Alternative), up to powerplant capacity, for as many months as necessary to release the remaining equalization volume. The volume of annual releases extending beyond the water year and the frequency at which these releases would be necessary were reported as one of the calculated water resource metrics.

Setting Powell's Monthly Release Volumes

In order to more efficiently model the different alternatives being evaluated in the LTEMP EIS, CRSS logic was modified to use an input release table and to allow minimum release constraints to vary among alternatives. The tables include monthly release volumes for water-year releases of 7.0, 7.48, 8.23, 9.0, 9.5, 10.5, 11.0, 12.0, 13.0, and 14.0 maf. In fixed-release-volume years (e.g., 8.23-maf release years), the monthly volumes used were directly from the input release tables presented in Section D.1.4, subject to other constraints such as

[3] Under the 70R Strategy, a surplus condition is based on the system space requirement at the beginning of each year. Based on the 70th percentile historical runoff, a normal 7.5-maf delivery to the Lower Division states, the Upper Basin scheduled use, and Lake Powell and Lake Mead volumes at the beginning of the year, the volume of water in excess of the system space requirement at the end of the year is estimated. If that volume is greater than zero, a surplus is declared. See Appendix A of the 2007 Interim Guidelines Final EIS (Reclamation 2007) for the full 70R computation.

ensuring Lake Powell stays at a safe operating capacity. In years with computed release volumes (e.g., equalization releases), the necessary water-year-release volume is computed, and the monthly release is interpolated between the two closest water-year releases. For example, if the equalization release is computed to be 12.5 maf, then the monthly release would be interpolated between the 12.0- and 13.0-maf monthly release volumes.

The minimum release constraints were also incorporated into CRSS because there are certain instances when the release from Lake Powell may be computed to be less than the alternative's minimum release constraints. In these cases, the alternative's minimum release constraint is used, subject to the physical ability to release the water. Furthermore, the implementation of these constraints does not result in a modification of the annual release volume.

D.1.3.3 Lake Mohave and Lake Havasu

Lake Mohave and Lake Havasu are operated in accordance with their existing rule curves.

D.1.4 Representation of the Different Alternatives in CRSS

For each alternative, tables were developed that include the monthly release volumes that are modeled to occur under differing water-year release volumes. In most cases, the volumes in the tables represent some desired aspect of the alternatives and were developed by proportionally scaling monthly volumes to the water-year volume. However, in the minimum-water-release (7.0-maf) years and in the high-water-release years, the proportionally scaled monthly volumes in the tables were sometimes adjusted up to meet minimum release constraints or down to meet powerplant capacity. All alternatives met the minimum release constraints and were within powerplant capacity in an 8.23-maf release year. However, in some months for some alternatives, the proportionally scaled monthly volumes in the tables required adjustment to meet these constraints.

For example, the proportionally scaled monthly volumes in a 7.0-maf year were not always adequate to meet the minimum release requirement, as computed by the minimum hourly releases and ramping constraints. In these instances, the monthly release volume was set to the volume necessary to maintain minimum flow throughout the entire month. Similarly, in high-volume water-release years, the proportionally scaled monthly volumes in the tables were sometimes greater than the physical capacity of the Glen Canyon powerplant. In these instances, the monthly release volume in the table was set to powerplant capacity, reallocating the excess into other months of the water year. The annual release volume was not affected by these modifications.

In addition to the physical capacity of the powerplant represented in the monthly tables input to CRSS, the maximum release capacity of Glen Canyon Dam (powerplant and bypass volume) can also affect modeled monthly release volumes, particularly in years with an annual

release volume greater than 14.0 maf. The maximum release was modeled explicitly in CRSS as a function of reservoir head. In general, the maximum release was computed as 45,000 cfs; this flow was converted to a daily volume and then multiplied by the number of days in the month to determine the monthly maximum release volume. In months when the monthly release prescribed by the alternative was greater than the maximum capacity for the month, the monthly volume was capped at the physical capacity, and the remaining volume was released in the following month(s).

Monthly release volume can also be affected by high-flow experiments (HFEs). For HFEs that required more water than was already allocated for the given month of the HFE, water was reallocated from later months to ensure the water-year release volume remained the same. For this EIS, the monthly reallocation of water for HFEs was modeled as a post-process to the sand-budget model (i.e., after the model determined the magnitude and duration of the HFE). Reservoir mass balance was computed for the affected months, and the resulting monthly releases and reservoir elevations were then passed to the hydropower model.

The monthly reallocation of releases to support an HFE does not affect the Lake Powell operating tier (and thus did not need to be explicitly modeled in CRSS). Operationally, the magnitude and duration of a HFE would be determined in either October–November or March–April. Because the Lake Powell annual operating tier is determined based on the August projection of the January 1 elevation, it is not yet known whether an HFE will take place that water year. Therefore, a modeled reallocation of water into November, for example, should not be considered in determining the annual operating tier because, operationally, this information would not be known until after the operating tier was already set.

Tables D-2 through D-11 are the monthly release tables used for all alternatives in CRSS, and Table D-12 summarizes the minimum release constraints used for each alternative. Figure D-2 shows the 8.23-maf release-year pattern for all alternatives. In addition, the experimental components of LTEMP that are modeled in CRSS are also discussed.

Long-term strategies (various implementations of the seven LTEMP alternatives; described in Appendix C) that would not affect monthly or annual releases from Lake Powell were not simulated in CRSS. These long-term strategies are labeled in the figures in this appendix as identical to another long-term strategy. For example, the only difference between long-term strategies D1 and D3 is that D1 includes trout management flows. Because trout management flows were not included in CRSS, results for D1 and D3 are identical and labeled as such in the water delivery results.

TABLE D-2 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative A

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
November	500,000	500,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
December	600,000	600,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
January	600,000	800,000	800,000	800,000	850,000	950,000	950,000	1,000,000	1,000,000	1,000,000
February	600,000	600,000	600,000	650,000	650,000	650,000	700,000	800,000	800,000	900,000
March	500,000	600,000	600,000	650,000	650,000	650,000	700,000	900,000	950,000	1,100,000
April	500,000	500,000	600,000	600,000	650,000	750,000	900,000	1,000,000	1,100,000	1,413,000
May	500,000	600,000	600,000	650,000	800,000	1,100,000	1,100,000	1,100,000	1,250,000	1,537,000
June	600,000	600,000	650,000	800,000	900,000	1,100,000	1,150,000	1,200,000	1,400,000	1,488,000
July	800,000	800,000	850,000	1,000,000	1,050,000	1,150,000	1,250,000	1,400,000	1,537,000	1,537,000
August	800,000	800,000	900,000	1,050,000	1,100,000	1,200,000	1,250,000	1,500,000	1,537,000	1,537,000
September	520,000	600,000	630,000	800,000	850,000	950,000	1,000,000	1,100,000	1,426,000	1,488,000

TABLE D-3 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative B

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
November	500,000	500,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
December	600,000	600,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000	800,000
January	600,000	800,000	800,000	800,000	850,000	950,000	950,000	1,000,000	1,000,000	1,000,000
February	600,000	600,000	600,000	650,000	650,000	650,000	700,000	800,000	800,000	900,000
March	500,000	600,000	600,000	650,000	650,000	650,000	700,000	900,000	950,000	1,100,000
April	500,000	500,000	600,000	600,000	650,000	750,000	900,000	1,000,000	1,100,000	1,413,000
May	500,000	600,000	600,000	650,000	800,000	1,100,000	1,100,000	1,100,000	1,250,000	1,537,000
June	600,000	600,000	650,000	800,000	900,000	1,100,000	1,150,000	1,200,000	1,400,000	1,488,000
July	800,000	800,000	850,000	1,000,000	1,050,000	1,150,000	1,250,000	1,400,000	1,537,000	1,537,000
August	800,000	800,000	900,000	1,050,000	1,100,000	1,200,000	1,250,000	1,500,000	1,537,000	1,537,000
September	520,000	600,000	630,000	800,000	850,000	950,000	1,000,000	1,100,000	1,426,000	1,488,000

TABLE D-4 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative C

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
November	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
December	754,360	754,360	830,000	830,000	830,000	830,000	830,000	830,000	830,000	830,000
January	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
February	609,215	663,640	730,180	817,484	874,175	987,557	1,044,248	1,157,630	1,271,012	1,388,429
March	643,264	700,730	770,990	863,174	923,033	1,042,752	1,102,611	1,222,330	1,342,049	1,474,882
April	572,129	623,240	685,730	767,719	820,959	927,439	980,679	1,087,159	1,193,639	1,311,782
May	592,562	645,500	710,220	795,138	850,279	960,562	1,015,703	1,125,985	1,236,268	1,358,631
June	619,811	675,180	742,880	831,703	889,380	1,004,734	1,062,411	1,177,765	1,293,119	1,421,109
July	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
August	550,661	599,850	660,000	738,913	790,155	892,640	943,882	1,046,366	1,148,851	1,262,562
September	400,482	436,260	480,000	537,391	574,659	649,192	686,460	760,995	835,528	918,227

TABLE D-5 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative C with Low Summer Flows

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
November	436,260	436,260	480,000	480,000	480,000	480,000	480,000	480,000	480,000	480,000
December	754,360	754,360	830,000	830,000	830,000	830,000	830,000	830,000	830,000	830,000
January	692,498	754,360	830,000	929,239	993,680	1,122,562	1,187,003	1,315,885	1,444,767	1,537,189
February	609,215	663,640	730,180	817,484	874,175	987,557	1,044,248	1,157,630	1,271,012	1,388,429
March	643,264	700,730	770,990	863,174	923,033	1,042,752	1,102,611	1,222,330	1,342,049	1,474,882
April	708,598	771,899	849,296	950,842	1,016,781	1,148,660	1,214,599	1,346,477	1,478,355	1,487,603
May	733,905	799,467	879,628	984,801	1,053,095	1,189,683	1,257,977	1,394,566	1,531,154	1,537,189
June	767,648	836,224	920,070	1,030,079	1,101,513	1,244,381	1,315,815	1,458,684	1,488,000	1,487,603
July	410,410	447,074	491,901	550,715	588,906	665,288	703,479	779,862	894,506	1,110,981
August	410,410	447,074	491,901	550,715	588,906	665,288	703,479	779,862	894,506	1,110,981
September	397,172	432,652	476,034	532,951	569,911	643,829	680,789	754,704	865,651	1,075,143

TABLE D-6 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative D

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	664,609	723,467	763,000	858,351	919,662	1,042,283	1,103,594	1,226,216	1,348,837	1,471,459
February	587,262	639,271	675,000	758,457	812,632	920,983	975,159	1,083,510	1,191,860	1,300,211
March	620,206	675,132	713,000	801,004	858,219	972,648	1,029,863	1,144,292	1,258,721	1,373,150
April	552,170	601,070	635,000	713,134	764,072	865,949	916,887	1,018,763	1,120,640	1,222,516
May	571,506	622,119	657,000	738,108	790,830	896,274	948,996	1,054,440	1,159,884	1,265,328
June	598,005	650,965	688,000	772,331	827,497	937,830	992,997	1,103,330	1,213,663	1,323,996
July	651,718	709,434	749,000	841,702	901,823	1,022,067	1,082,188	1,202,431	1,322,674	1,442,918
August	652,434	710,214	750,000	842,627	902,814	1,023,190	1,083,377	1,203,753	1,324,128	1,444,503
September	522,090	568,328	600,000	674,286	722,451	818,776	866,939	963,265	1,059,593	1,155,919

TABLE D-7 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative D with Low Summer Flows

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	664,609	723,467	763,000	858,351	919,662	1,042,283	1,103,594	1,226,216	1,348,837	1,471,459
February	587,262	639,271	675,000	758,457	812,632	920,983	975,159	1,083,510	1,191,860	1,300,211
March	620,206	675,132	713,000	801,004	858,219	972,648	1,029,863	1,144,292	1,258,721	1,373,150
April	730,640	795,346	840,007	943,631	1,011,033	1,145,837	1,213,239	1,348,044	1,482,848	1,487,603
May	756,226	823,198	869,423	976,676	1,046,439	1,185,964	1,255,726	1,395,252	1,534,777	1,537,189
June	791,289	861,367	909,735	1,021,961	1,094,958	1,240,952	1,313,949	1,459,944	1,487,603	1,487,603
July	427,856	465,748	491,901	552,582	592,052	670,992	710,463	789,403	908,217	1,126,373
August	427,856	465,748	491,901	552,582	592,052	670,992	710,463	789,403	908,217	1,126,373
September	414,056	450,723	476,033	534,756	572,953	649,349	687,544	763,936	878,920	1,090,039

TABLE D-8 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative E

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	683,468	747,279	781,296	883,660	950,130	1,083,070	1,149,540	1,282,480	1,415,420	1,548,360
February	604,808	661,275	691,377	781,960	840,780	958,420	1,017,240	1,134,880	1,252,520	1,370,160
March	638,457	698,066	729,843	825,465	887,558	1,011,743	1,073,835	1,198,020	1,322,205	1,446,390
April	568,537	621,618	649,915	735,065	790,357	900,942	956,235	1,066,820	1,177,405	1,287,990
May	588,202	643,119	672,394	760,490	817,695	932,105	989,310	1,103,720	1,218,130	1,332,540
June	615,733	673,220	703,866	796,085	855,967	975,732	1,035,615	1,155,380	1,275,145	1,394,910
July	670,795	733,423	766,809	867,275	932,513	1,062,988	1,128,225	1,258,700	1,389,175	1,519,650
August	560,700	599,148	659,223	720,900	760,950	841,050	881,100	961,200	1,041,300	1,121,400
September	489,300	522,852	575,277	629,100	664,050	733,950	768,900	838,800	908,700	978,600

TABLE D-9 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative E with Low Summer Flows

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	480,000	480,000	642,583	642,583	642,583	642,583	642,583	642,583	642,583	642,583
November	500,000	500,000	641,532	641,532	641,532	641,532	641,532	641,532	641,532	641,532
December	600,000	600,000	715,885	715,885	715,885	715,885	715,885	715,885	715,885	715,885
January	683,468	747,279	781,296	883,660	950,130	1,083,070	1,149,540	1,282,480	1,415,420	1,537,189
February	604,808	661,275	691,377	781,960	840,780	958,420	1,017,240	1,134,880	1,252,520	1,381,331
March	638,457	698,066	729,843	825,465	887,558	1,011,743	1,073,835	1,198,020	1,322,205	1,446,390
April	714,353	775,725	823,598	922,047	985,976	1,113,833	1,177,761	1,305,618	1,433,475	1,487,603
May	739,062	802,556	852,085	953,940	1,020,080	1,152,359	1,218,499	1,350,778	1,483,058	1,537,189
June	773,654	840,120	891,967	998,589	1,067,825	1,206,296	1,275,531	1,414,002	1,487,603	1,487,603
July	426,654	463,308	491,901	550,701	588,883	665,246	703,428	779,792	878,014	1,052,213
August	426,654	463,308	491,901	550,701	588,883	665,246	703,428	779,792	878,014	1,052,213
September	412,890	448,363	476,032	532,937	569,885	643,787	680,738	754,638	849,691	1,018,269

TABLE D-10 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative F

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	444,800	444,800	493,860	493,860	493,860	493,860	493,860	493,860	493,860	493,860
November	430,450	430,450	477,930	477,930	477,930	477,930	477,930	477,930	477,930	477,930
December	444,800	444,800	493,860	493,860	493,860	493,860	493,860	493,860	493,860	493,860
January	399,780	444,800	493,860	566,090	587,333	697,737	762,803	849,488	1,127,401	1,405,315
February	491,970	541,610	599,950	679,580	713,503	847,624	926,667	1,388,429	1,388,429	1,388,429
March	701,570	767,290	848,690	954,120	1,009,323	1,199,050	1,310,865	1,537,189	1,537,189	1,537,189
April	830,780	904,790	999,830	1,118,560	1,189,069	1,412,584	1,487,603	1,487,603	1,487,603	1,487,603
May	1,101,480	1,170,880	1,279,340	1,390,680	1,521,482	1,576,859	1,576,859	1,576,859	1,576,859	1,576,859
June	1,123,140	1,176,360	1,259,500	1,344,870	1,487,603	1,487,603	1,487,603	1,487,603	1,487,603	1,487,603
July	347,480	388,920	432,370	498,850	514,205	610,863	667,828	743,719	987,030	1,230,340
August	347,480	388,920	432,370	498,850	514,205	610,863	667,828	743,719	987,030	1,230,340
September	336,270	376,380	418,440	482,750	497,627	591,167	646,294	719,741	955,206	1,190,672

TABLE D-11 Monthly Release Volumes (in ac-ft) by Water-Year Release for Alternative G

	Water-Year Release (maf)									
Month	7	7.48	8.23	9	9.5	10.5	11	12	13	14
October	635,300	635,300	699,000	699,000	699,000	699,000	699,000	699,000	699,000	699,000
November	635,300	635,300	699,000	699,000	699,000	699,000	699,000	699,000	699,000	699,000
December	615,305	615,305	677,000	677,000	677,000	677,000	677,000	677,000	677,000	677,000
January	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
February	524,523	614,396	676,000	710,256	761,538	864,103	915,385	1,017,949	1,120,513	1,223,077
March	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
April	561,988	635,300	699,000	760,989	815,934	925,824	980,769	1,090,659	1,200,549	1,310,440
May	580,721	573,497	631,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,121
June	561,988	635,300	699,000	760,990	815,934	925,824	980,768	1,090,659	1,200,549	1,310,440
July	580,721	614,396	676,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,120
August	580,721	635,300	699,000	786,355	843,132	956,685	1,013,462	1,127,015	1,240,568	1,354,120
September	561,991	615,306	677,000	760,990	815,934	925,824	980,768	1,090,658	1,200,549	1,310,440

TABLE D-12 Minimum Release Constraints (cfs) Used for Each Alternative

Alternative	Minimum Release (cfs)
A	6,562.50
B	6,500.00
C	6,520.83
D[a]	6,520.83
E	6,520.83
F	5,000.00
G	8,000.00

[a] For Alternative D, with steady weekend flows for invertebrate production, the May–August minimum release constraint is 8,000 cfs.

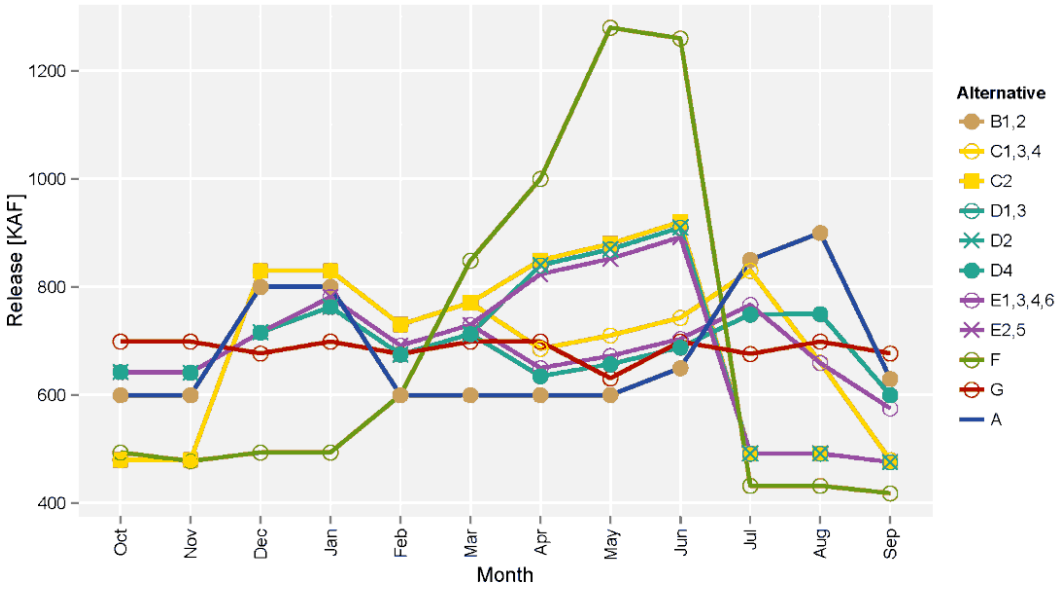

FIGURE D-2 Monthly Releases (kaf) for Each Alternative in an 8.23-maf Release Year (Note that long-term strategies C2, D1, D2, D3, E2, and E5 are shown with the monthly distributions when low summer flows are implemented. Low summer flows would not be implemented in all years.)

D.1.4.1 Experimental Components Modeled in CRSS

Specific to the LTEMP EIS, both experimental treatments—low summer flows and May–August steady weekend flows for invertebrate production—were incorporated into CRSS. The following sections discuss how these experimental components were modeled in CRSS.

Low Summer Flows

Low summer flows were implemented in CRSS as an experimental component under Alternatives C, D, and E. The objective of low summer flows is to produce warmer temperatures (i.e., greater than 13°C [55°F] for Alternatives C and E and greater than 14°C [57°F] for Alternative D) at the confluence with the Little Colorado River (T_{LCR}) in July, August, and September. In May, these alternatives would switch to a low summer flow pattern, releasing less water during these months, if all three of the following conditions are true: (1) the projected annual water-year release is <10 maf, (2) projected T_{LCR} is cold[4] in any of the three target months using the base release pattern, and (3) switching to the low-summer-flow pattern would result in warm[5] temperatures in all three of the target months. Alternatives that have low summer flows as an experimental component would use the base release tables, unless these three conditions were met. For example, Alternative E (long-term strategy 2) would use release volumes from Table D-8, but would switch to the release volumes in Table D-9 if the above conditions were met. Note that Alternatives C and E were modeled with low summer flows during the entire 20-yr LTEMP period, whereas Alternative D was modeled with implementation of low summer flows only during the second 10 yr of the LTEMP period.

The projected temperature conditions were calculated using regression equations that considered monthly elevations and releases and the calendar-year inflow at Lake Powell, and were empirically developed from observed conditions. The regression equations[6] to solve for T_{LCR} in July, August, and September were as follows:

July: $T_{LCR} = T_o + 3.791 \div (0.000461 \times \textit{Apr Projected Release}_{JUL})^{0.63} \times (36.31 - T_o)$,
where: $T_o = 249.4 - (0.0668 \times \textit{Apr Projected EOM Elev}_{JUL}) + (3.766\text{E-}7 \times \textit{Apr Projected CY Inflow})$

4 Cold is defined as <13°C (55°F) for long-term strategies C2, E2, and E5 and <14°C (57°F) for long-term strategies D1, D2, and D3.

5 Warm is defined as >13°C (55°F) for long-term strategies C2, E2, and E5 and >14°C (57°F) for long-term strategies D1, D2, and D3.

6 Regression equations were log-transformed for inclusion into CRSS.

August: $T_{LCR} = T_o + 3.791 \div (0.000461 \times Apr\ Projected\ Release_{AUG})^{0.63} \times (34.81 - T_o)$, where: $T_o = 297.2 - (0.0802 \times Apr\ Projected\ EOM\ Elev_{AUG}'') + (4.915E\text{-}7 \times Apr\ Projected\ CY\ Inflow)$

September: $T_{LCR} = T_o + 3.791 \div (0.000476 \times Apr\ Projected\ Release_{SEP})^{0.63} \times (30.01 - T_o)$, where: $T_o = 327.9 - (0.0886 \times Apr\ Projected\ EOM\ Elev_{SEP}) + (5.342E\text{-}7 \times Apr\ Projected\ CY\ Inflow)$

where:

T_{LCR} = temperature at the Little Colorado River Confluence, °C

T_o = Lake Powell release temperature, °C

EOM Elev = Lake Powell projected end-of-month elevation, ft

CY Inflow = Lake Powell projected calendar-year inflow, ac-ft

Release = Lake Powell projected monthly release volume, ac-ft

Steady Weekend Flows for Invertebrate Production

Steady weekend flows for invertebrate production were an experimental component of Alternative D. For the long-term strategy that included these flows, the May–August minimum release constraint was increased to 8,000 cfs.

D.1.5 Input Hydrology

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-yr period from 1906 through 2010, from 29 individual inflow points (or nodes) on the system. The locations of the hydrologic input sites are shown in Figure D-3.

Typically, CRSS is run with the full suite of available natural flow traces created using a resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997). Using the ISM on a 105-yr record (1906–2010) results in 105 inflow traces (i.e., plausible inflow sequences). For this EIS, however, because of the complexity, resource and timing constraints, and number of loosely coupled models used to analyze other resource impacts, every fifth trace from the 105 natural flow traces was selected, resulting in 21 traces.

Figures D-4 and D-5 compare the differences between using 105 traces and using 21 traces, and indicate that the distribution of 21 traces is very similar to the distribution of the full 105 traces for Lake Powell annual inflow, annual and monthly releases, and end-of-December pool elevation.

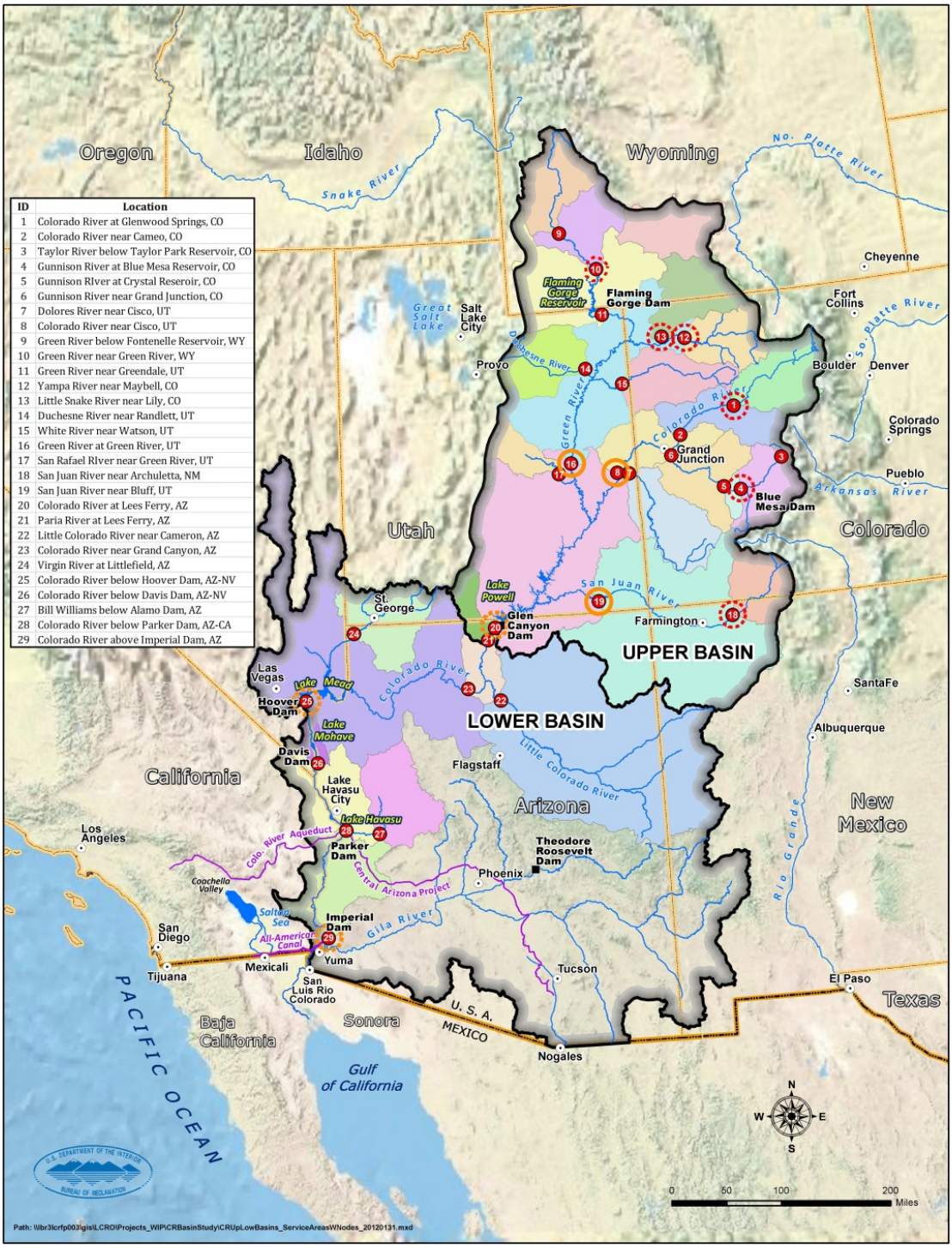

FIGURE D-3 Locations of CRSS 29 Natural Flow Nodes

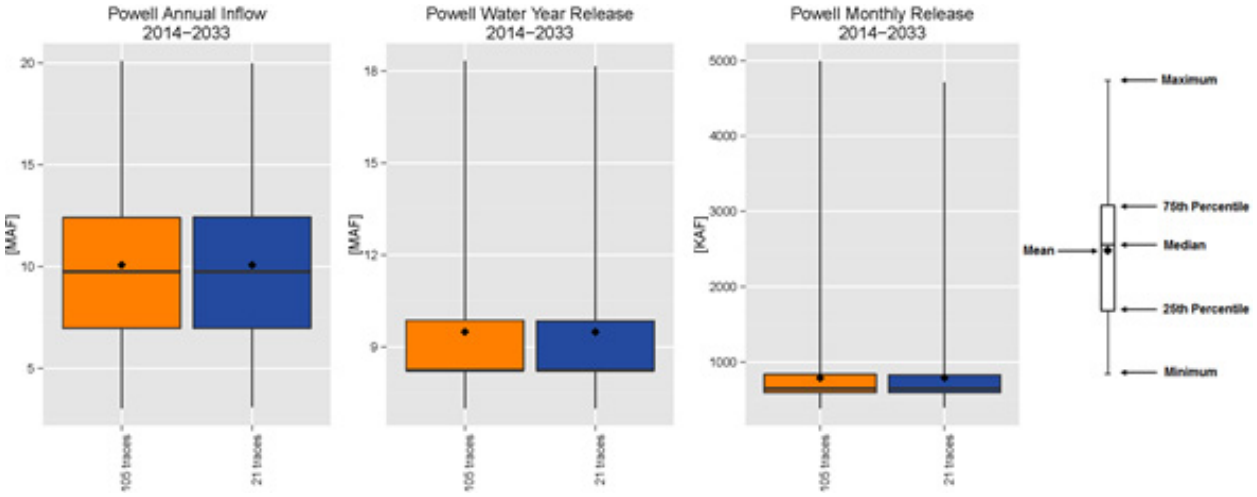

FIGURE D-4 Comparison of CRSS Results Generated Using 105 Traces (orange) and 21 Traces (blue) for Lake Powell Annual Inflow (left), Lake Powell Water-Year Release Volume (center), and Lake Powell Monthly Release Volume (right)

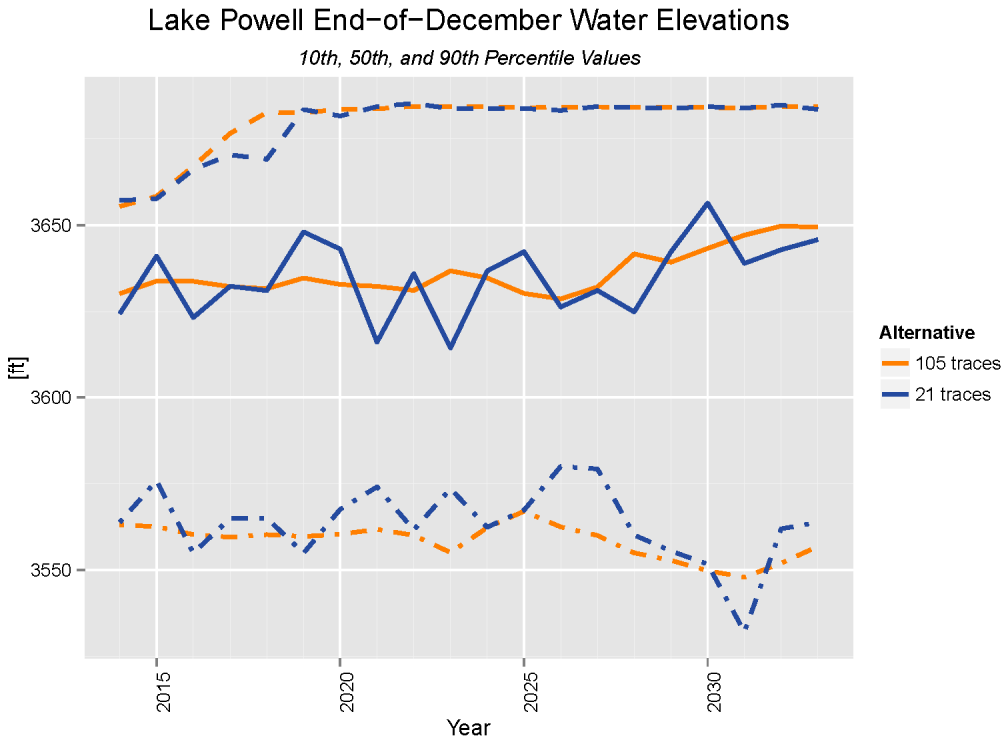

FIGURE D-5 Comparison of CRSS Results Generated Using 105 Traces (orange) and 21 Traces (blue) for Lake Powell End-of-December Water Elevations at the 10th (dashed and dotted lines), 50th (solid lines), and 90th (dashed lines) Percentiles

D.1.6 Input Demands

The LTEMP modeling utilized the Basin Study current projected demand scenario (Reclamation 2012b) for the input demands into CRSS. Table D-13 summarizes the demands by state.

D.1.7 Other Key Assumptions

A number of changes to CRSS were described in the Basin Study (Appendix G-2) including how the model treats implementation of Upper Colorado River water rights and intentionally created surplus.

Future water deliveries to Mexico were modeled as follows:

1. The model accounts for the entire delivery to Mexico at the Northerly International Boundary (NIB).

2. Water deliveries to Mexico are pursuant to the requirements of the 1944 Treaty. This provides annual deliveries of 1.5 maf to Mexico and up to 1.7 maf during Lake Mead flood control release conditions.

3. For modeling purposes, it is assumed that during shortage conditions, Mexico shares shortage in proportion to U.S. users in the Lower Basin (16.67%). This assumption is consistent with that used in the modeling supporting 2007 Interim Guidelines Final EIS (Reclamation 2007).[7]

4. Minute No. 318 and Minute No. 319 were not modeled as part of the LTEMP EIS because modeling began before they could be incorporated into CRSS.

The Warren H. Brock Reservoir was assumed to operate every year beginning in 2013 and is assumed to conserve approximately 90% of non-storable flows. This reduces the average annual volume of non-storable flows delivered to Mexico from 73 kaf/yr (historical average from 1964 through 2010, excluding flood years on the Gila or flood control releases) to 7 kaf/yr.

Bypass of return flows from the Welton-Mohawk Irrigation and Drainage District to the Cienega de Santa Clara in Mexico was assumed to be 109 kaf/yr (historical average from 1990 through 2010) and was not counted as part of the 1944 Treaty delivery to Mexico.

The Yuma Desalting Plant was assumed to not operate during the LTEMP period.

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[7] Allocation of Colorado River water to Mexico is governed by the 1944 Treaty. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico.

TABLE D-13 Input Demands by State

	Input Demand (ac-ft)						
	Upper Division States				Lower Division States		
Year	Colorado	New Mexico	Utah	Wyoming	Arizona[a]	California	Nevada
2013	2,524,327	592,772	1,017,031	539,545	2,800,000	4,400,000	300,000
2014	2,524,552	601,496	1,018,144	539,755	2,800,000	4,400,000	300,000
2015	2,524,776	610,220	1,019,258	539,965	2,800,000	4,400,000	300,000
2016	2,536,669	618,944	1,020,371	542,900	2,800,000	4,400,000	300,000
2017	2,548,562	627,668	1,021,485	545,835	2,800,000	4,400,000	300,000
2018	2,560,455	636,392	1,022,599	548,769	2,800,000	4,400,000	300,000
2019	2,572,347	645,116	1,023,712	551,704	2,800,000	4,400,000	300,000
2020	2,584,240	653,840	1,029,826	554,639	2,800,000	4,400,000	300,000
2021	2,596,133	658,483	1,033,820	557,574	2,800,000	4,400,000	300,000
2022	2,608,026	663,126	1,037,813	560,509	2,800,000	4,400,000	300,000
2023	2,619,919	667,769	1,041,807	563,443	2,800,000	4,400,000	300,000
2024	2,631,812	672,412	1,045,801	566,378	2,800,000	4,400,000	300,000
2025	2,643,705	677,055	1,049,794	569,313	2,800,000	4,400,000	300,000
2026	2,655,597	681,698	1,053,788	572,248	2,800,000	4,400,000	300,000
2027	2,667,490	686,341	1,057,781	575,183	2,800,000	4,400,000	300,000
2028	2,679,383	690,984	1,061,775	578,117	2,800,000	4,400,000	300,000
2029	2,691,276	695,627	1,065,769	581,052	2,800,000	4,400,000	300,000
2030	2,703,169	700,270	1,074,762	583,987	2,800,000	4,400,000	300,000
2031	2,715,062	702,863	1,080,156	586,922	2,800,000	4,400,000	300,000
2032	2,726,954	705,456	1,085,550	589,857	2,800,000	4,400,000	300,000
2033	2,738,847	708,049	1,090,943	592,791	2,800,000	4,400,000	300,000

[a] There are an additional 50,000 ac-ft/yr of Arizona demands within the Upper Basin, represented in CRSS.

D.2 SUPPLEMENTAL INFORMATION ON IMPACT MODELING

The following sections provide more detailed information on the impacts of the different LTEMP alternatives, particularly for low summer flows, the carryover equalization release metric, and alternative-specific comparisons to Alternative A (No-Action Alternative). These results supplement those covered in Section 4.1 of this EIS.

D.2.1 Low Summer Flows

During years with low summer flows, releases would be lower than typical in July, August, and September and proportionally higher in May and June, in order to maintain the same annual release volume. In years when the required annual release volume is not known until the end of the water year (e.g., during balancing or equalization), the low-summer-flows monthly volumes may end up being higher or lower than those originally projected in April because of changing hydrologic conditions. Figure D-6 shows the modeled frequency of occurrence of low summer flows. Note that Alternatives C and E were modeled with implementation of low

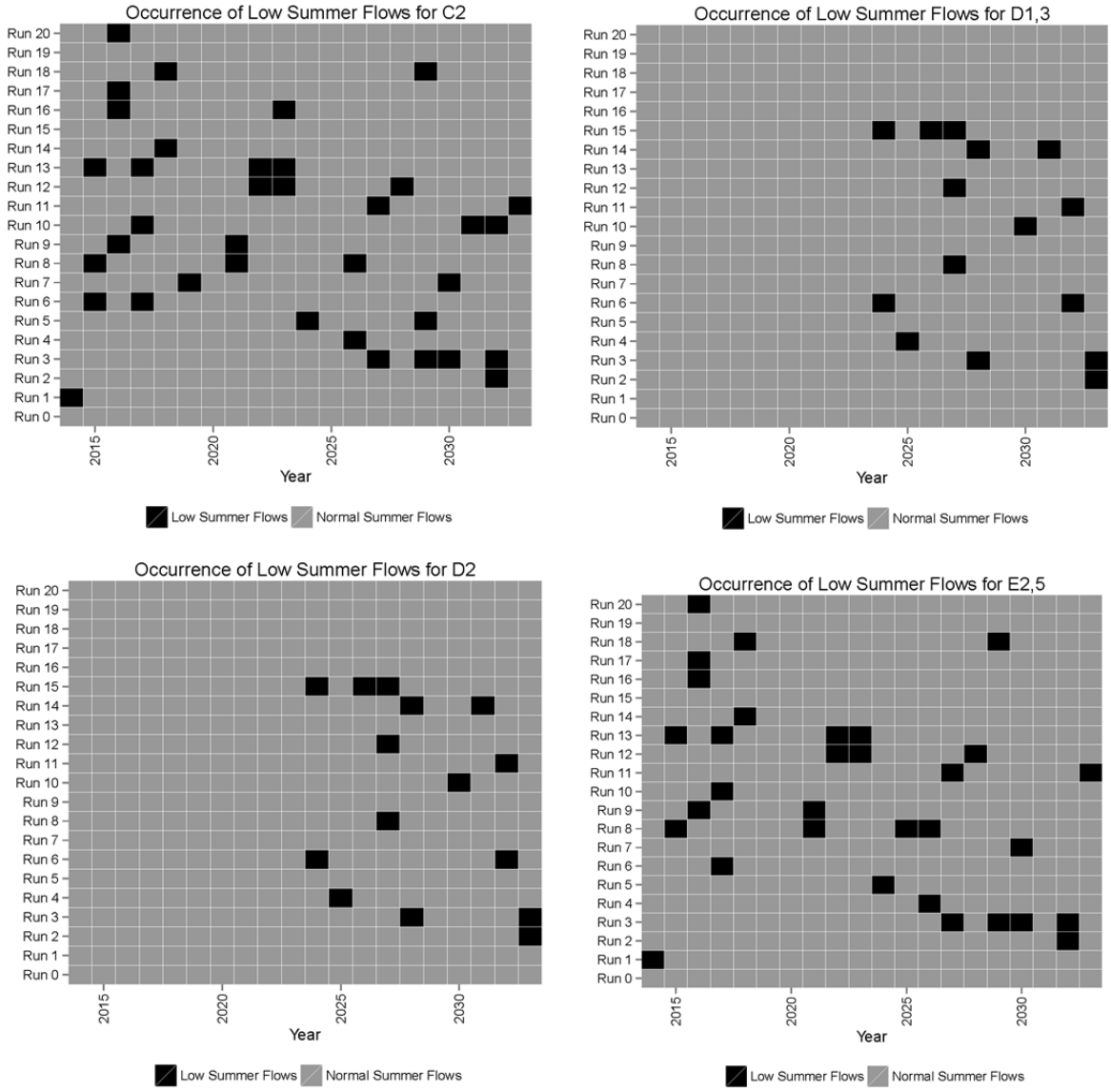

FIGURE D-6 Occurrences of Low Summer Flows in Applicable Alternatives (Numbers after alternative letter designations represent the long-term strategies that would implement low summer flows.)

summer flows during the entire 20-yr period, whereas Alternative D was modeled with low summer flows only during the second 10 yr of the LTEMP period. For those alternatives with low summer flows, the modeled number of low summer flows in the 20-yr period ranged from zero to four occurrences per trace. Depending on the alternative, the average ranged from 0.7 to 1.8 low summer flows per 20-yr run.

D.2.2 Modeled Annual Releases Extending beyond the End of the Water Year

The frequency (Figure D-7) and volume (Figure D-8) of exceptions to meeting the annual release target volumes specified by the Interim Guidelines were one of the calculated water

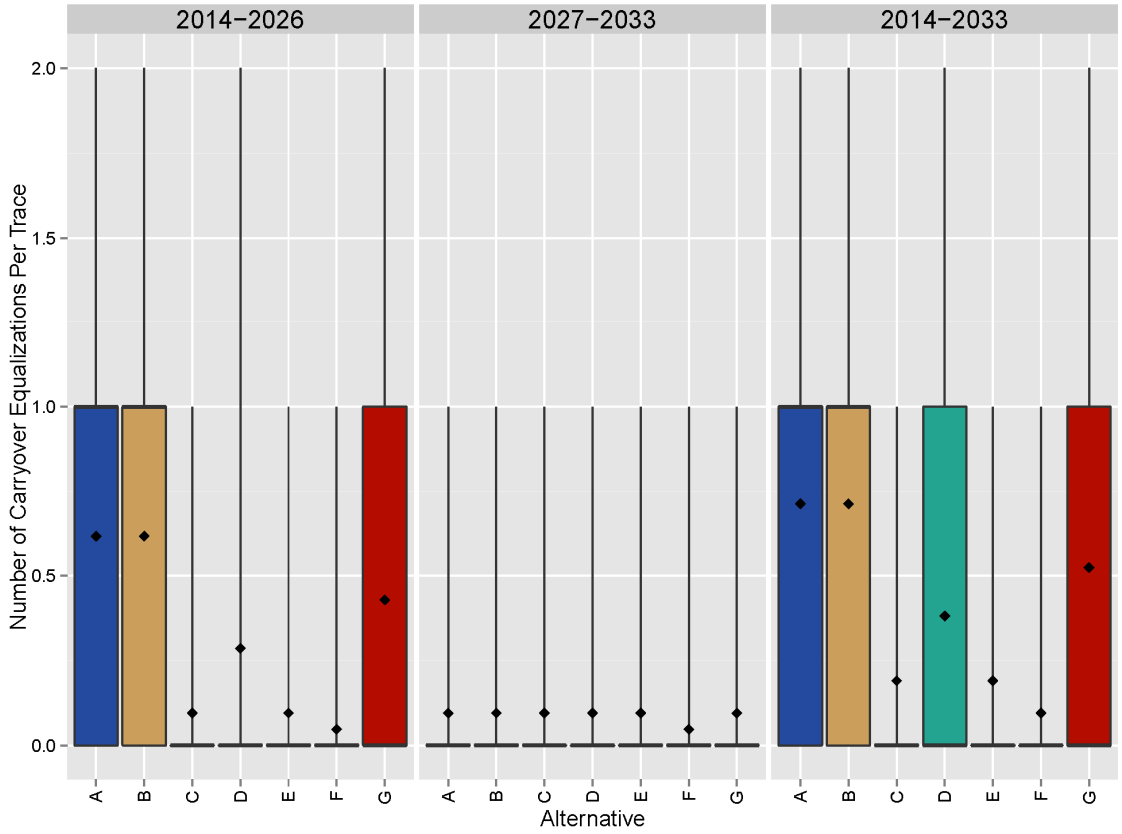

FIGURE D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the End of the Water Year per 20-yr Trace for Each of the Alternatives (See Figure 4-2 for an explanation of how to interpret this graph. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

resource metrics. Note that there is the possibility of exceptions occurring under all alternatives, including Alternative A (the No-Action Alternative).

D.2.3 Lake Elevation

Figures D-9 through D-14 present end-of-December elevations for Lake Powell and Figures D-15 through D-20 present percentage of traces below Lake Powell's minimum power pool for each alternative, and compare them to Alternative A. These graphs show different implementations of each alternative (referred to here as long-term strategies). These strategies are given the letter designation of the alternative (A–G) and a number designating the long-term strategy for the alternative. See Section 4.1 and Appendix C for descriptions of the experiments included in each long-term strategy. For both of these parameters, only very small differences between Alternatives B–G and Alternative A were found.

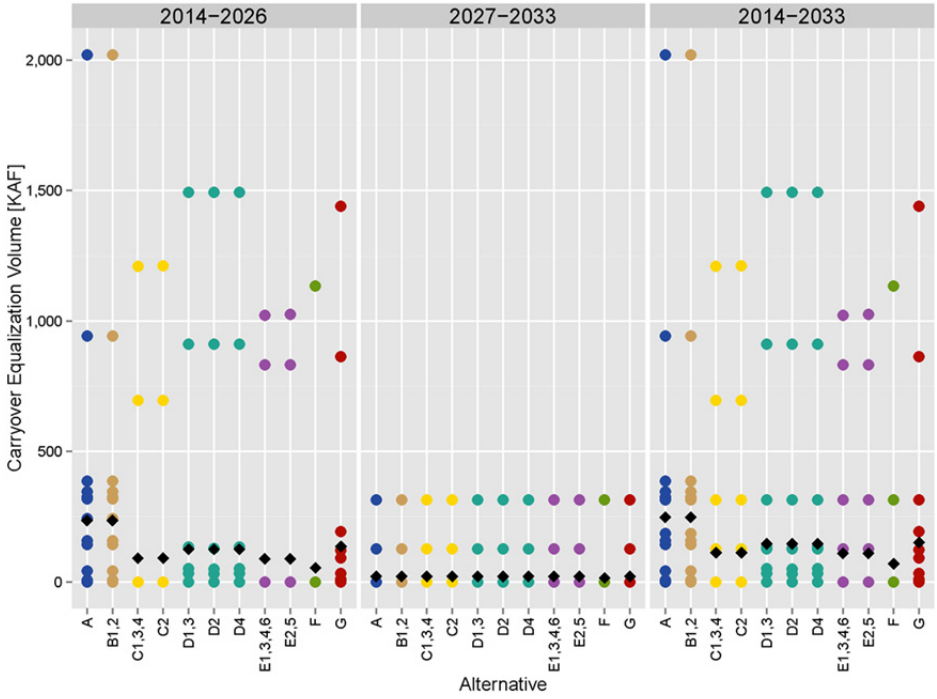

FIGURE D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the Water-Year Releases by Trace for Each of the Alternatives (Each value represents the median carryover equalization volume for one trace. Because there are few traces with more than one occurrence, the median value typically represents the only nonzero instance. For each alternative there are 21 possible carryover equalization values for each period and alternative combination [21 traces].)

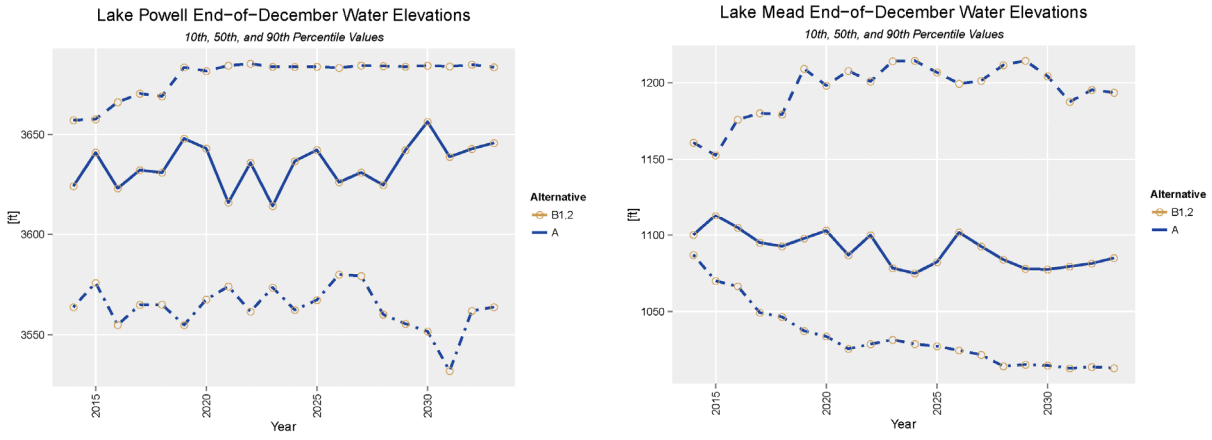

FIGURE D-9 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and B

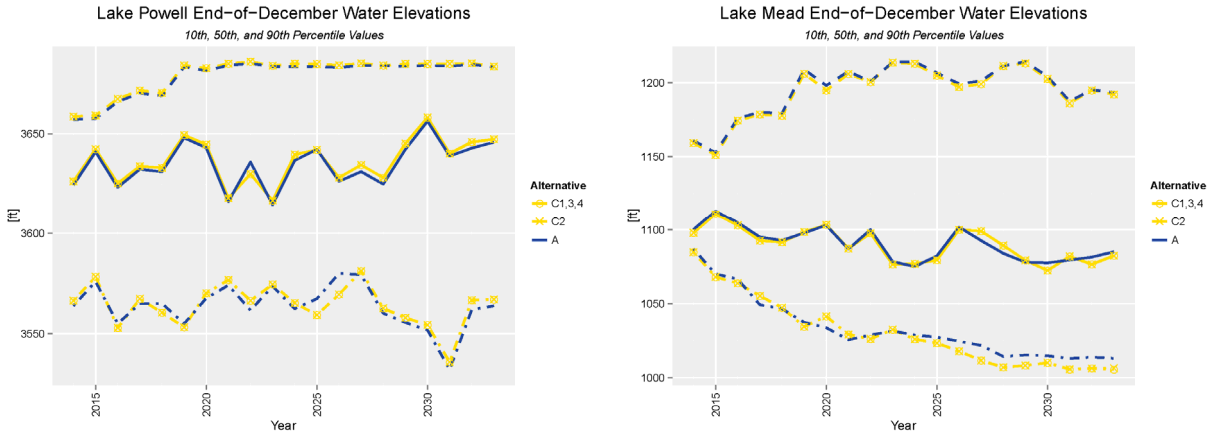

FIGURE D-10 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and C

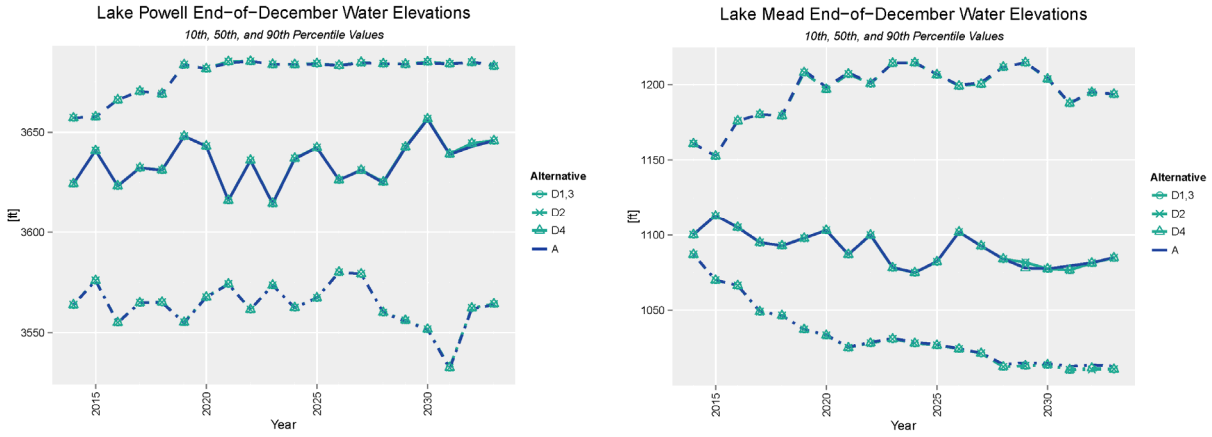

FIGURE D-11 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and D

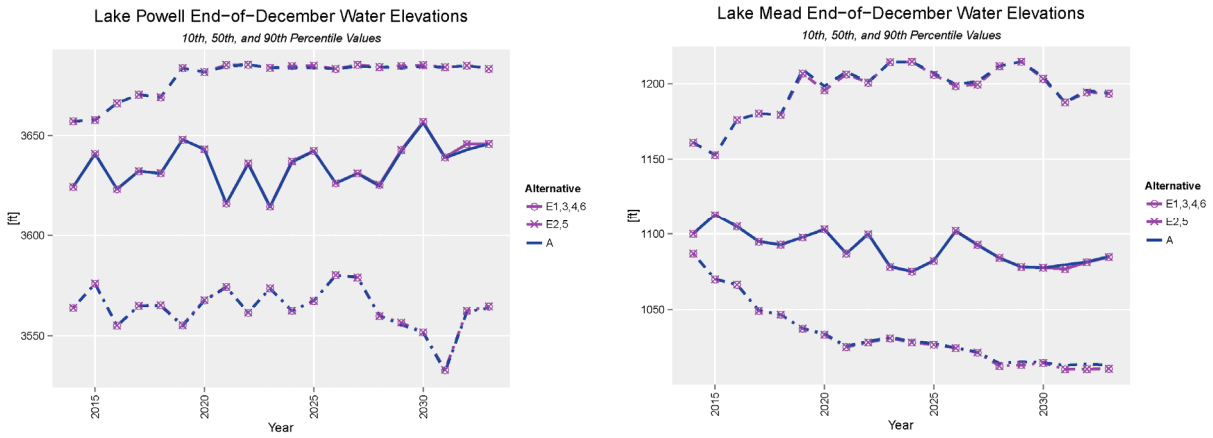

FIGURE D-12 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and E

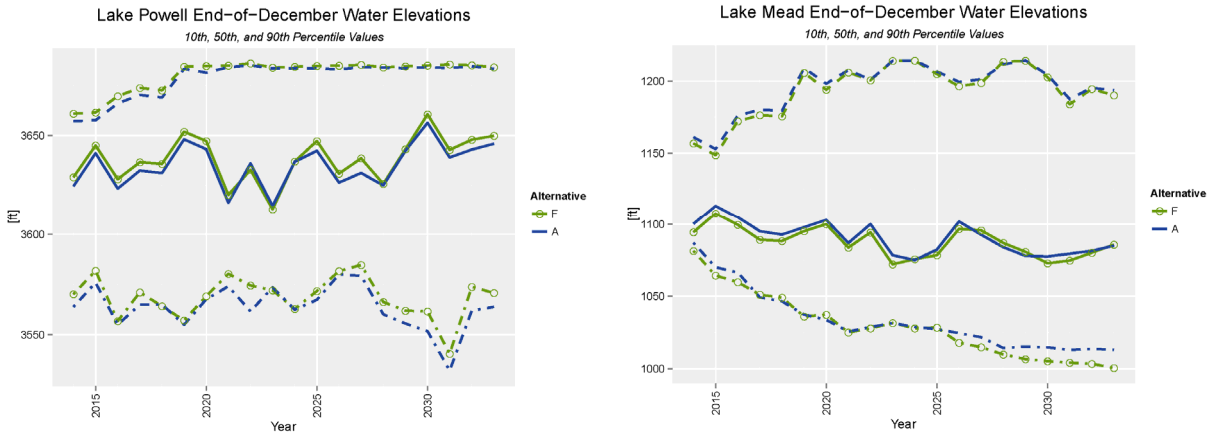

FIGURE D-13 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and F

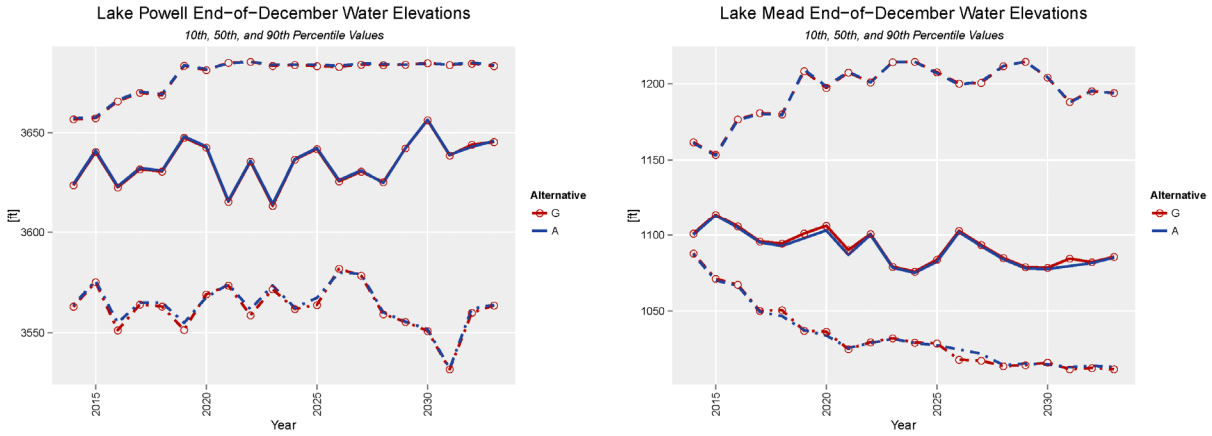

FIGURE D-14 Lake Powell (left) and Lake Mead (right) End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and G

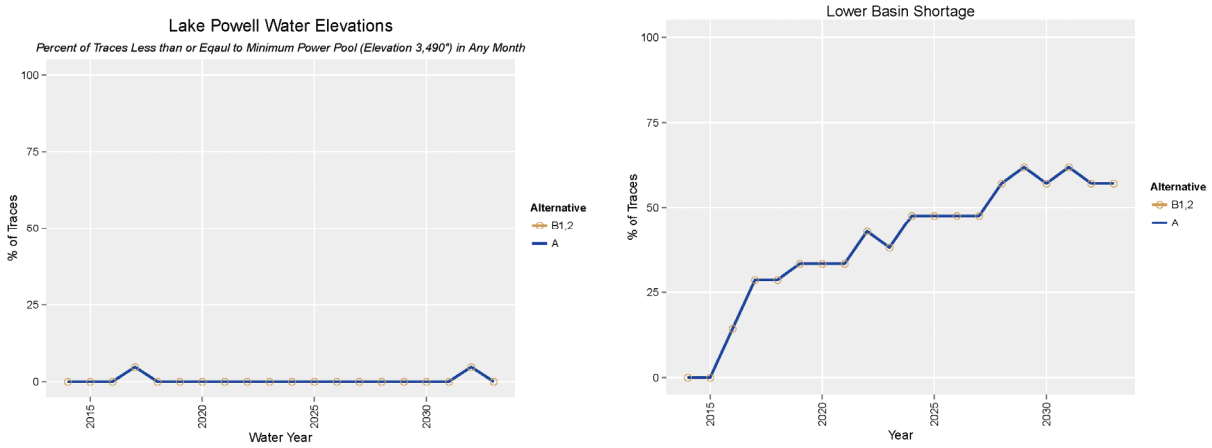

FIGURE D-15 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and B

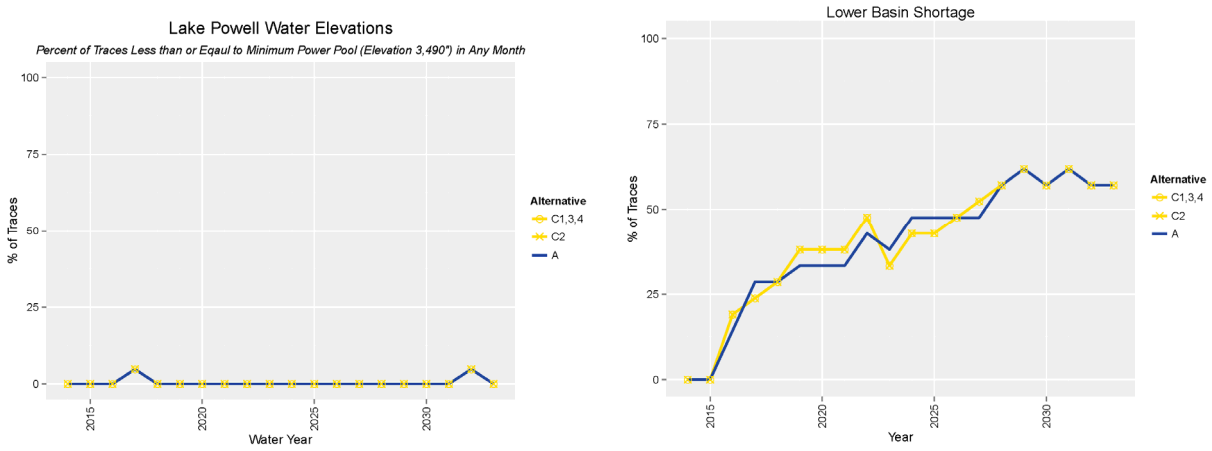

FIGURE D-16 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and C

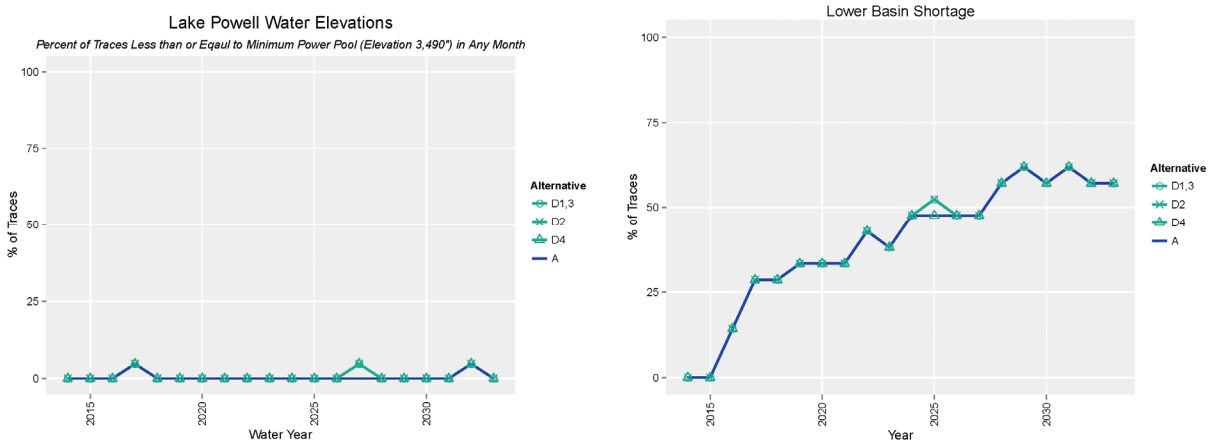

FIGURE D-17 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and D

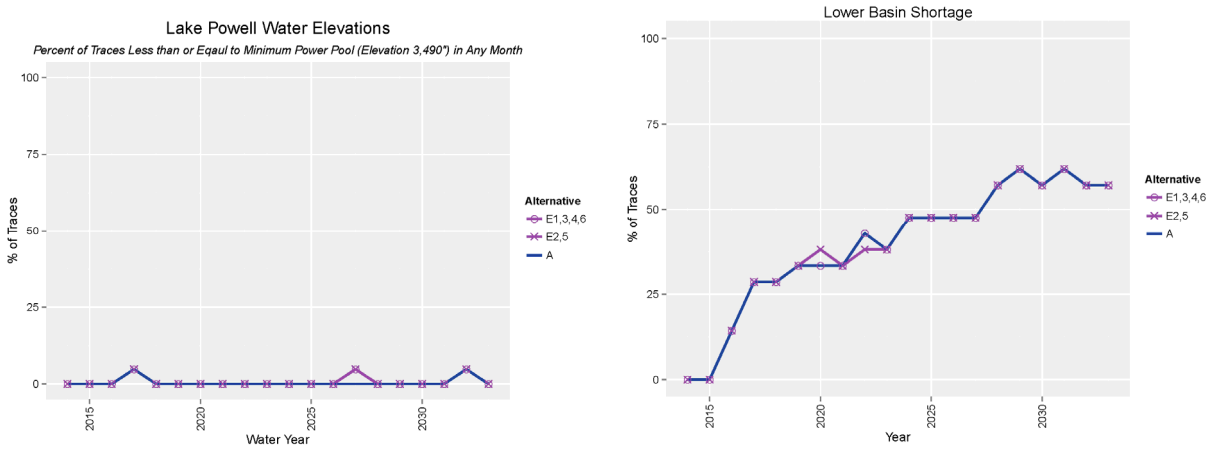

FIGURE D-18 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and E

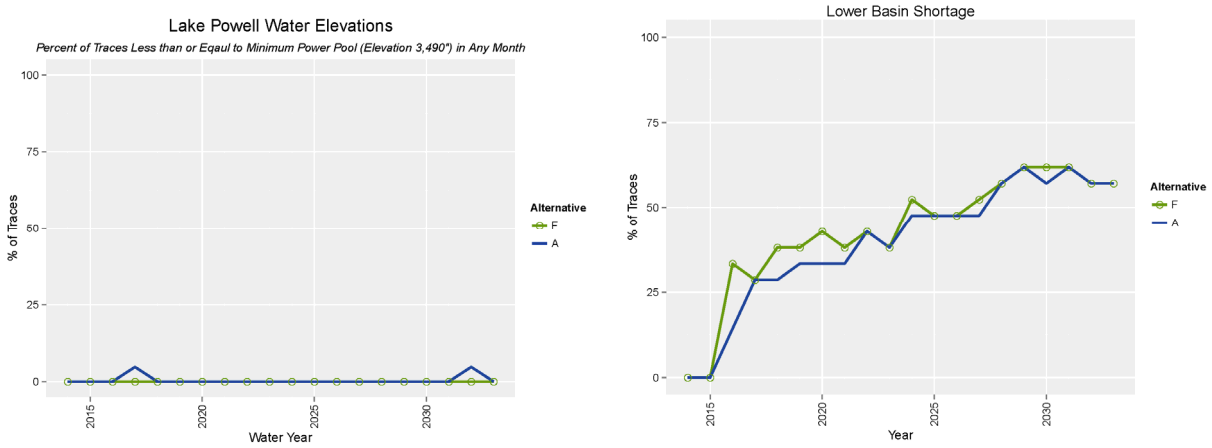

FIGURE D-19 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and F

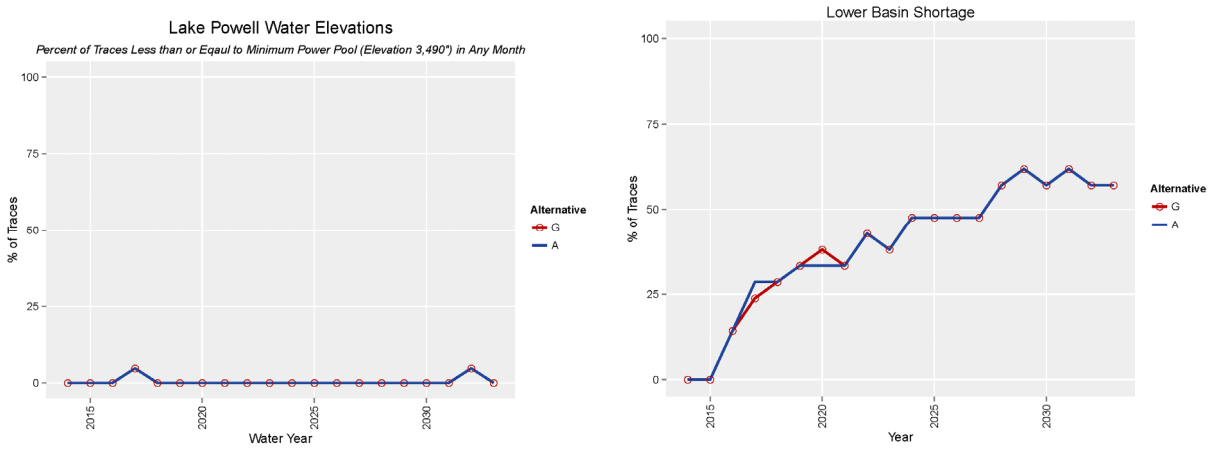

FIGURE D-20 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces under Alternatives A and G

D.3 REFERENCES

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APPENDIX E:

SEDIMENT RESOURCES TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX E:

SEDIMENT RESOURCES TECHNICAL INFORMATION AND ANALYSIS

E.1 INTRODUCTION

This technical appendix focuses on sediment resources. The sediment resource goal is to increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes. One interpretation of this goal is to promote and maintain sandbars downstream of Glen Canyon Dam for the benefit of other resources. Currently, there is no peer-reviewed model or program that can simulate or predict sediment bar response to Glen Canyon Dam operations. Because no such model is available, other information and analyses were used in this Environmental Impact Statement (EIS) to analyze the effects alternatives would have on sediment resources. The sand budget model, which is peer reviewed and was used in the 2011 high-flow experiment (HFE) protocol environmental assessment (EA) (Reclamation 2011), provides the best available modeling method to estimate the effects of different flows on the potential for sandbar growth.

Seven alternatives were analyzed. Some of these alternatives would use condition-dependent or experimental elements that would be implemented under an adaptive management framework that would allow modification of flow and non-flow actions as new information is obtained. Critical uncertainties were identified that could lead to changes in flow and non-flow actions; these were used to identify multiple long-term strategies for those alternatives with condition-dependent actions (Alternatives B, C, D, and E). These long-term strategies were essentially different versions of the analyzed alternatives. The condition-dependent experimental elements included in the 19 strategies that were analyzed are presented in Appendix C; a full description of the alternatives can be found in Chapter 2 of this EIS.

E.1.1 Analysis Period

Sediment analysis spanned water years 2014 through 2033 (i.e., October 1, 2013, to September 30, 2033) (Figure E-1). However, the hourly dam release data developed for the hydropower analysis (GTMax-Lite) followed a calendar-year framework (i.e., January 1, 2013, through December 31, 2033). Development of sediment data for simulation input were analyzed in terms of sediment years (i.e., July 1, 2013, through June 30, 2033), which coincides with the accounting periods currently used by the Bureau of Reclamation (Reclamation) for determining whether or not a HFE should be conducted (Russell and Huang 2010).

E.1.2 General Scope

In order to address uncertainty, the analysis conducted for this EIS covered a range of hydrology scenarios and tributary sediment delivery scenarios. Hydrologic futures were

developed using the Colorado River Simulation System (CRSS) (Appendix D). One-hundred and five 20-year hydrologic traces were developed from the 105-year period of record; for modeling (Section 4.2.1.1 of this EIS), every fifth hydrologic trace was used, yielding 21 potential hydrologic futures to be analyzed.

Three sediment input time series were developed to address uncertainty in the future delivery of sand to the Colorado River from tributaries. Two main tributaries—the Paria River and the Little Colorado River—deliver sand to the Colorado River downstream of Glen Canyon Dam and upstream of Lake Mead. Three 20-year sediment traces were developed for the two tributaries (Section E.2.1.3), spanning the available historical data.

In summary, there were 19 long-term strategies, 21 hydrology traces per long-term strategy, and three sediment traces per hydrology trace. This produced 63 simulations per long-term strategy, 1,197 simulations in all.

E.2 METHODS

Resource models were used to evaluate and compare the impacts of alternatives. Figure E-2 illustrates the inputs, intermediate calculations, and output of the models. This appendix will describe and discuss those parts of the flowchart circled in red: the modified sand budget model (including development of model inputs) and the sediment metrics.

E.2.1 Sand Budget Model

E.2.1.1 Model Description

A reach-based sediment budget model for the Colorado River from Lees Ferry (river mile [RM] 0) to approximately Bright Angel Creek (RM 87) was developed by the U.S. Geological Survey (USGS) (Wright et al. 2010). Using gage data at RM 30, RM 61, and RM 87, the model was calibrated and validated to the time period of 2002–2009. The model uses empirically based rating curves, which are formulated on a particle-size-specific basis. On the basis of observed transport rates, the transport function changes when flows exceed 25,000 cfs. Initial sand bed size and thickness are user-specified for each reach (RM 0–RM 30, RM 30–RM 61, and RM 61–RM 87), and a budget is developed by tracking the incoming and outgoing suspended sand flux for each reach. The incoming sand flux for RM 0–RM 30 consists mainly of Paria River inputs, and ungaged tributaries in the reach are assumed to be 10% of Paria River inputs. The ungaged tributaries for RM 30–RM 61 are assumed to be negligible, so the flux into the reach equals the flux out of RM 0–RM 30. The flux into RM 61–RM 87 consists of the flux out of RM 30–RM 61, contributions from the Little Colorado River, and ungaged tributaries, which are assumed to be negligible. Figure E-3 provides a schematic of the sand budget model.

E.2.1.2 Sand Budget Model Modifications

The sand budget model has been updated to meet the specific analytical needs since its inception. During analysis for the 2011 High Flow Experiment (HFE) Environmental Assessment (EA) (Reclamation 2011), a protocol was developed to determine whether a HFE could be implemented to improve/maintain the sandbar sediment resource (Russell and Huang 2010). The model was updated to include the HFE protocol and to identify the largest HFE that could be implemented within each sediment accounting period without causing the Marble Canyon sediment balance to be negative for that period. Marble Canyon is the focus of the sediment balance because (1) the sand budget model was calibrated and validated for the first 87 mi downstream of Lees Ferry; and (2) the gage record for the Little Colorado River is relatively short, and therefore there is less confidence in using the data for predictive purposes. The protocol in the model assumes that the implementation of an HFE occurs on April 1 for the spring accounting period and on November 1 for the fall accounting period.

For the LTEMP EIS, the water volumes used by each HFE were accommodated by adjusting monthly volumes in the rest of the water year instead of simply adjusting the releases for the remainder of the implementation month as was done for the HFE EA. One of two different reallocation schemes is implemented depending on the alternative: a sequential reallocation scheme or an average reallocation scheme.

The sequential reallocation scheme was applied to Alternatives A and B (because they have the same monthly release volume allocations). The months from which to reallocate water were specified in order, along with the minimum release volume for each month and the minimum release flow rate. Water was reallocated from the months, in order, until the water volume needed for an HFE was achieved. If the volume needed for an HFE could be borrowed from the first month in the list, then no water was borrowed from the following listed months. If the necessary HFE volume could not be taken from the first month without violating either the minimum monthly volume or the minimum release discharge, then the next month in the list was accessed for additional volume.

The average reallocation scheme was applied to the rest of the alternatives because their monthly release volume distributions differed from Alternative A. This method borrowed a percentage of the monthly volume from each month specified. The volume of water borrowed was not the same across months, but the percentage borrowed from each month was consistent; a higher monthly volume before reallocation means more water taken and applied to the HFE volume. There is a user-specified minimum release discharge that cannot be violated for the average reallocation scheme.

Another modification made to the sand budget model (which did not affect the triggering of an HFE) was to track the necessary parameters to determine whether a trout management flow (TMF) would be triggered for a water year. For a description of TMFs, see Chapter 2 of this EIS. A simple binary file was developed to identify water years meeting the requirement for a TMF; parameters indicating trout recruitment and the triggering of a TMF are all flow related.

The primary results from the first iteration of the modified sand budget model are two files per simulation: one identifying the timing and size of HFEs, and one identifying the timing of TMFs. This information is fed back to the GTMax-Lite model (Figure E-2) for refined hourly dam release hydrographs.

E.2.1.3 Modified Sand Budget Model Inputs

Primary model inputs to the sand budget model are (1) flow hydrographs and (2) tributary sand inputs. The initial conditions of sand bed thickness and average bed grain size were also specified; these values are constant across simulation and are not alternative dependent.

Flow Hydrographs

The model-predicted suspended sand transport rates were calibrated and validated (as part of the model development; Wright et al. 2010) at gage measurement locations, namely the gages at RM 30, RM 61, and RM 87. The flow hydrograph at these locations needs to be specified for the sand budget model and are developed using the Colorado River Flow, Stage, and Sediment (CRFSS) model. The CRFSS model has a one-dimensional unsteady-flow model component that routes a dam-release flow hydrograph and provides hydrographs at locations requested by the user. The CRFSS model uses average channel geometry based on previously measured cross-sections in Marble and Grand Canyons (Wiele and Smith 1996; Wiele et al. 2007). For each dam release hydrograph provided by GTMax-Lite (Figure E-2), there were three hydrographs developed by the CRFSS model (at RM 30, RM 61, RM 87) for use in the modified sand budget model.

Tributary Sand

Both the Paria River and the Little Colorado River have sediment records that were used to develop a time series of sand load (a sediment trace). Although the Little Colorado River record is for only 18.5 years, it is the best available dataset. Three sediment traces were developed for each tributary to address uncertainty in future tributary sand delivery. Sediment data were obtained from two sources: published data from the Grand Canyon Monitoring and Research Center (GCMRC 2015) and from Topping (2014). The period of record for the two tributaries and the sources of the data are presented in Table E-1.

The model simulation period covers 21 calendar years, which corresponds to 41 sediment accounting periods, or ~20.5 sediment years (Figure E-2). An index sequential approach was used to develop statistics for each record. In general, an index sequential method cycles through each year in a historic record and generates time series (or traces) for a specific duration; for years toward the end of the record, the requisite time period is achieved by "wrapping around" to the beginning of the record. This technique is typically used for hydrologic data cycling through water years (Reclamation 2007; Ouarda et al. 1997), whereas the method is employed here for sediment data and cycles through sediment years. The "wrap around" for the sediment analysis

means that for the Paria River, the fall 2013 accounting period is followed by the spring 1964 accounting period; likewise, for the Little Colorado River the fall 2013 accounting period is followed by the spring 1994 accounting period. The record for the Little Colorado River is short enough relative to the 21-year period that every index sequential sediment trace covers the entire period of record.

Paria River. Because fall 2013 is the first full accounting period for which an HFE would be considered in the simulation, only index sequential segments beginning with fall accounting periods are used in the statistical analysis. The three traces selected were approximately the 10%, 50%, and 90% non-exceedance traces from the index sequential statistics. The three selected traces for the Paria River also cover the entire period of record. Figure E-4 presents the sand input from the Paria River for the historical record grouped into accounting periods, along with the index sequential 41-accounting period (20.5-year) sand loads. Only the 20.5-year sand load sequences beginning with a fall accounting period are presented in Figure E-4; these are the data from which the statistics are developed for identifying three representative traces. Figure E-5 presents the cumulative sand load for the three traces that were identified for the use in the EIS modeling. Again, these traces were identified based on cumulative sand load and to ensure the entire historical record is represented in the modeling.

These three traces are not consistently low, medium, and high relative to each other throughout the 20-year period. Moving from beginning to end of the simulation period, s1 (sediment trace 1) is not always less than s2, and s2 is not always less than s3. In fact, s3 is comparable to s2, except in the last couple of years when the s3 trace jumps significantly; this jump corresponds to the fall 1980 accounting period. In addition, s1 has the most sediment contributions for approximately the first 3 years. These are three different sediment traces that were selected to be representative of the historical record.

Once the three sets of 41 accounting periods were identified for use in the simulation, the necessary simulation records (traces) were completed by applying the appropriate sections of the historical record. The periods of record used for s1, s2, and s3 are presented in Table E-2.

Little Colorado River. The record for the Little Colorado River is shorter than the simulation period, so every trace covers the entire period of record. In addition, the HFE protocol as implemented in the modified sand budget model assesses the balance of sand in Marble Canyon to determine whether an HFE is simulated. The balance of sand in Eastern Grand Canyon—and therefore the sediment input from the Little Colorado River—is less critical to the simulations and analysis performed for this EIS.

The index sequential method for the Little Colorado River was performed on a calendar year basis, and the simulation periods for s1, s2, and s3 are presented in Table E-3. Figure E-6 presents the sediment traces used as input for the modified sand budget model.

Initial Conditions

The initial conditions to be specified in the sand budget model for each reach are bed thickness and median bed sediment grain size, D_{50}. The initial conditions specified for the EIS analysis come from the best available data nearest the simulation start date of January 1, 2013. Wright et al. (2010) found that varying initial bed D_{50} by ±10% from the initial estimated values (0.4, 0.3, and 0.3 mm for Upper Marble Canyon [UMC], Lower Marble Canyon [LMC], and Eastern Grand Canyon [EGC], respectively) yielded between 3 and 7% difference in total flux for the three reaches; varying initial bed thickness from the initial estimated values (0.4, 0.5, and 0.5 m for UMC, LMC, and EGC, respectively) by ±10% yielded a difference in total sand flux of less than 0.5%. The simulations conducted for this analysis used initial condition values for UMC, LMC, and EGC of 0.46, 0.38, and 0.43 mm, respectively, for grain size and 0.30, 0.37, and 0.27 m, respectively, for bed thickness.

High Flow Experiments

The modified sand budget model identified the largest HFE that would not violate water and sediment availability rules. The HFEs that the model considered are user specified. Eighteen HFEs that are specified for this analysis (Table E-4), and HFEs 1–13 are consistent with the HFEs considered for the HFE EA (Reclamation 2011). Longer-duration HFEs (A–E in Table E-4) were suggested for consideration in the EIS, and two alternatives consider HFEs lasting longer than 96 hours: Alternative D and Alternative G. HFE C in Table E-4 was originally defined as lasting 240 hours at 45,000 cfs for Alternative G. Alternative D was crafted after seeing the results of the Alternatives A, B, C, E, F, and G (Section 2.2.4 of this EIS), and HFE C in Table E-4 was defined as 250 hours for this alternative.

Proactive spring HFEs would be triggered based on hydrology. Conceptually, a large snowpack in the mountains leads to a prediction of a wet year; if the predicted annual runoff volume is great enough (greater than 10 million ac-ft, or 10 maf), then a proactive spring HFE would be implemented. The purpose of this HFE is to redistribute the available bed sediment onto sandbars and channel margins so that it would be stored at elevations above those of the subsequent large runoff volume. The proactive spring HFE implemented in the model is identical to HFE 6 in Table E-4 in terms of peak discharge and duration at peak discharge.

E.2.2 Sediment Metrics

Prior to modeling for the LTEMP EIS, a number of metrics were crafted to evaluate the alternatives in terms of their performance with regard to the sediment resource goal. The metrics developed prior to modeling were surrogates intended to be representative of sediment resource response; it was assumed that if the surrogate performed well, the sediment resource also would respond well. The metrics developed were the sand load index (SLI), the standard deviation of high flows (SDHF), and the sand mass balance index (SMBI).

E.2.2.1 Sand Load Index (SLI)

The potential for building sandbars was estimated using the SLI, which is a comparison of the mass of sand transported at RM 30 when river flows ≥31,500 cfs relative to the total mass of sand transported at all flows, as shown in equation 1:

$$SLI = \frac{Q_{s,Q>31.5}}{Q_{s,total}} \quad (1)$$

where:

SLI = sand load index

$Q_{s,Q>31.5}$ = sand flux at RM 30 when river flows at RM 30 are greater than 31,500 cfs

$Q_{s,total}$ = total sand flux at RM 30 during analysis period.

The index varies from 0 (no sand transported at flows ≥31,500 cfs) to 1 (all sand transported at flows ≥31,500 cfs). An SLI of 0 would indicate that there are no flows above 31,500 cfs during a simulation; the alternative that there are flows above 31,500 cfs but no sediment flux occurring is for all practical purposes impossible.

The larger the SLI for an alternative, the more potential there is for bar growth. The SLI only estimates the potential for (and not actual) bar growth, because all sandbars have a maximum potential deposition volume; the closer any given bar is to full, the less deposition will occur (Wiele and Torizzo 2005).

E.2.2.2 Standard Deviation of High Flows (SDHF)

This index was intended to represent a greater likelihood of more robust sandbars. Historical sandbar surveys indicate that individual bars respond differently to different HFEs (Hazel et al. 2010). Some sandbars are smaller after a 45,000 cfs experiment. Equation 2 shows how this value is calculated for each water year, and the metric is averaged across the 20-water-year analysis period.

$$SDHF = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad (2)$$

where:

SDHF = standard deviation of high flows

N = sample size (in this case, 63 per alternative)

x_i= individual observed peak discharge, cfs

$\bar{x}$ = sample mean of peak discharges, cfs.

E.2.2.3 Sand Mass Balance Index (SMBI)

This index quantifies the amount of sand that is left in storage in Marble Canyon (RM 0 to RM 61) at the end of a simulation relative to the amount of sand that is present at the beginning of the simulation. This is the most direct application of the modified sand budget model; it tracks the amount of sand that comes into the individual reaches compared to the amount of sand that leaves the individual reaches (Figure E-7). This index is not directly representative of the resource goal. However, this metric does provide insight into how the amount of sediment in Marble Canyon is affected by dam operations. If more sand comes into Marble Canyon than leaves Marble Canyon, there will be an increase in stored sand, and a positive SMBI. Conversely, a greater amount of sand leaving Marble Canyon than entering will yield a negative SMBI.

E.3 RESULTS

Two iterations of the modified sand budget model were completed for each simulation (Figure E-2). The first iteration determined the timing and size of triggered HFEs, as well as identifying whether TMFs would be triggered. This information was passed back to GTMax-Lite where the hourly dam release hydrographs were refined based on the HFE schedule and TMF schedule.

The second iteration of the modified sand budget model did not allow additional HFEs to be implemented because the refined GTMax-Lite dam releases already include the HFEs and TMFs. The second iteration was used to obtain sediment-related data for sediment metrics to be calculated for each alternative.

E.3.1 HFEs Determined by Alternative

The sediment metrics for each alternative are closely related to the number of HFEs that occur for the alternative. The number of HFEs is not a sediment metric itself, but understanding the HFEs that occur under an alternative helps to clarify the sediment metrics discussed in the following sections. The average number of HFEs that occur (across 63 simulations per alternative) is compared, along with the number of HFEs that occur based on sediment trace (average across 21 simulations). Results for long-term strategies C3, E3, E5, and E6 are not presented in this section, because HFEs are not included in these long-term strategies.

Figure E-8 presents the breakdown of the average number of HFEs for each long-term strategy (across 21 hydrology and 3 sediment traces) by HFE type (Table E-4). Only Alternatives D and G allow for HFEs longer than 96 hours, and Alternative G has the most HFEs on average. Alternatives A and B have the fewest HFEs on average. Under Alternative A (no-action alternative) the HFE protocol would expire in 2020, so a little more than half of the

simulation period does not have HFEs simulated. Alternative B stipulates that HFEs would not be implemented more often than once every 2 years. This limits the number of HFEs to one-fourth of the simulation period. Alternative F has a 24-hour 45,000-cfs flow at the beginning of the spring peak period (e.g., on May 1) as part of the alternative definition. Those experiments are not captured in Figure E-8; this figure represents the sediment-triggered and hydrology-triggered HFEs identified from the modified sand budget model. More information on the alternative definitions can be found in Chapter 2 of this EIS.

Figure E-9 compares the average number of HFEs simulated (not by HFE type) for the three different sediment traces. Remember that s1, s2, and s3 do not equate to low, medium, and high; they are three sediment traces intended to be representative of the historical sediment records in terms of exceedance probability, as well as ensuring that the entire period of record is represented by the three traces. Figure E-9 shows some variability among the sediment traces, although the general trends between alternatives as shown in Figure E-8 are maintained. Sediment trace s2 commonly has the lowest number of simulated HFEs. Sediment trace s1 has the most simulated HFEs for Alternatives A, B, and F. Sediment trace s3 has the most simulated HFEs for Alternatives C (except long-term strategy C4), D, and G. Sediment traces s1 and s3 are very similar for Alternatives E (except long-term strategy E4) and F with regard to the number of HFEs triggered.

The majority of HFEs are triggered in the fall, because sediment from the Paria is related to monsoonal precipitation and the majority of the sediment delivery occurs in the fall. Fall HFEs account for 77% of all HFEs simulated; the remaining 23% of HFEs that occur in the spring include proactive spring HFEs, which are triggered by hydrology (wet years) and not by sediment delivery.

E.3.2 Metrics

Plots have been developed for each metric to statistically describe the alternative performance from the 63 different simulations for each long-term strategy. The statistics represented in these plots include a weighting scheme based on each sediment trace's exceedance probability. The weighting scheme for the box and whisker plots is as follows: s1 = 0.1754, s2 = 0.6313, s3 = 0.1933. In addition, a different set of weights was used for a climate change analysis to represent the fact that future hydrology in the Upper Colorado River Basin is expected to be drier than the historical hydrology (Section 4.16.1.2 of this EIS). Plots using climate change weighting are provided for each sediment resource metric in Section E.3.3.

The box and whisker plots provide information on the following statistical representations of the distribution of performance across 63 simulations per long-term strategy: minimum, maximum, mean, median, 25th percentile, and 75th percentile, as described in Figure E-10.

E.3.2.1 Sand Load Index (SLI)

The SLI as described in Section E.2.2.1 reflects the potential for sandbar growth. Figure E-11 presents SLI values for all long-term strategies. Overall, Alternative G has the highest SLI values, followed by Alternatives F, D, C, and E. Alternatives A and B have the lowest SLI values, which is consistent with the number of HFEs that can be triggered under each alternative.

Figure E-11 matches the general pattern of the number of HFEs shown in Figure E-8. One notable exception is Alternative F; Figure E-8 represents the sediment-triggered and hydrology-triggered HFEs, whereas Figure E-11 includes data from the alternative-defined spring experiments that occur each year under Alternative F regardless of sediment availability.

There is a nonzero SLI for long-term strategies C3, E3, E5, and E6, even though there are no HFEs simulated for these long-term strategies. Some hydrologic years are wet enough to necessitate flows above 31,500 cfs being released from Glen Canyon Dam as normal (non-HFE) operations. The sand transported while flows are above 31,500 cfs under these conditions contributes to a nonzero SLI.

E.3.2.2 Standard Deviation of High Flows (SDHF)

As described in Section E.2.2.2, this metric was intended to reflect variability in flow, which was thought to be positively related to the ability to build more robust sandbars. Figure E-12 presents the statistical distribution of SDHF values for the long-term strategies, which is similar to the general pattern shown for the SLI in Figure E-11.

The SDHF mean is plotted against the SLI mean in Figure E-13. A strong correlation exists between the SDHF and the SLI. Therefore, the SDHF was not considered with the SLI for alternative comparison in this EIS.

E.3.3 Sand Mass Balance Index (SMBI)

This metric does not represent the sediment metric directly (Section E.2.2.3); however, it does provide an index to relative changes in sediment balance that would result under different alternatives. If an alternative reduces the overall sediment balance (the amount of sediment in the sandbars and eddies, and on the channel bed) then this net depletion will result in less sediment being available for bar building during future HFEs.

The only long-term strategies that do not significantly reduce the sediment balance over the duration of the simulation period are those that do not have HFEs (long-term strategies C3, E3, E5, and E6), as shown in Figure E-14. The mass balance of sediment is affected by high flows. HFEs have been called a “double-edged sword” by Rubin et al. (2002) because they necessarily export relatively large volumes of sand in order to transfer sand to high-elevation portions of some sandbars (Wright et al. 2008). There is an inverse relationship between sandbar

building potential and sediment balance; more sandbar building potential reduces the sediment remaining within the channel. Figure E-15 plots the mean SMBI relative to the mean SLI. Although there is variation among the alternatives, a higher SLI tends to create a larger net deficit of sand (lower SMBI value) in Marble Canyon. Two exceptions are Alternatives B and D. Alternative B would produce a large net deficit in SMBI but has a relatively low SLI; the relatively low SLI is a result of the limited number of HFEs under this alternative, but this does not produce a correspondingly low SMBI because the larger daily fluctuations during intervening flows transport more sediment. Alternative D has relatively high SMBI and SLI values; more HFEs (including longer duration HFEs) yields the higher SLI value and the combination of relatively even monthly distributions along with relatively small daily fluctuations contributes to a higher SMBI.

E.3.4 Alternative Performance under Climate Change Scenarios

Weights were applied to hydrology traces to reflect expected changes in hydrology under climate change. This weighting scheme was intended to represent future hydrology in the basin, which is expected to be drier than the historical hydrology (Section 4.16.1.2 of this EIS). Figure E-16 presents SLI values calculated under the long-term strategies using the climate change weights. Figure E-17 shows that there is little difference in long-term strategy performance in terms of SLI when comparing the climate change weights to the historical weights. The small difference that does exist could be described as a slight improvement in performance under the climate change weighting.

Figure E-18 presents SDHF values under long-term strategies when the climate change weights were used. Figure E-19 shows that there was little difference between SDHF values calculated using the climate change weights and those calculated using the historical weights. The most notable difference is a slight reduction in the 75th percentile, which indicates less variability in the metric when climate change weights are used.

Figure E-20 presents SMBI values under long-term strategies when the climate change weights were used. Figure E-21 shows that there was some difference between SMBI values calculated using the climate change weights and those calculated using the historical weights. When climate change weights were used, the interquartile ranges and the means were higher, which indicates less net depletion. Interestingly, the minima and maxima do not change appreciably, meaning these extremes are likely due to specific simulations (combination of hydrology and sediment traces).

E.3.5 Relative Impacts of Dam Operations and Hydrology on Performance

Modeling results were evaluated to determine the effect of the following management actions on sediment resources: proactive spring HFEs, spring HFEs, fall HFEs, TMFs, daily fluctuations and intervening flows, load-following curtailment, low summer flows, and general hydrology (wet vs. dry). These evaluations were made using the model runs of the various long-

term strategies, which included some, but not necessarily all, elements. Additional modeling did not take place to answer these questions.

HFEs, whether they are proactive spring HFEs, spring HFEs, or fall HFEs, are the most influential management action in terms of sediment resources. Whether a given HFE type (magnitude and duration) occurs in the fall or the spring does not affect the sediment resource differently. The timing of sediment delivery from the Paria River (during the summer-fall monsoon season) leads to larger and more frequent fall HFEs, but that is due to input, not management actions.

TMFs did not show a significant impact on the sediment resource. This is due in part to the fact that one of the primary factors in triggering a TMF is a spring HFE, which, in the model, increased trout recruitment (Section 4.4.1.2 of this EIS). Spring HFEs have a relatively large effect on the SLI and SMBI that tends to mask a TMF's impacts on sediment. Another reason TMFs have little impact on sediment because of their effect on release volume. In order to provide the flow for TMFs, the average flow in the remainder of the late spring/early summer period tends to be lower than if there were no TMF. The effect of higher flows for the TMFs and the lower flows means a very minor difference in net sediment transport.

Figure E-22 shows the time series of flow (Q) at RM 30, the SLI, and the SMBI for the simulation hydrology trace 1/sediment trace 3 (t01s3) for the period March 1, 2021, to August 1, 2021. Long-term strategies C1 and C2 are plotted for comparison. Both simulations have the same HFE triggered in spring 2021; however, TMFs are implemented under long-term strategy C1 but not under long-term strategy C2. In the figure, the TMF flows can be seen in early May, June, and July in the top graph. Notice the time series of SLI and SMBI show a strong signal response in early April due to the HFE, and practically no signal response from the TMF flows.

Alternatives C and E differ in daily fluctuation levels, as well as monthly volume allocations; this is the best comparison we can make (without performing targeted modeling) on the effects of daily fluctuations. Alternative C has lower daily fluctuations than Alternative E, but has relatively high spring volume compared to the more even monthly pattern of Alternative E. Although lower daily fluctuations reduce sediment transport, higher monthly volumes increase transport. It was not possible to reconcile the relative importance of daily fluctuations and monthly volume allocations without additional modeling. However, Alternative C and Alternative E were compared using the long-term strategy where no HFEs are allowed (long-term strategies C3 and E3). This comparison takes into account both daily fluctuations and monthly volume allocations. There was no difference in SMBI values between long-term strategies C3 and E3 (Figure E-23), and there was a minor difference in SLI values (Figure E-24). Because there are no HFEs in long-term strategies C3 and E3, all of the values for SLI are below 0.2 and any differences between these alternatives are minor.

Load-following curtailment is a management action intended to retain sediment for HFEs by reducing daily fluctuations before and/or after the HFE for a period of weeks or months. Load-following curtailment is specified as fluctuations being limited to ±1,000 cfs about the mean daily flow (a 2,000 cfs range of fluctuation). This management action does not appear to

make a difference in the modeled metric values, because an HFE will necessarily reduce the non-HFE mean flow around which daily fluctuations occur; the daily fluctuations associated with lower means tend to have fluctuation ranges not much greater than the ±1,000 cfs specified for load-following curtailment. Figure E-25 shows the smaller fluctuation range leading up to a fall HFE and the associated impact on SLI and SMBI (hydrology trace 6, sediment trace 3). Long-term strategies E1 and E2 are compared here, but the same comparison could be made using other long-term strategies (C1 and C2 or D1 and D2) with similar trends. Although there are differences in metric values between long-term strategies E1 and E2 for the months following the HFE, the SMBI is different by only 9 ktons at the end of the water year, and the SLI is the same by the end of the water year.

Low summer flows are a management action intended to provide warmer water for humpback chub during the summer. These lower flows would also be expected to conserve sediment inputs during the monsoon period. Implementing low summer flows in the summer requires increasing average monthly release volumes in other non-summer months (especially in the spring), thereby counteracting, in the long term, any short-term increase in sediment conservation (Figure E-26).

Annual inflow volume that reflects annual variation in precipitation and runoff is the main driving force on sediment processes. Release volumes are governed by legal release requirements (Section 1.9 of this EIS). For the SLI, wetter hydrology means a lower metric value (Figure E-27). This is true for the long-term strategies that do not have limitations on the number of HFEs that can be triggered. The trend lines with a positive slope in Figure E-22 are Alternative A (no HFEs after 2020), Alternative B (long-term strategies B1 and B2; not more than one HFE every 2 years), and long-term strategies C3, E3, E5, and E6 (no HFEs). Based on modeled SMBI values, wetter hydrology is expected to transport more sediment downstream under all long-term strategies (Figure E-28).

E.4 LAKE DELTAS

The impact of sediment delta formation due to different alternatives must be inferred, because there are no models for this physical process. The following discussion and conclusions are based on existing data and on some of the modeling data for the sediment resource alternative analysis.

Lake deltas are formations that occur when sediments transported in high-energy riverine flow fall out of the water column as the river enters a lake and loses energy. The Colorado River, along with a number of smaller rivers (that used to be tributaries to the Colorado River but are now emptying directly into Lake Powell or Lake Mead) have deltas that form in locations determined by reservoir elevation. As the elevations of the reservoirs change, the locations of the deltas will also change (Figure E-29).

Lake Powell and Lake Mead deltas can be grouped into two categories: those deltas whose size and location would be affected by dam operations, and those whose location, but not size, would be affected by dam operations.

Only the Colorado River delta in Lake Mead can be affected in terms of both location and size; all other deltas' positions are affected by reservoir elevation (and their delta size is unaffected by dam operations). Using historical data from the GCMRC data portal (http://www.gcmrc.gov/discharge_qw_sediment/stations/GCDAMP), less than half (approximately 46%) of the suspended sand load reaching the gage above Diamond Creek (USGS gage 09404200) since October 2002 can be accounted for as suspended sand leaving Marble Canyon (USGS gage 09383100). The other half of the suspended sand reaching Diamond Creek comes from tributaries downstream of Marble Canyon, most notably the Little Colorado River. Figure E-30 compares the cumulative sand load above Diamond Creek (RM 225) to the cumulative sand load at Desert View (RM 61). This figure demonstrates that the amount of sediment passing RM 225 is approximately 22,000 ktons in the approximately 12.5-year time span since October 2002; this can be extrapolated to about 35,200 ktons of sand for a 20-year period (the same duration as the LTEMP analysis period). Similarly, the approximately 10,000 ktons of sand that have passed RM 61 since October 2002 can be extrapolated to approximately 16,200 ktons of sand for a 20-year period.

The mean SMBI resulting from the 20-year simulations indicates that there may be anywhere from 1,000 to 3,300 ktons of net loss in Marble Canyon sand, depending on the alternative. This decrease in Marble Canyon sand increases the amount of sand going past RM 61 by approximately 6% for Alternative A and 20% for Alternative F, as compared to historical data. Assuming all of the sand leaving Marble Canyon eventually passes Diamond Creek, these increased fluxes leaving Marble Canyon represent less than a 10% change in sand flux at RM 225 compared to the historical data.

The alternatives considered will have minimal impacts on the size of the Colorado River delta in Lake Mead, which is the only delta that could be affected in terms of size and location by Glen Canyon dam operations.

The positions of deltas in Lake Powell and Lake Mead are directly affected by reservoir elevation (Figure E-29). Changes to reservoir elevations are calculated in the CRSS model (Section 4.1 and Appendix D of this EIS). The elevation of the reservoirs is compared to full pool elevations of 3,700 ft for Lake Powell and 1,229 ft for Lake Mead. The reservoir elevations from the alternatives are compared on a monthly basis and minima, means, and maxima were determined for the 63 simulations under each alternative. Figure E-31 presents the pool elevation for Lake Powell and Figure E-32 presents the pool elevation for Lake Mead. There is more variability related to differences in hydrology (compare the minimum and maximum for a given month) than there is related to different alternatives (compare colors across months). Pool elevations are ultimately controlled by regional hydrologic conditions and will not be affected by the alternatives. Alternative F is slightly different than the other alternatives because the monthly release volumes are low through winter. This small difference is not as pronounced as the variability due to annual inflow.

E.5 LIMITATIONS AND KNOWN ISSUES

E.5.1 Geographic Scope

The geographic scope of this EIS includes the Colorado River from Glen Canyon Dam downstream, and west, to Lake Mead (Section 1.5.1 of this EIS). This geographic scope in terms of Colorado River Mile is from RM 15 (Glen Canyon Dam; RM 0 is at Lees Ferry) to RM 347 (Hoover Dam). The numerical model upon which the sediment resource analysis is based extends from RM 0 to RM 87, although uncertainty in sand load from the Little Colorado River limited the analysis to Marble Canyon (RM 0 to RM 61).

E.5.2 Modeling Improvements

The average reallocation scheme (Section E.2.1.2) requires specification of a minimum flow rate about which fluctuations occur. The modeling for alternatives that use the average reallocation scheme and that allowed for daily fluctuations (Alternatives C, D, and E) have a fluctuation range specified at 5,000 cfs to 8,000 cfs. Due to differing up- and down-ramp rates, the average discharge is not 6,500 cfs, but is closer to 6,521 cfs. Alternatives C and E used a specified flow rate of 6,500 cfs, but this error was found before modeling of Alternative D, and 6521 cfs was used for this alternative. Fixing the minimum flow rate for Alternatives C and E may result in a small adjustment to the results, but should not change relative rankings among alternatives.

Load-following curtailment was not implemented for all long-term strategies of Alternatives C and E. Fixing this issue is not expected to affect modeling results.

In a few cases during the modified sand budget modeling, sufficient water volume was identified to sustain an HFE; however, the water surface elevation in Lake Powell was below the minimum power pool intake elevation. This did not allow GTMax-Lite to develop refined hourly flows. In such cases, the sand budget model for the appropriate simulation(s) was run again without allowing an HFE to occur during the problem accounting period. A potential fix for this issue could result in the occurrence of a small HFE. This fix is expected to affect results for a given simulation; however, when considering the averaging across 63 simulations, the net effect is expected to be small.

Initial conditions for bed thickness and bed material size may not have been consistent between the first and second runs of the modified sand budget model for all long-term strategies. Wright et al. (2010) found that varying initial conditions by ±10% made less than a 7% difference in model results, so this fix is not expected to make a difference in alternative analysis.

One of the long-term strategies for Alternative D (D2) included sustained low flows for benthic invertebrate production (Section 2.2.4 of this EIS). The set of months from which water is reallocated to support an HFE is not the same set of months when these sustained low flows

are implemented, and implementing this in the model proved iterative and perhaps not as representative as it could be. Further modification to the sand budget model may improve the implementation of this flow management action; anticipated effects of this effort are unknown.

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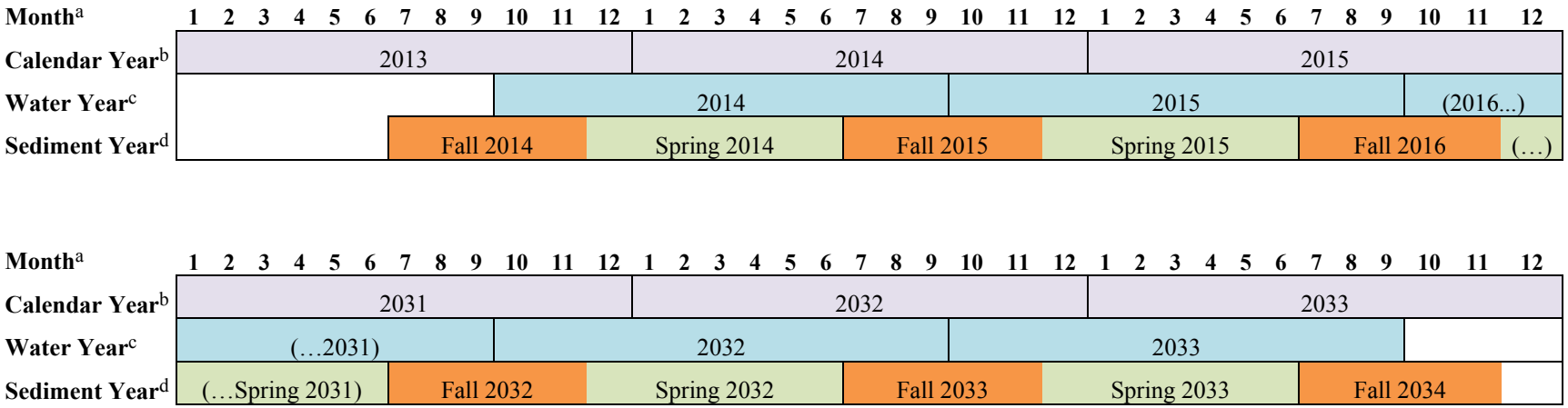

[a] 1 = January; 2 = February; 3 = March; 4 = April; 5 = May; 6 = June; 7 = July; 8 = August; 9 = September; 10 = October; 11 = November; 12 = December.

[b] Model simulations run for 21 calendar years.

[c] Analysis of alternatives covers 20 water years.

[d] Two accounting periods (spring/fall) per sediment year.

FIGURE E-1 Comparison of Calendar, Water, and Sediment Years

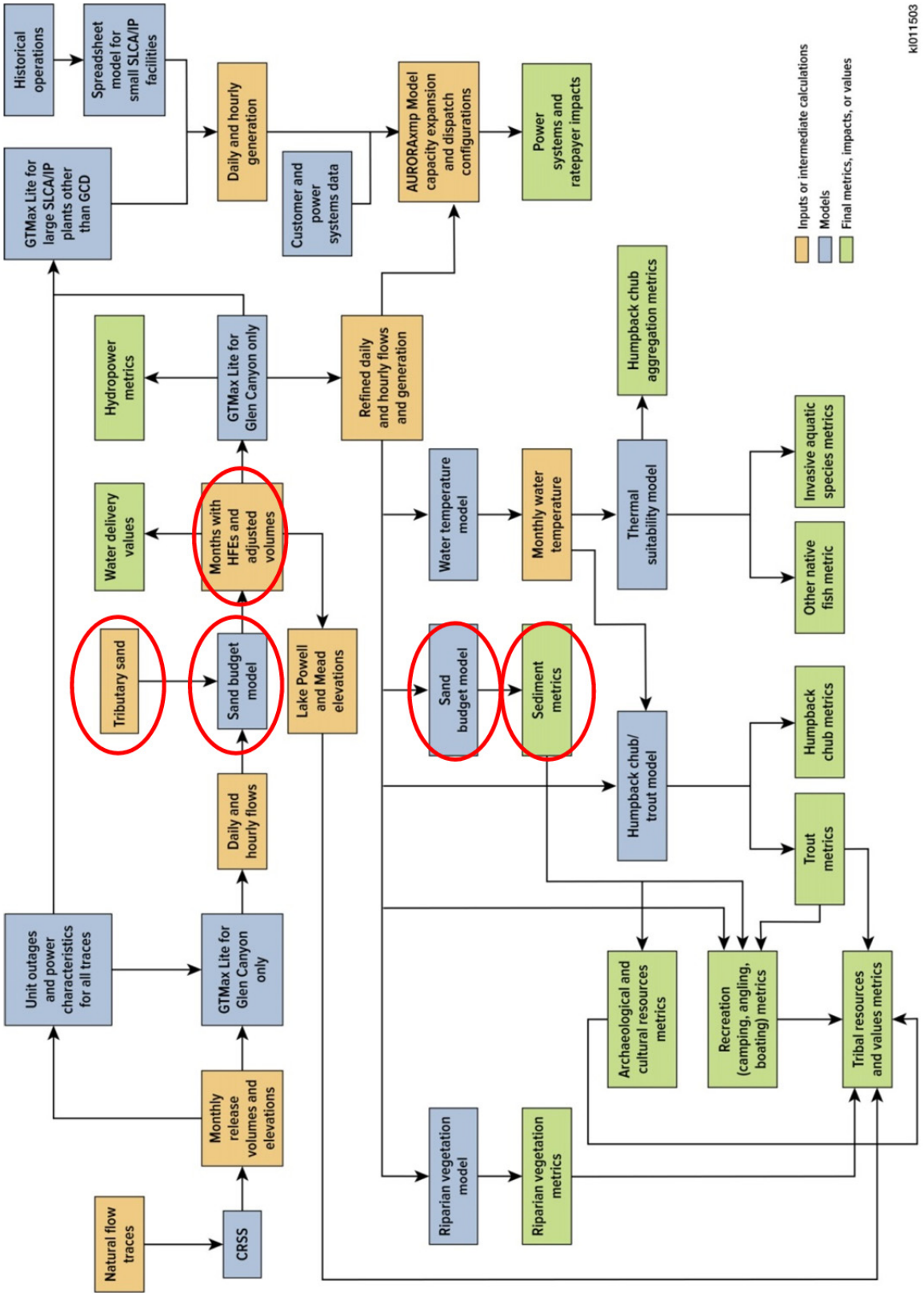

FIGURE E-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output

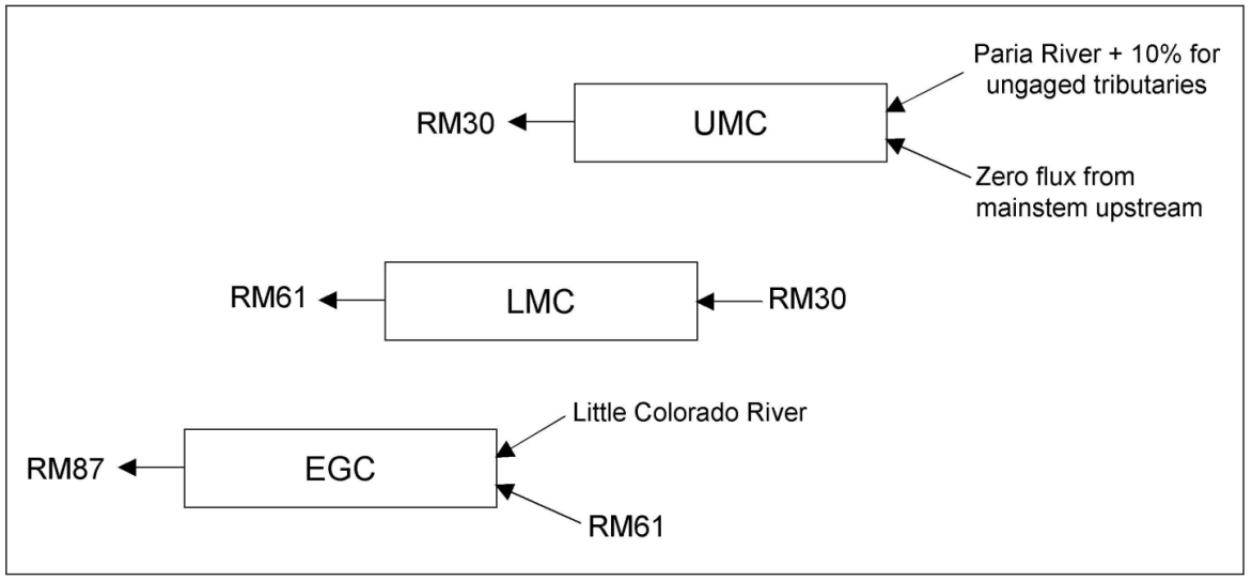

FIGURE E-3 Conceptual Schematic of the Sand Budget Model (UMC = Upper Marble Canyon; LMC = Lower Marble Canyon; EGC = Eastern Grand Canyon)

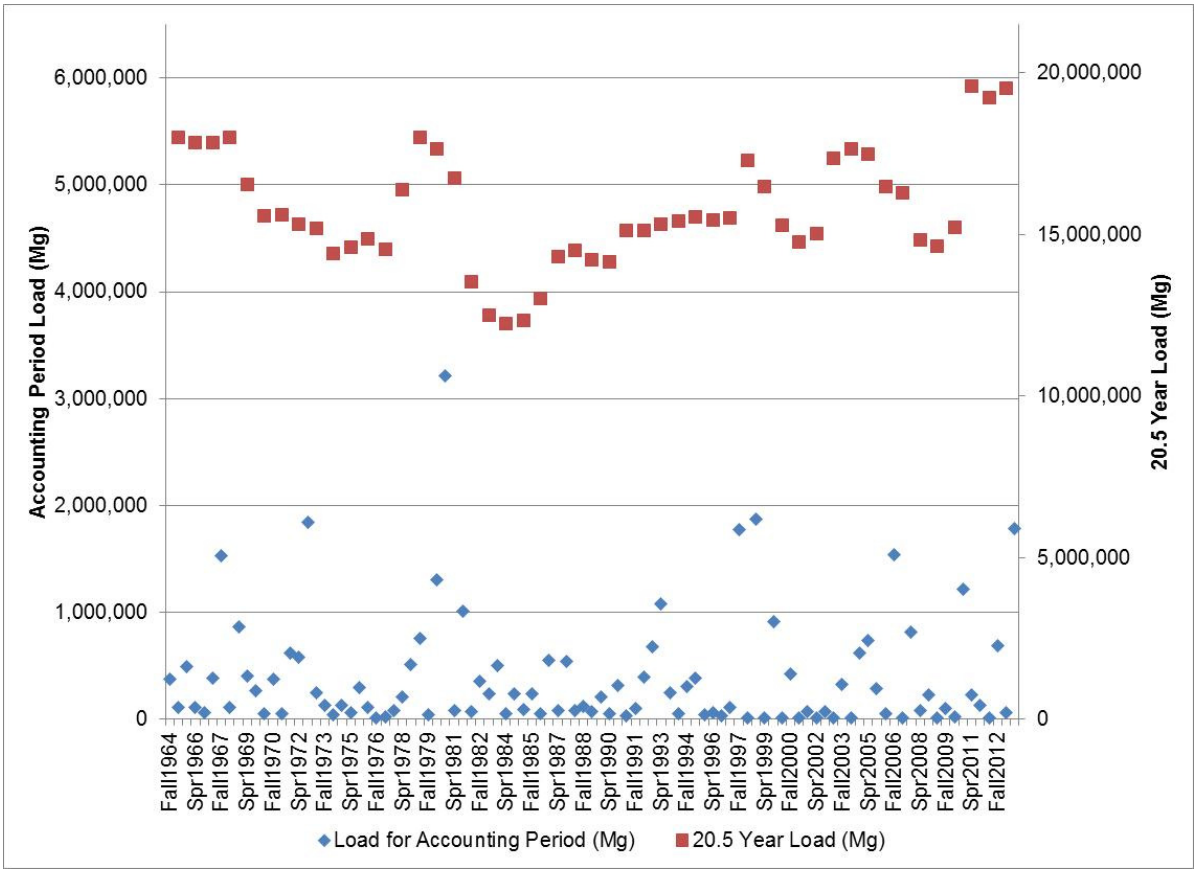

FIGURE E-4 Historical Paria Sediment Load per Accounting Period and the 20.5-year Load for the Trace That Begins in Each Fall Accounting Period

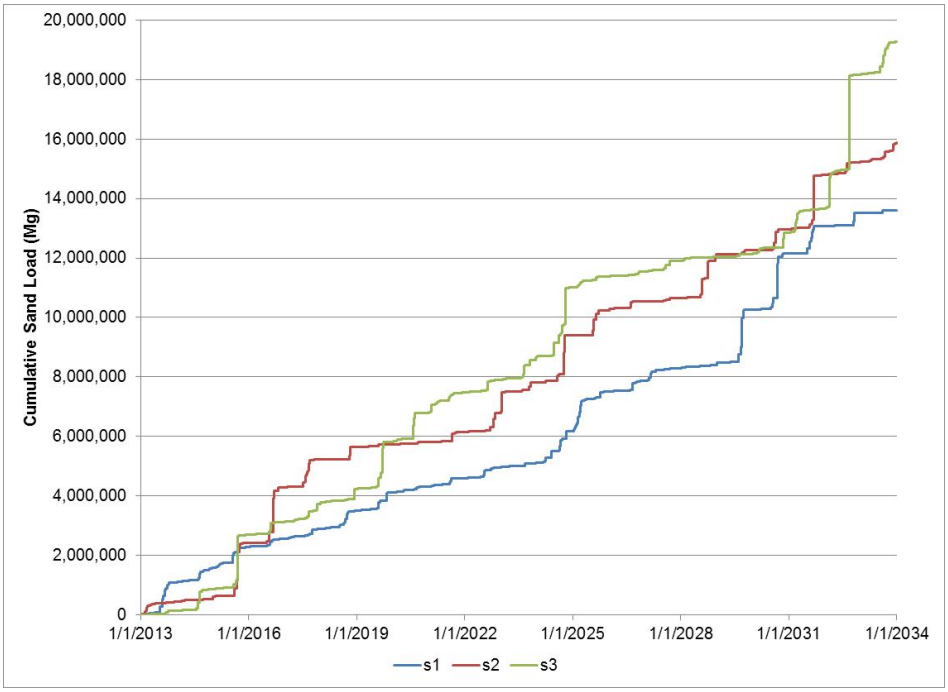

FIGURE E-5 Sediment Traces s1, s2, and s3 for the Paria River (presented as cumulative load) Used in the Modeling to Account for Uncertainty in Future Delivery

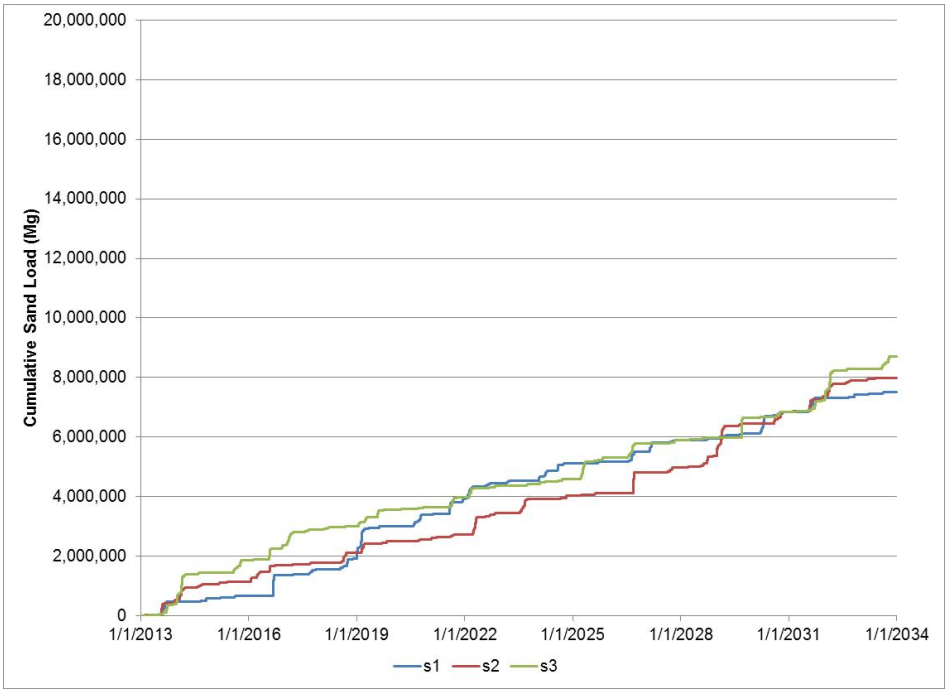

FIGURE E-6 Little Colorado River Sediment Traces (presented as cumulative loads) for s1, s2, and s3 Used in the Modeling to Account for Uncertainty in Future Delivery

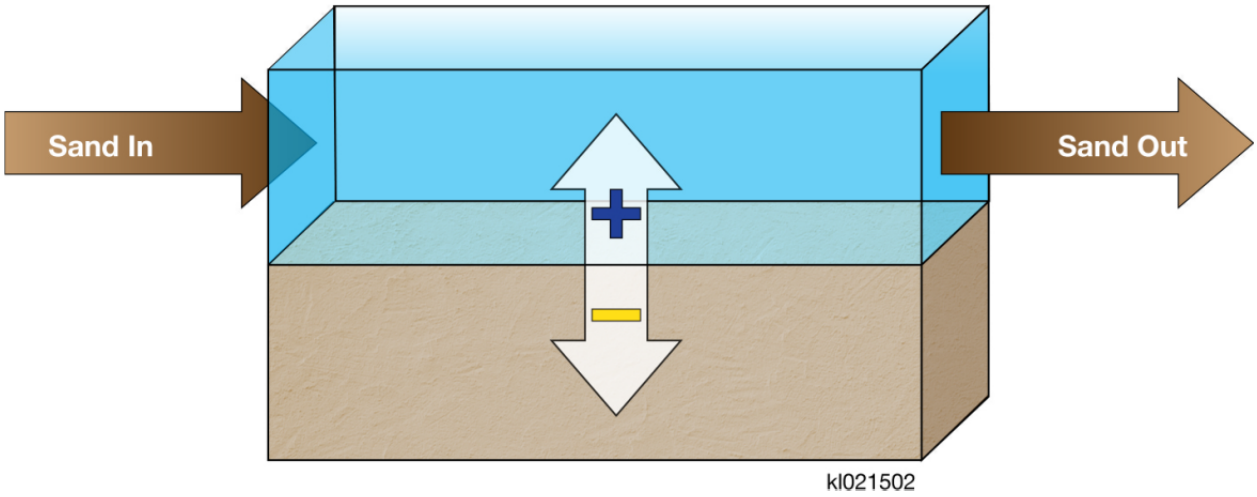

FIGURE E-7 Conceptual Representation of the Sand Mass Balance Index

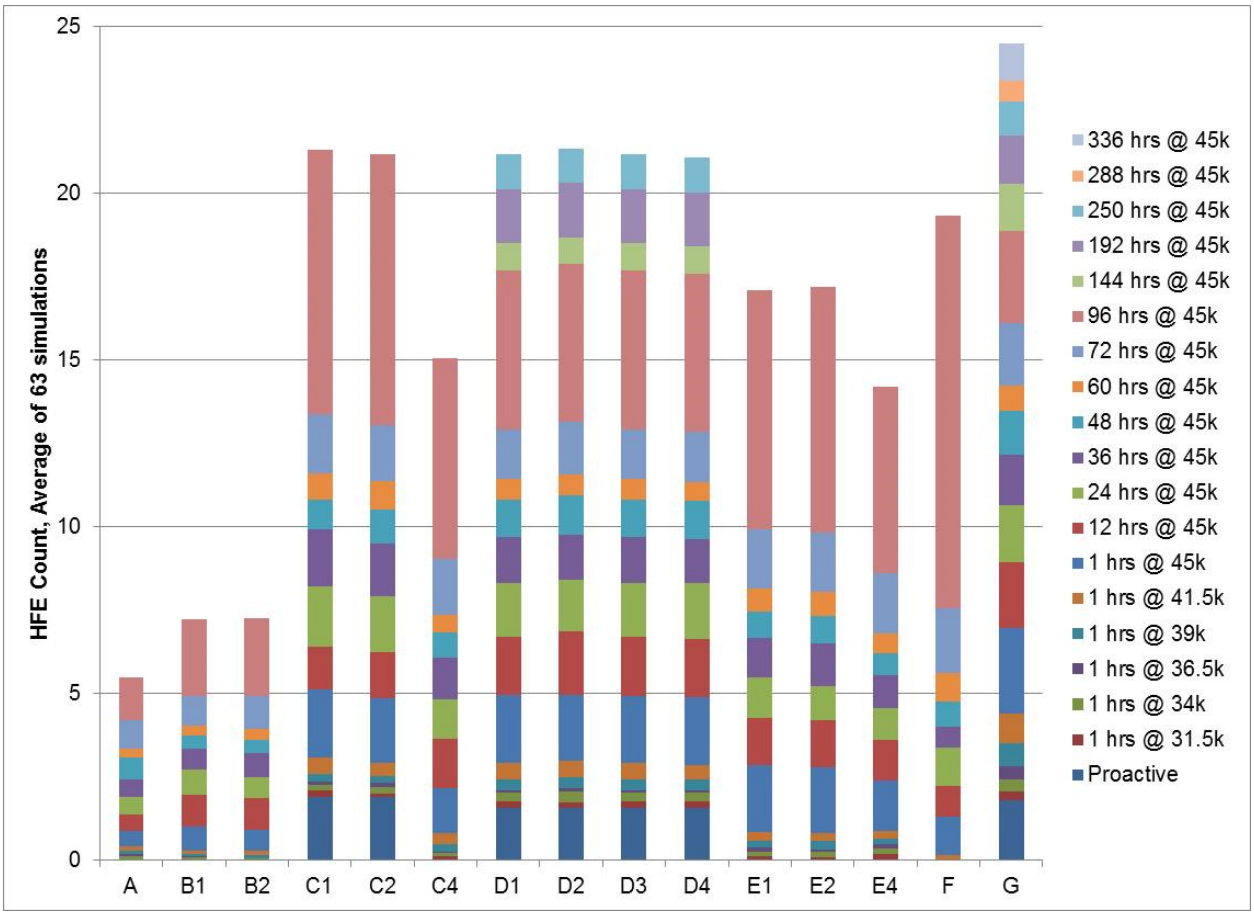

FIGURE E-8 Average Sediment and Hydrology Triggered HFE Count by Type for Each Long-Term Strategy (long-term strategies C3, E3, E5, and E6 by definition have no HFEs)

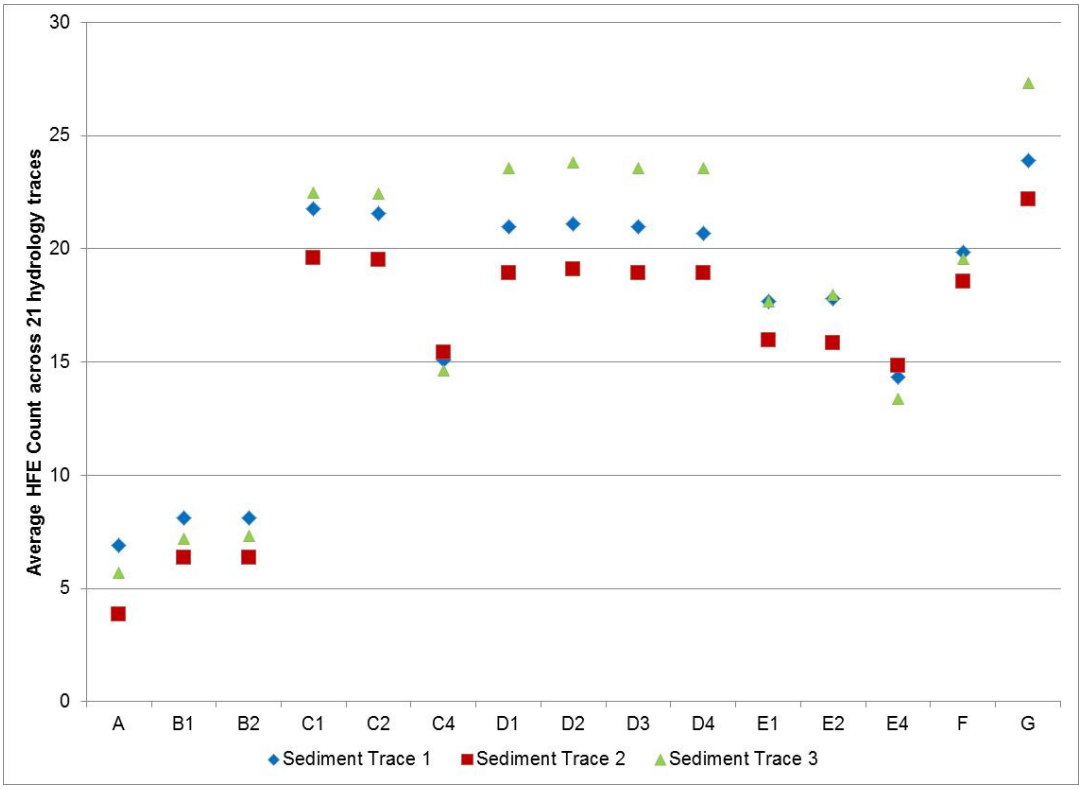

FIGURE E-9 Average HFE Count for Sediment Traces s1, s2, and s3 for Each Long-Term Strategy (long-term strategies C3, E3, E5, and E6 by definition have no HFE)

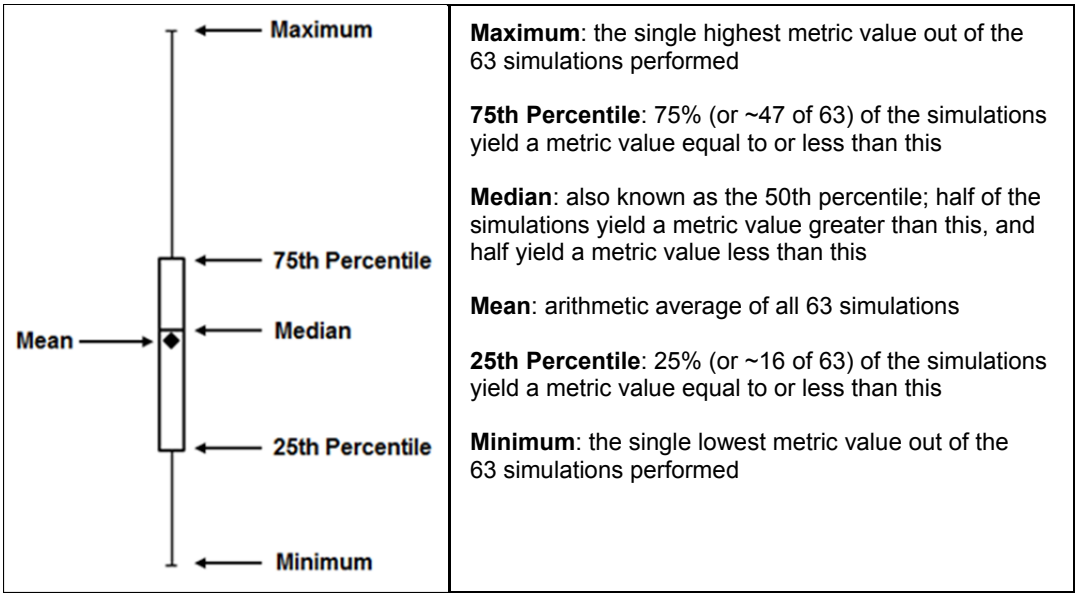

FIGURE E-10 Definition of the Statistics Represented by the Box and Whisker Plots Used in This Analysis

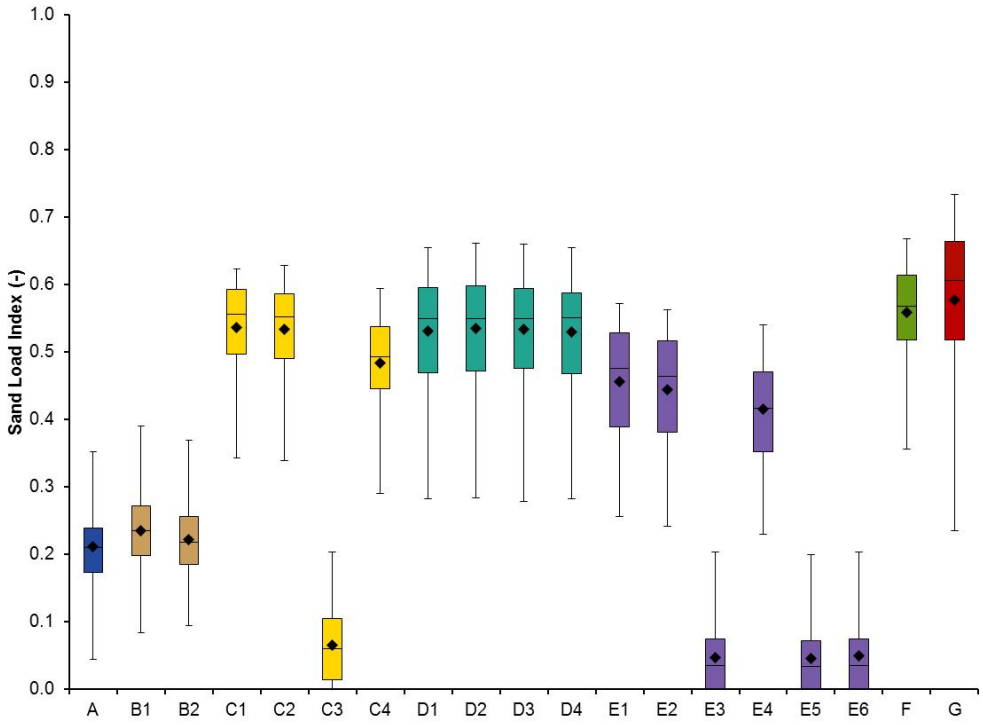

FIGURE E-11 Sand Load Index Statistics from 63 Simulations for Each Long-Term Strategy

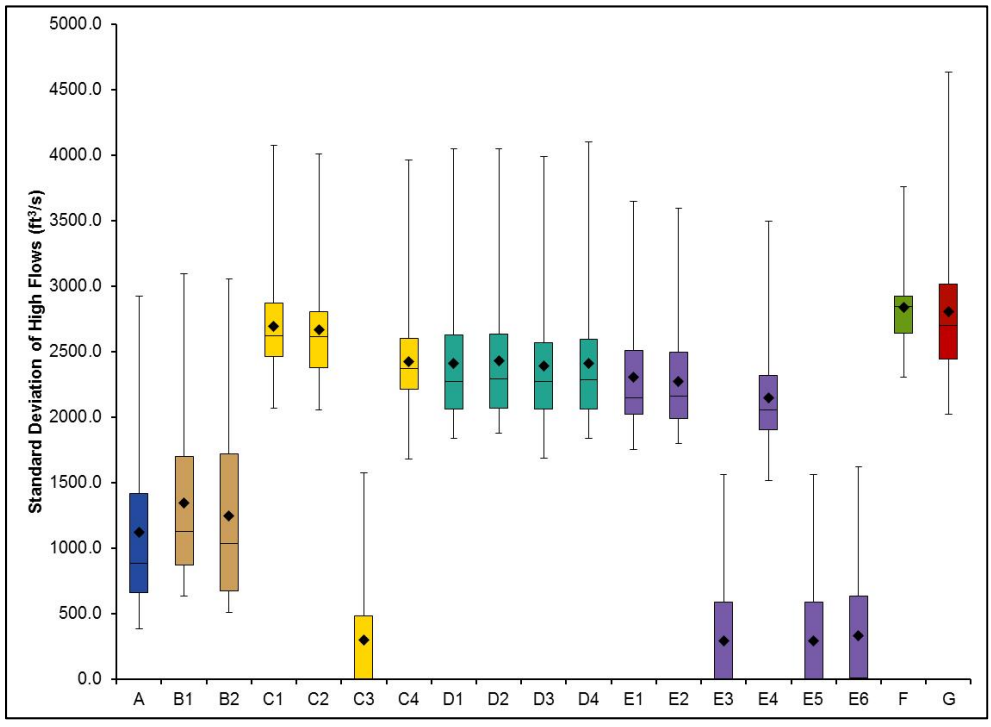

FIGURE E-12 Standard Deviation of High Flows Statistics from 63 Simulations for Each Long-Term Strategy

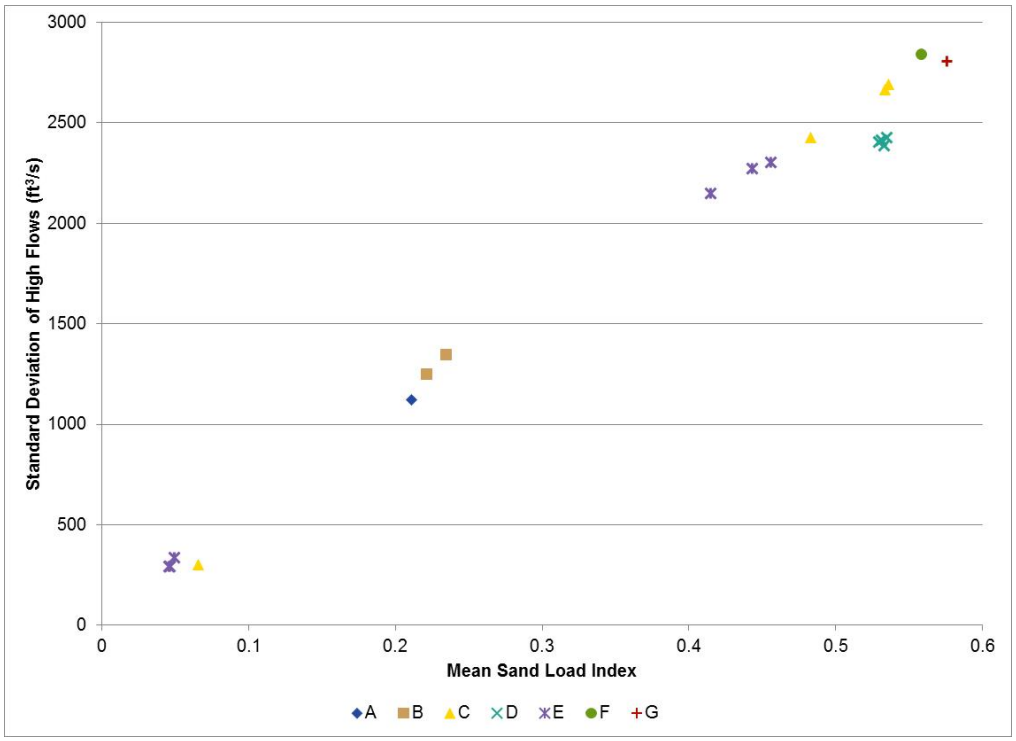

FIGURE E-13 Correlation between SDHF and SLI (r = 0.99, *P* < 0.001)

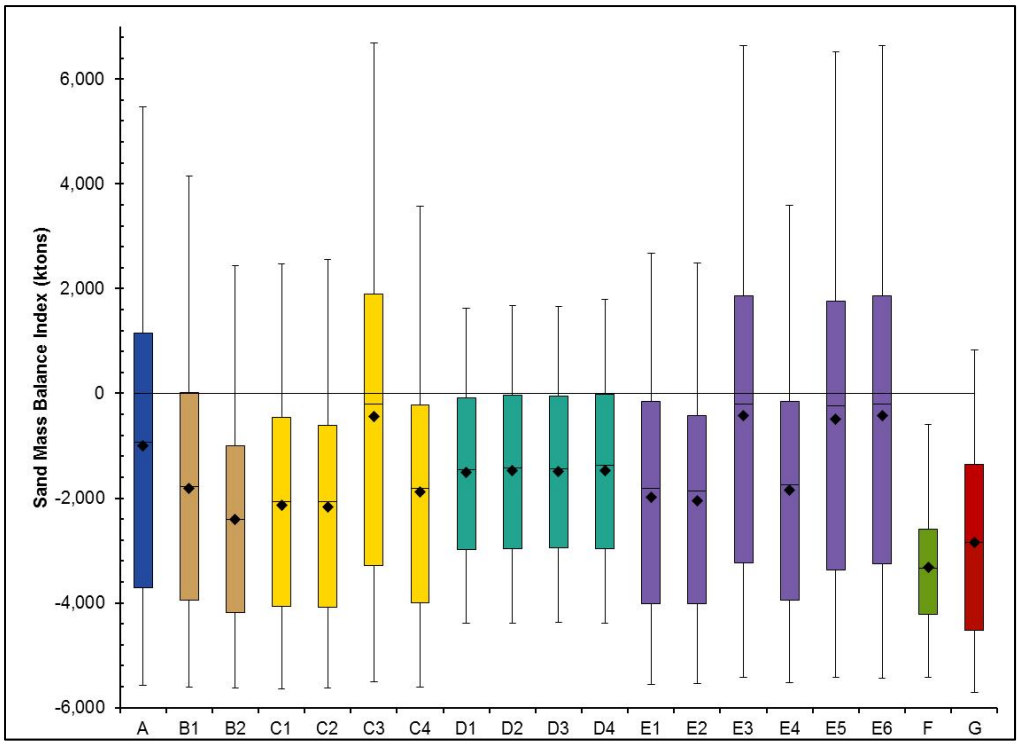

FIGURE E-14 Sand Mass Balance Index Statistics from 63 Simulations for Each Long-Term Strategy

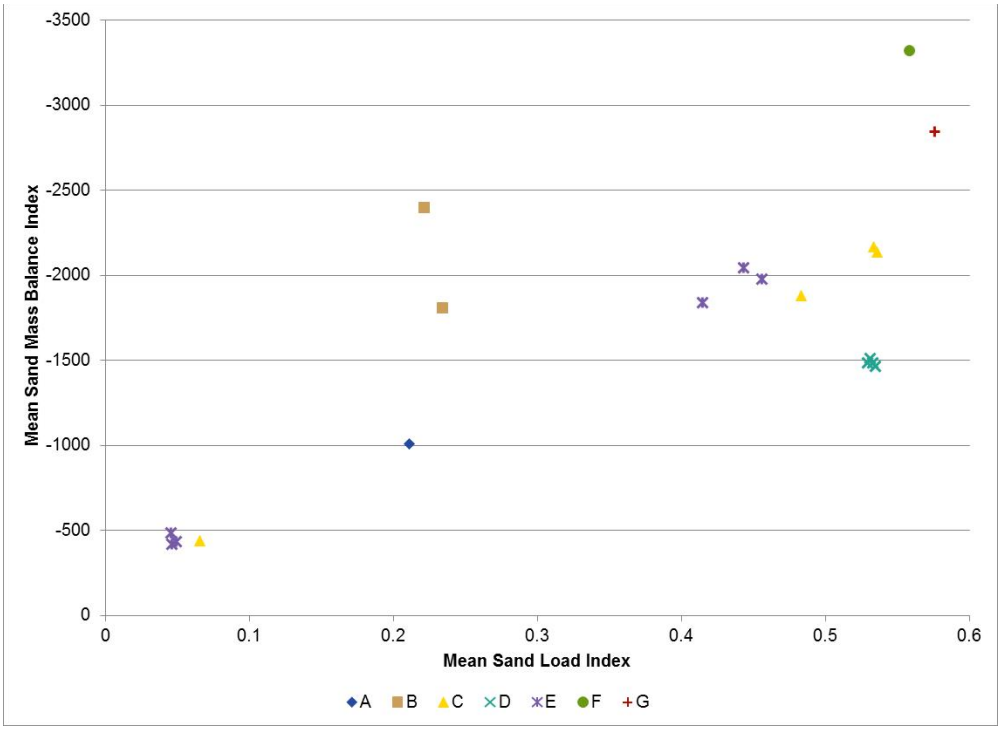

FIGURE E-15 Correlation between SMBI and SLI (r = 0.75, *P* < 0.001) (Note that the *y*-axis values are negative and in reverse order.)

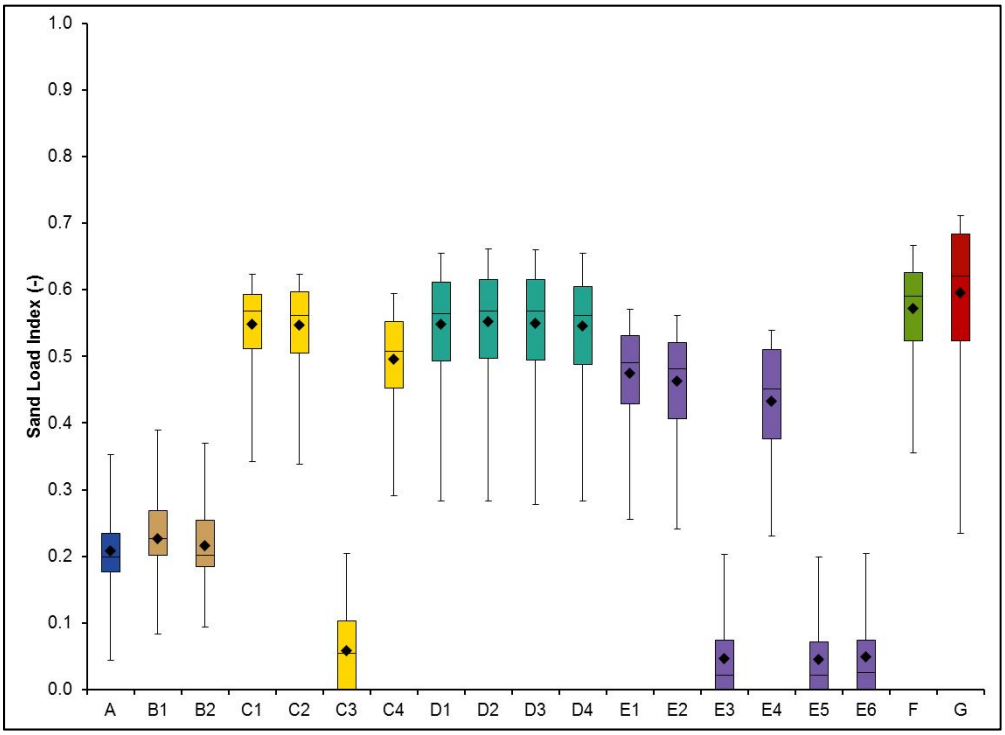

FIGURE E-16 Sand Load Index for Long-Term Strategies Using Climate Change Weights (Compare to Figure E-11, which uses historical weights.)

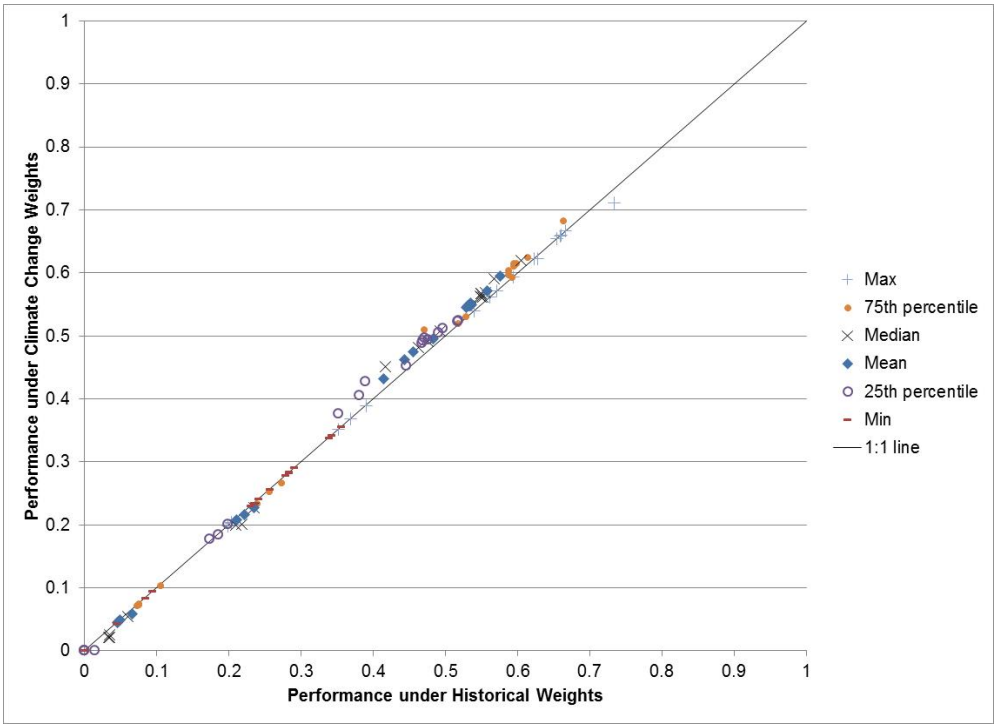

FIGURE E-17 Comparison of the Sand Load Index between Climate Change and Historical Weights

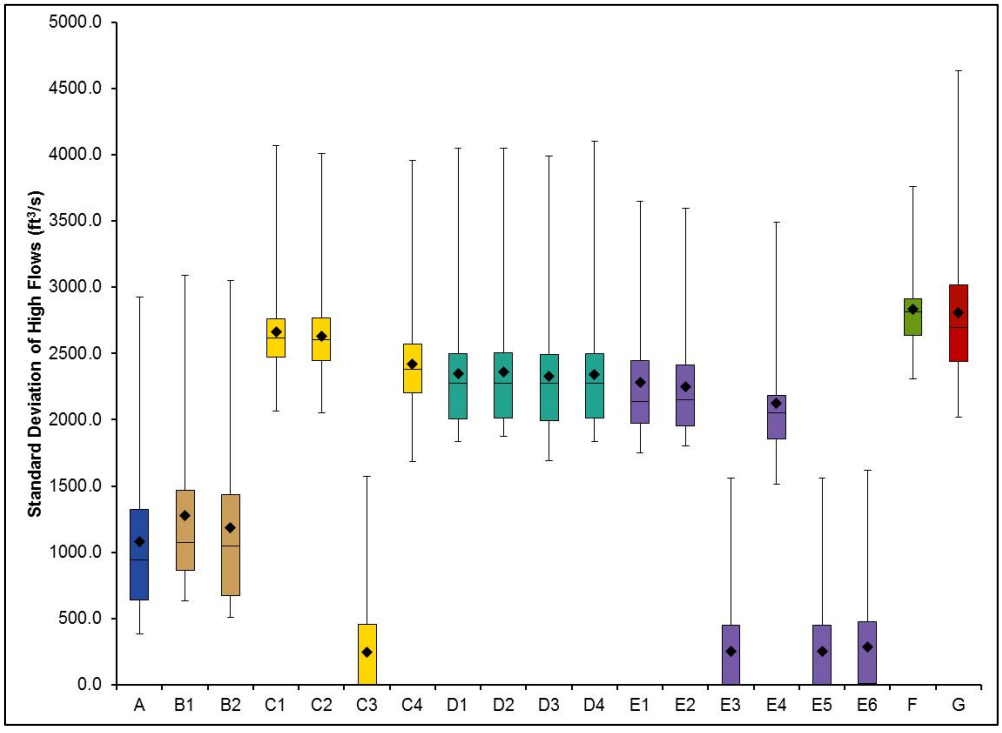

FIGURE E-18 Standard Deviation of High Flows Using Climate Change Weights (Compare to Figure E-12, which uses historical weights.)

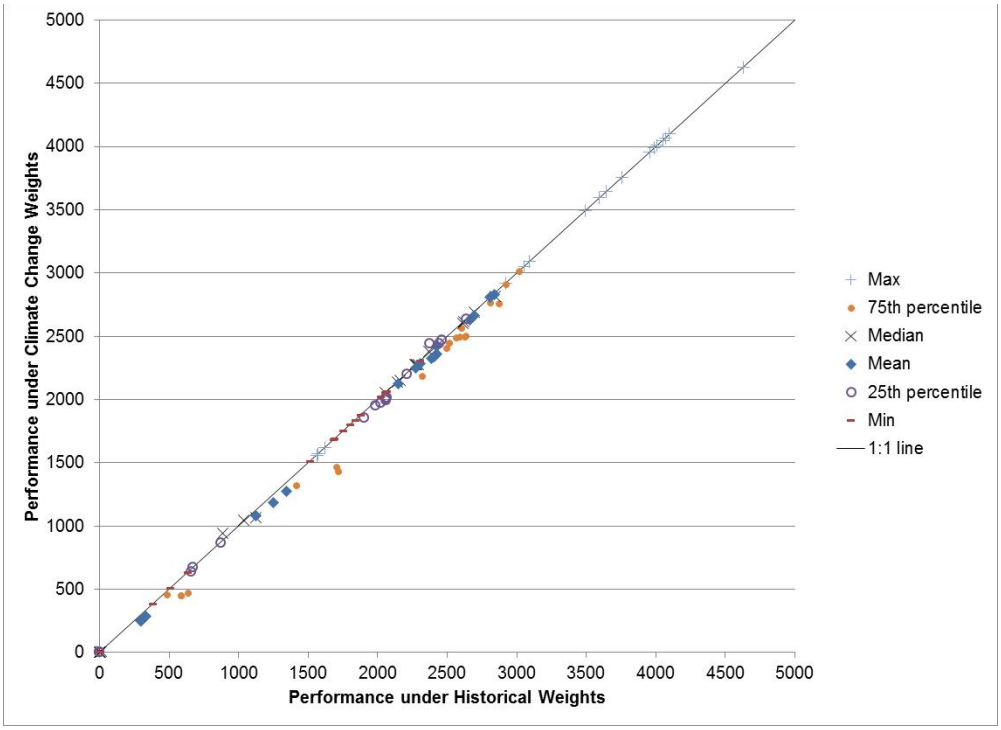

FIGURE E-19 Comparison of the Standard Deviation of High Flows between Climate Change and Historical Weights

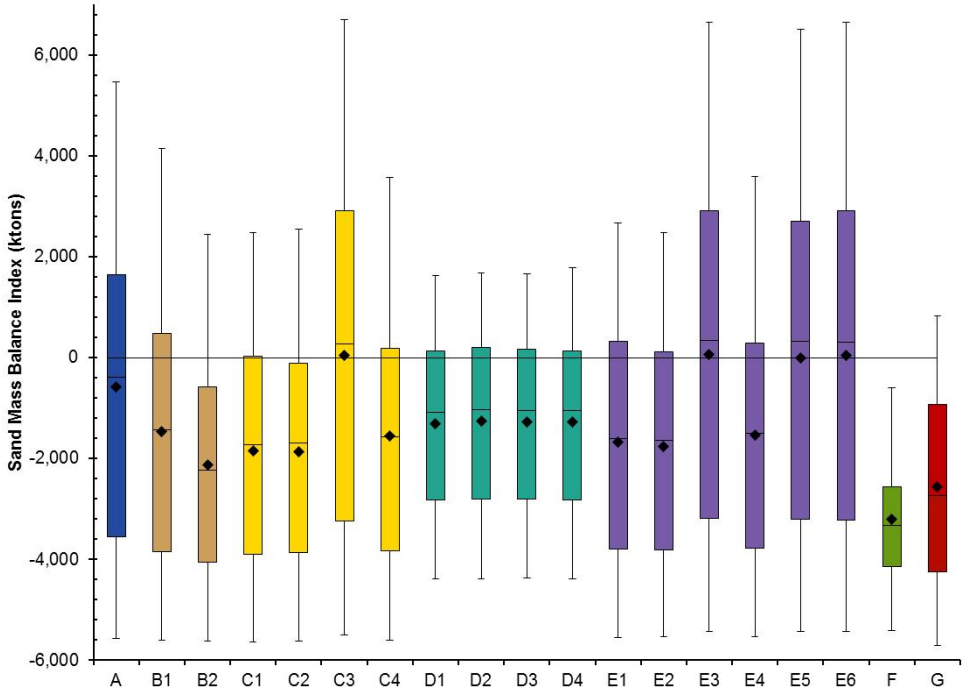

FIGURE E-20 Sand Mass Balance Index Using Climate Change Weights (Compare to Figure E-14, which uses historical weights.)

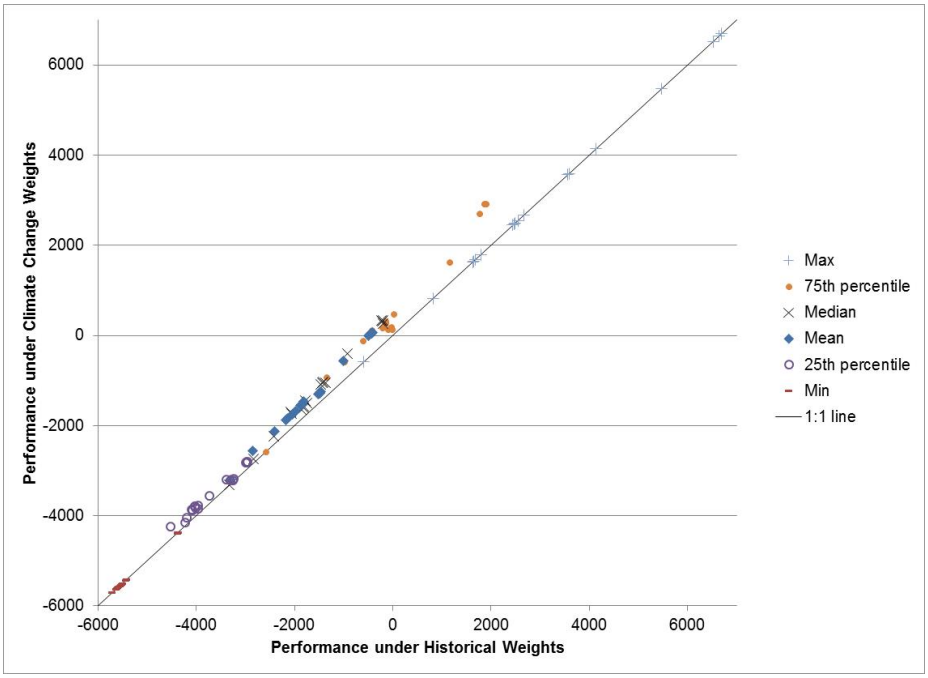

FIGURE E-21 Comparison of the Sand Mass Balance Index between Climate Change and Historical Weights

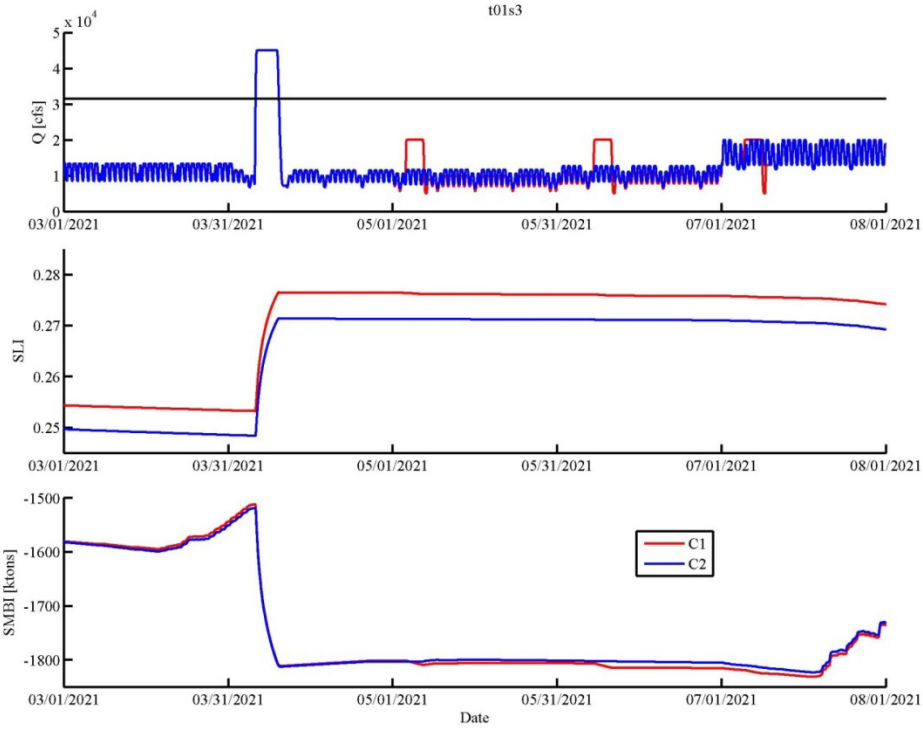

FIGURE E-22 Comparison of Long-Term Strategies C1 and C2 for Hydrology Trace 1, Sediment Trace 3 (TMF flows have very little effect on SLI or SMBI.)

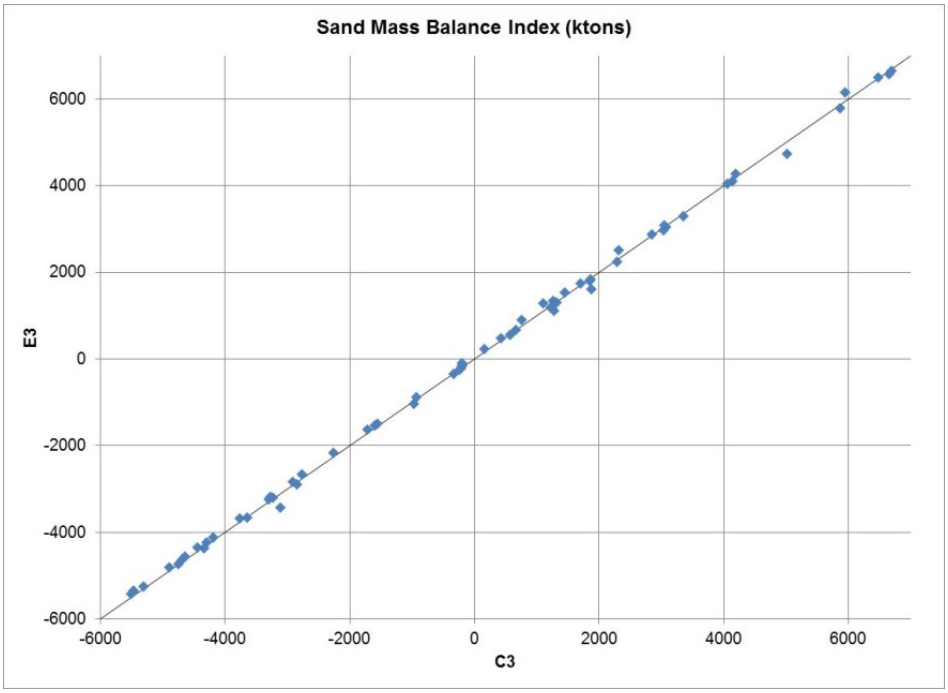

FIGURE E-23 SMBI for Alternative E Plotted against Alternative C (The combination of intervening flows and monthly volumes yields no difference in SMBI.)

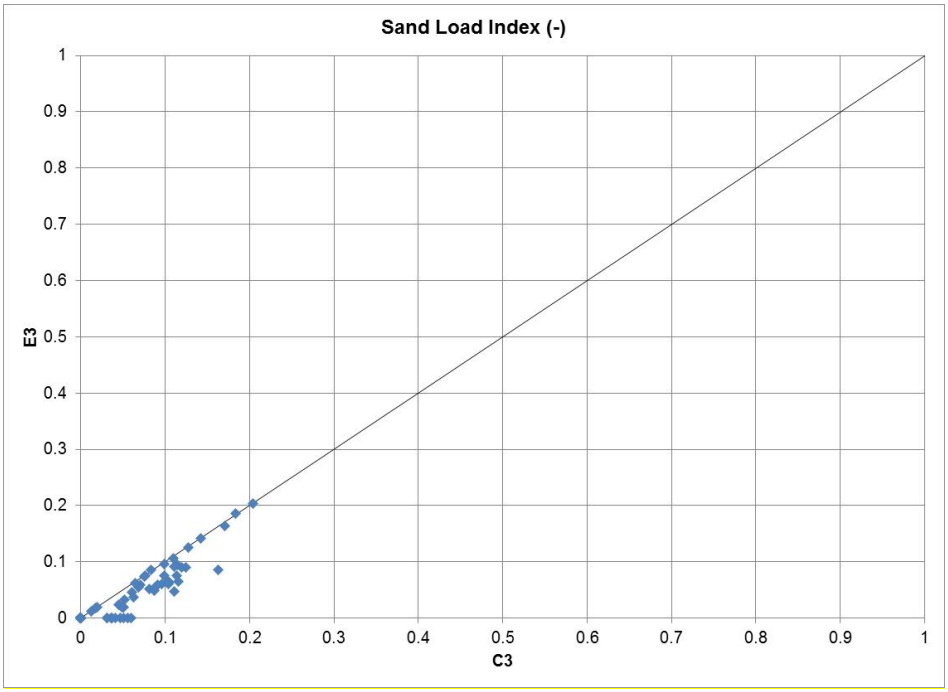

FIGURE E-24 SLI for Alternative E Plotted against Alternative C (The combination of intervening flows and monthly volumes yields small differences in SLI.)

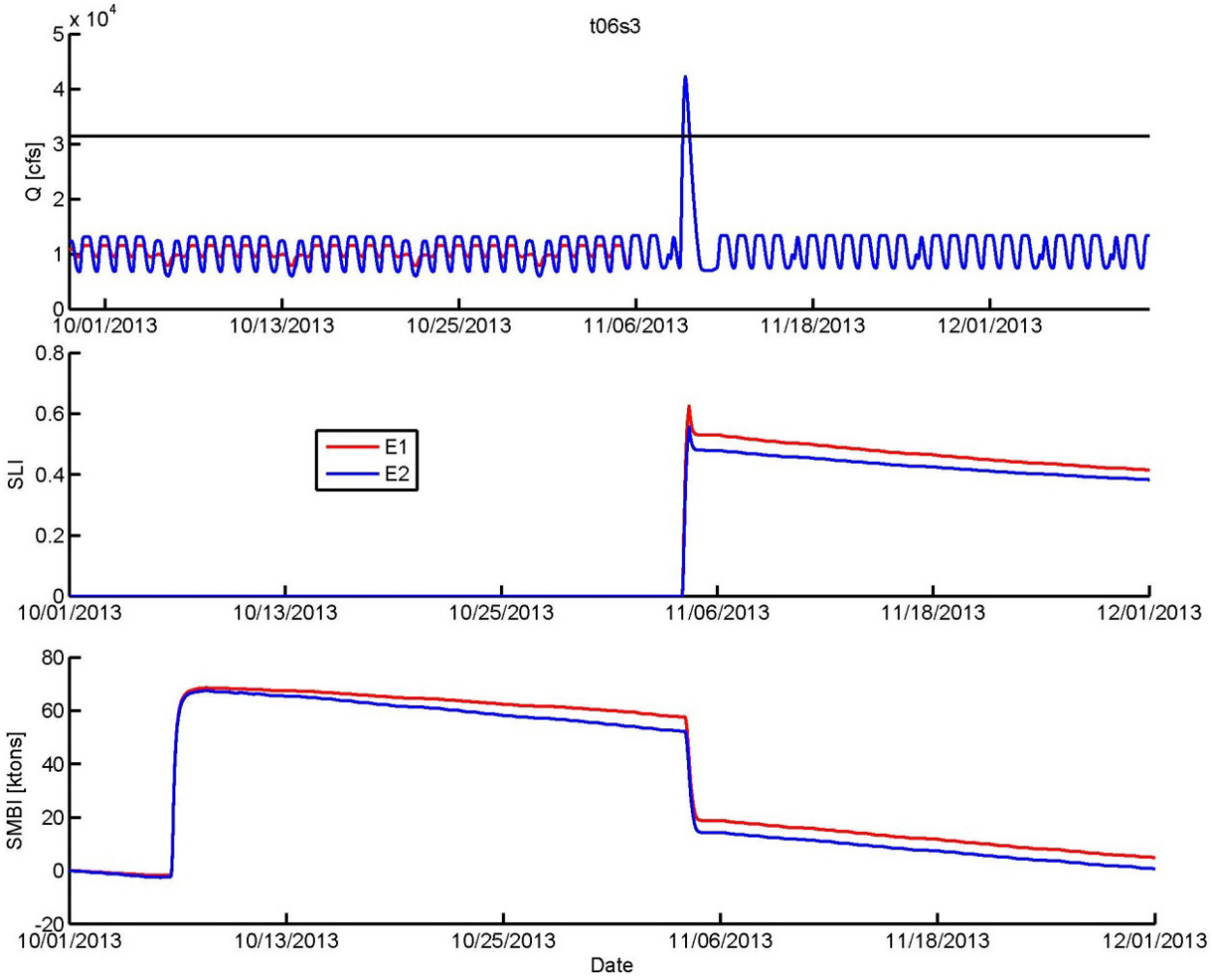

FIGURE E-25 Load-Following Curtailment Effects on SLI and SMBI (Although small effects are noticeable for the month after an HFE, by the end of the calendar year there is no difference in SLI and the difference in SMBI is 9 ktons.)

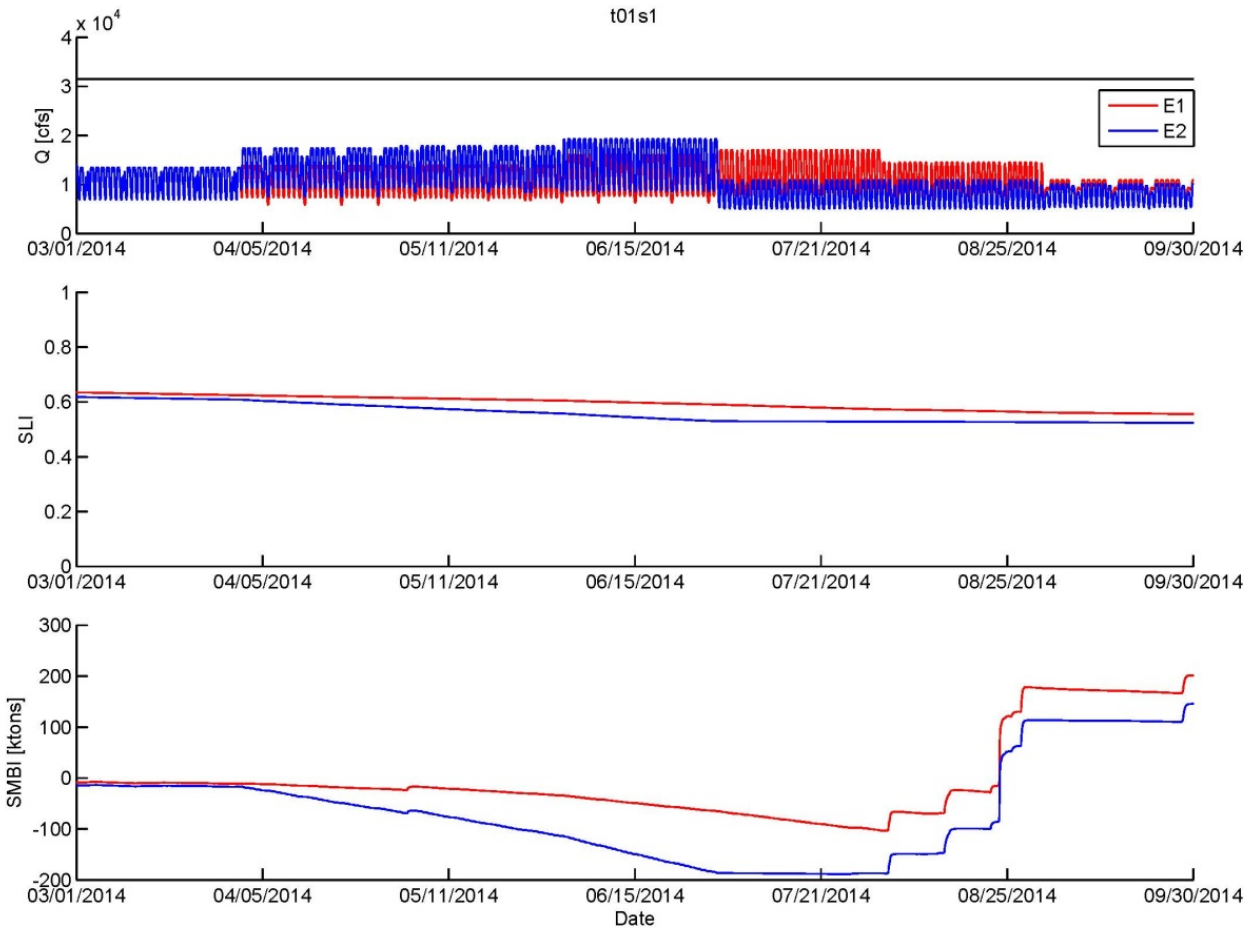

FIGURE E-26 Low Summer Flows for WY 2014, Hydrology Trace 1, Sediment Trace 1 (Long-term strategy E2 has low summer flows starting in July; this necessitates higher flows in April–June. Both SLI and SMBI are higher for alternative strategies without low summer flows [long-term strategy E1] than for those with low summer flows [long-term strategy E2].)

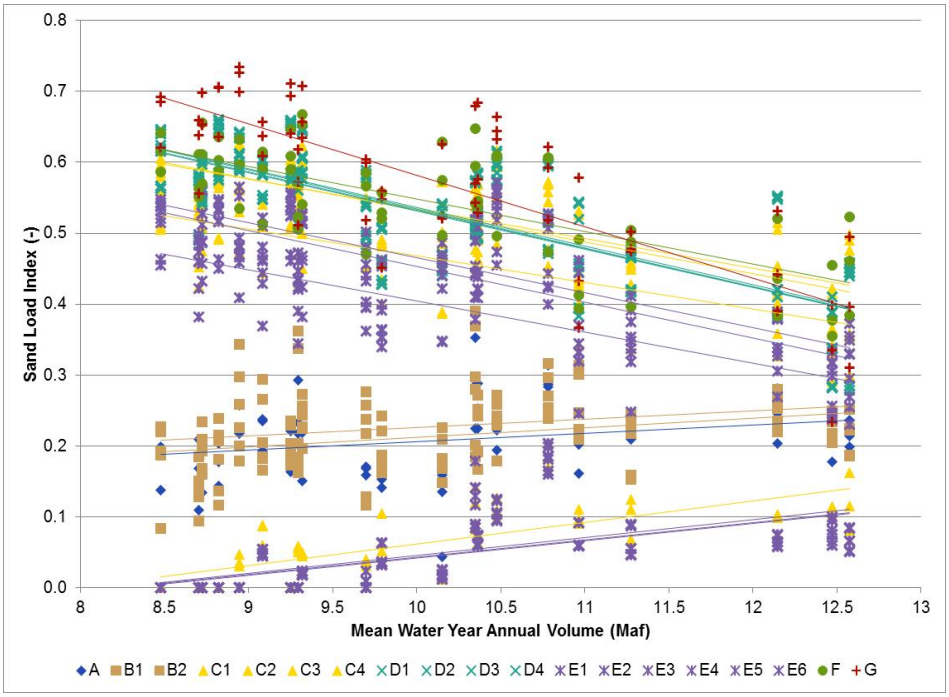

FIGURE E-27 Hydrology Impacts on the Sand Load Index (Wetter hydrological conditions tend to reduce SLI for long-term strategies without defined restriction on the number of HFEs that can be triggered [long-term strategies C1, C2, D1, D2, D3, D4, E1, E2, F, G]. Wetter hydrological conditions tend to increase SLI for long-term strategies with defined restrictions on the number of HFEs that can be triggered [long-term strategies A, B1, B2, C3, C4, E3, E4, E5, E6].)

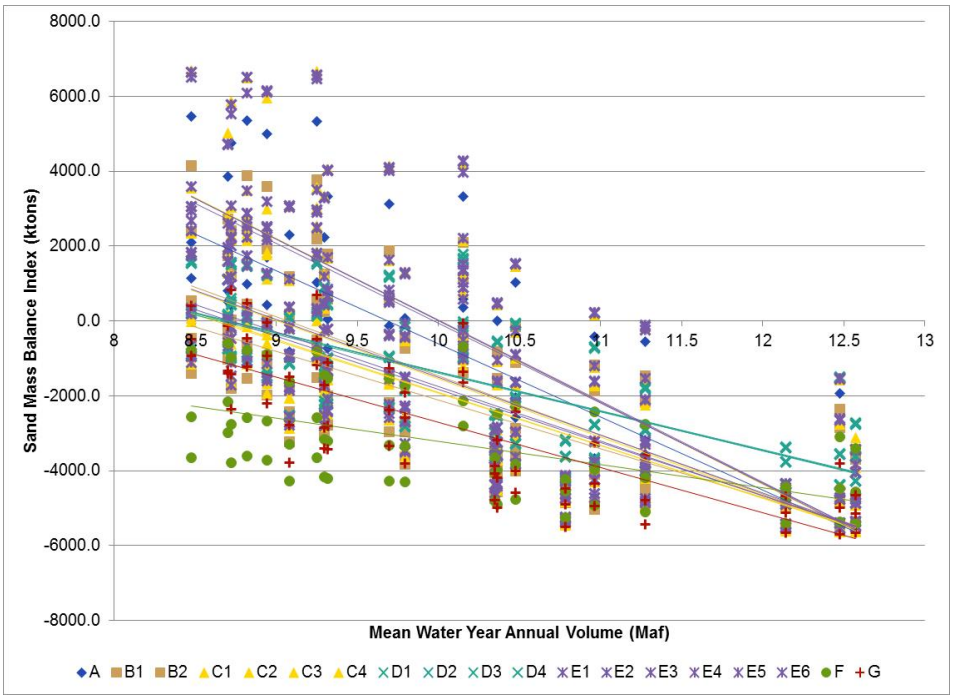

FIGURE E-28 Hydrology Impacts on the Sand Mass Balance Index (Wetter hydrological conditions create lower Sand Mass Balance Index values.)

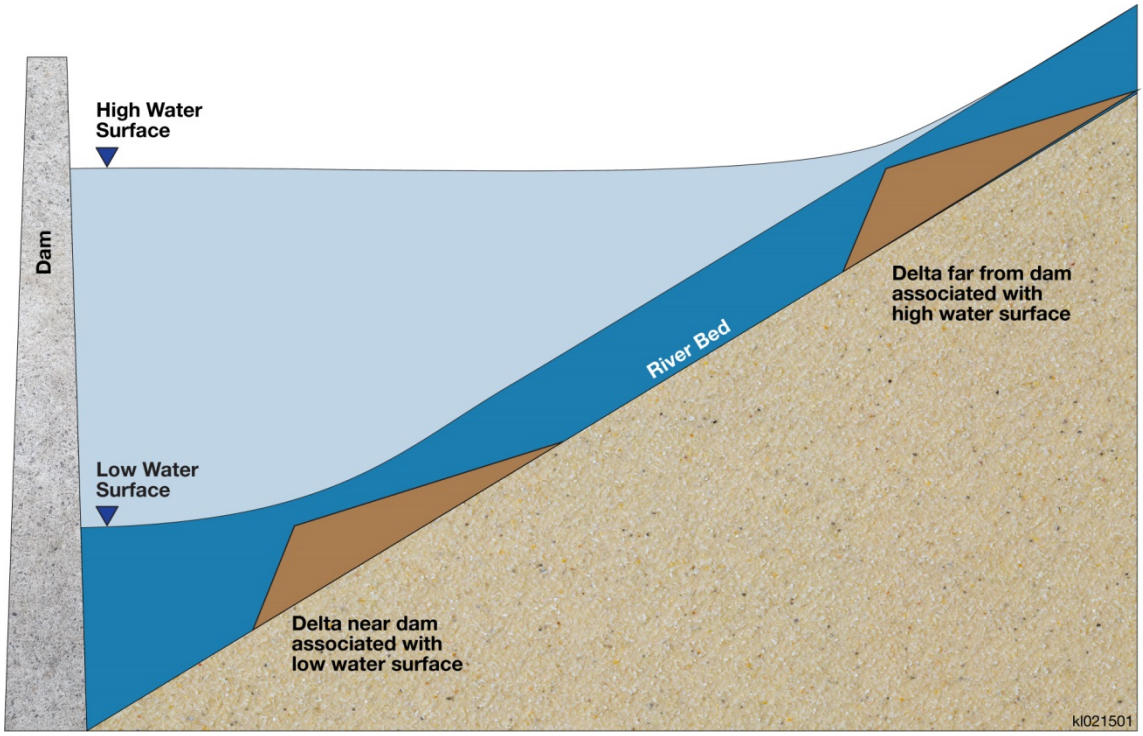

FIGURE E-29 Conceptual Diagram of Water Surface Elevation Affecting Delta Location

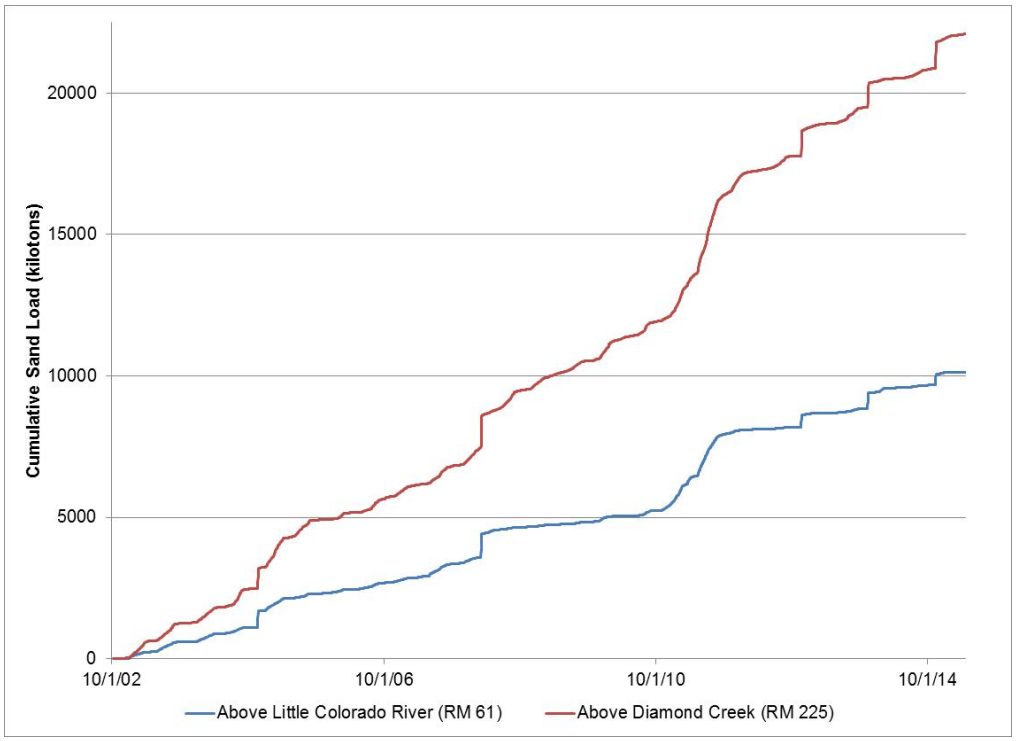

FIGURE E-30 Historical Cumulative Sand Load Leaving Marble Canyon (RM 61) and Reaching the Gage above Diamond Creek (RM 225) (Source: GCMRC 2015)

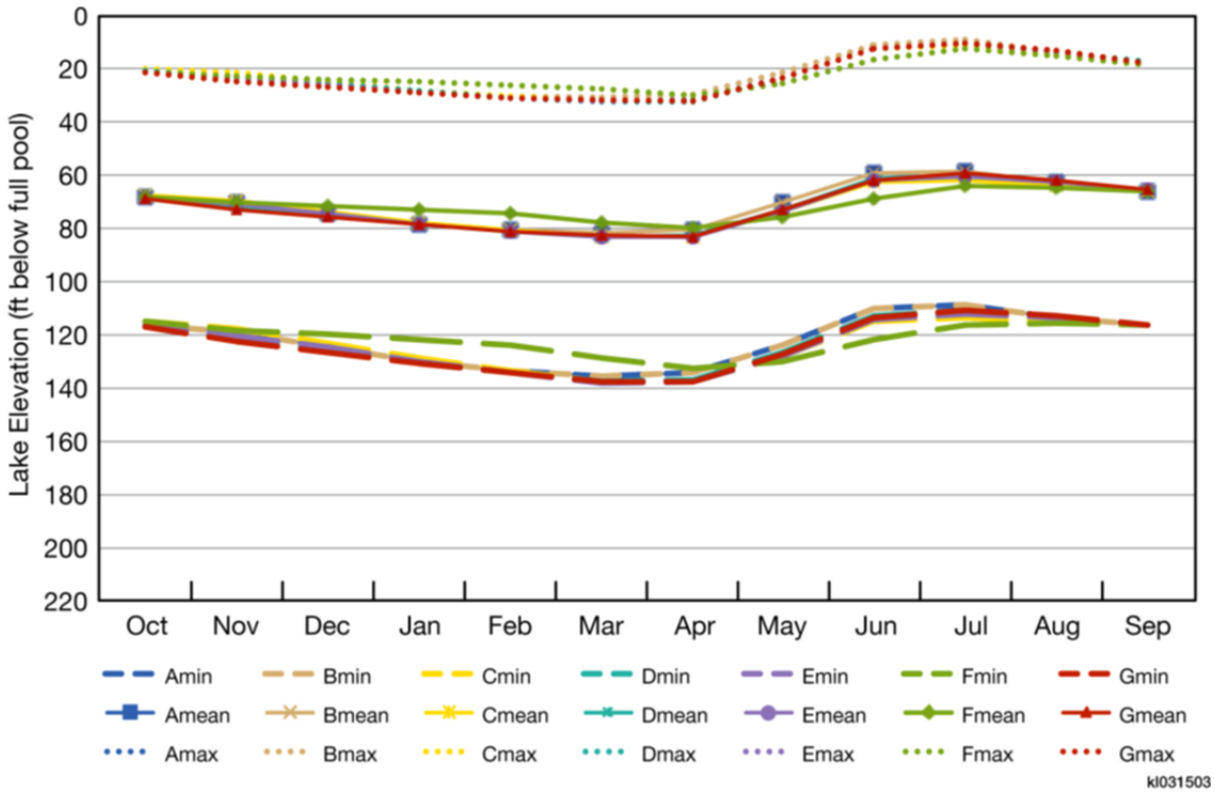

FIGURE E-31 Hydrology Impacts of Lake Powell Pool Elevations by Month across Alternatives

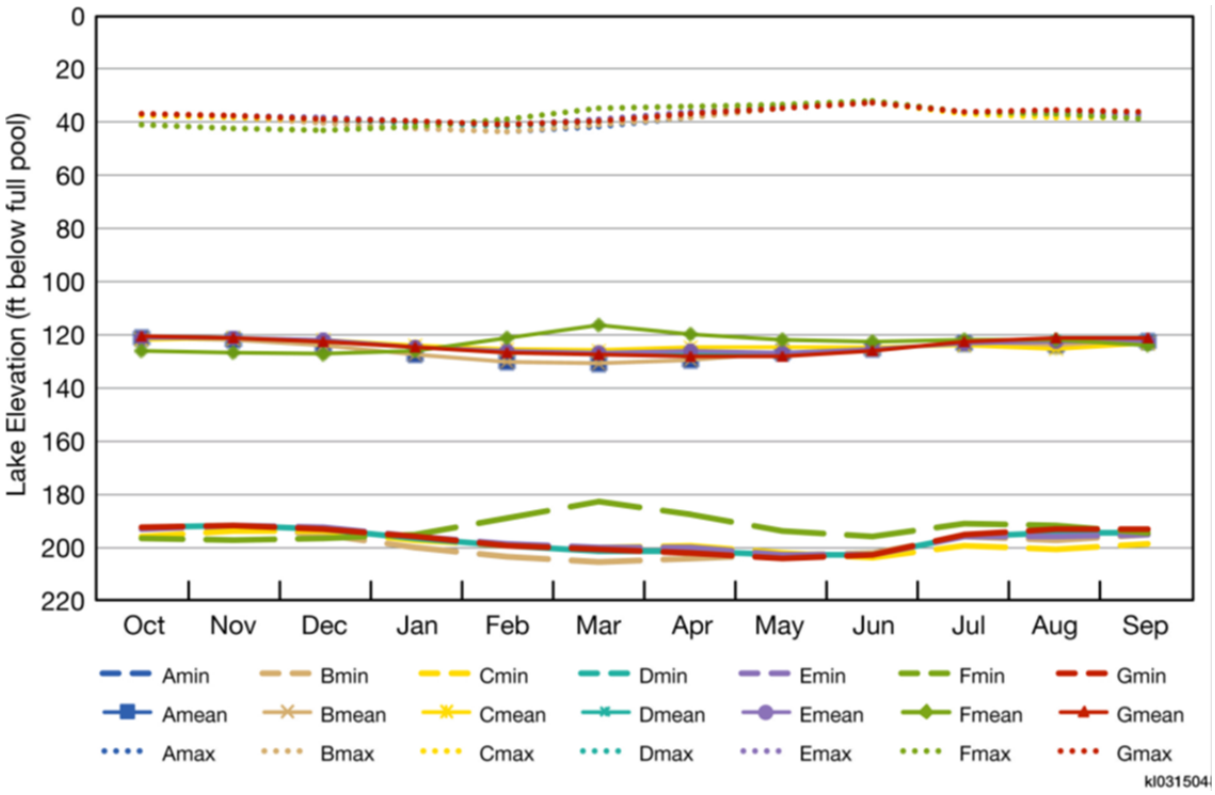

FIGURE E-32 Hydrology Impacts of Lake Mead Pool Elevations by Month across Alternatives

TABLE E-1 Sources for Historical Tributary Sediment Load Data

Tributary	Period of Record, by Source: Topping (2014)	Period of Record, by Source: GCMRC (2015)	Record Length
Paria River	10/1/1963 to 10/1/1996	10/1/1996 to 1/1/2014	50.3 years
Little Colorado River	10/1/1994 to 3/27/2013		18.5 years

TABLE E-2 Historical Periods Used for Paria Sediment Traces s1, s2, and s3

Sediment Trace	Sediment Accounting Periods	Simulation Period
s1	Fall 1981–Fall 2001	1/1/1981–12/31/2001
s2	Fall 1995–Fall 2013 : Spring 1964–Fall 1965	1/1/1995–11/30/2013 : 12/1/1963–12/31/1965
s3	Fall 2011–Fall 2013 : Spring 1964–Fall 1981	1/1/2011–11/30/2013 : 12/1/1963–12/31/1981

TABLE E-3 Historical Periods Used for Little Colorado River Sediment Traces s1, s2, and s3

Sediment Trace	Simulation Period
s1	1/1/1999–12/31/2012 : 1/1/1995–12/31/2001
s2	1/1/2007–12/31/2012 : 1/1/1995–12/31/2009
s3	1/1/2004–12/31/2012 : 1/1/1995–12/31/2006

TABLE E-4 List of HFEs Available for Sediment-Triggered Experiments (fall and spring)

HFE ID	Peak Discharge (cfs)	Duration at Peak (hours)
A	45,000	336
B	45,000	288
C	45,000	240 (Alternative G) 250 (Alternative D)
D	45,000	192
E	45,000	144
1	45,000	96
2	45,000	72
3	45,000	60
4	45,000	48
5	45,000	36
6	45,000	24
7	45,000	12
8	45,000	1
9	41,500	1
10	39,000	1
11	36,500	1
12	34,000	1
13	31,500	1

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APPENDIX F:

AQUATIC RESOURCES TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX F:

AQUATIC RESOURCES TECHNICAL INFORMATION AND ANALYSIS

F.1 INTRODUCTION

This technical appendix provides information pertaining to analyses of effects on aquatic ecological resources for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), including the aquatic food base, native and nonnative fishes, and fish parasites. It is intended to supplement the information presented in Sections 3.5 and 4.5 of the EIS.

Methods used to evaluate resources, including modeling methods, are described and results regarding effects of alternatives and associated long-term strategies are presented. Analysis of effects on the aquatic food base is based upon a review of literature pertaining to past studies and extrapolation of those results to qualitatively evaluate effects of alternatives and the associated long-term strategies. The evaluation of impacts on rainbow trout (*Oncorhynchus mykiss*), endangered humpback chub (*Gila cypha*), other native fish, nonnative fish, and fish parasites is based upon reviews of the scientific literature and upon the evaluation of performance metrics that were developed for the LTEMP assessment process. The values for the performance metrics were calculated using models developed to examine effects of alternatives on the various aquatic resources.

The potential effects of six action alternatives are compared to the no-action alternative (Alternative A), which describes how the dam is currently operated. Operations under Alternative A employ a release pattern established in the 1996 Record of Decision (ROD) (Reclamation 1996) associated with the 1995 Environmental Impact Statement (EIS) on operations of Glen Canyon Dam (Reclamation 1995). This operational release pattern, referred to as Modified Low Fluctuating Flows, moderated the releases relative to operations practiced in the 1960s through 1980s. As described in Chapter 2 of the EIS, Alternative A also includes various operational decisions and non-flow actions that have been established since the 1996 ROD.

Some of the alternatives under consideration in the EIS (especially Alternatives C, D, and E) are complex experimental or adaptive designs. These alternatives prescribe different management interventions depending on resource conditions. Various condition-dependent triggers govern the implementation of experiments. To understand effects of alternatives that incorporate multiple adaptive components, especially components that might be considered experimental, the complex alternatives were decomposed into 19 versions referred to as long-term strategies, with specific experimental elements included or excluded in each long-term strategy. Table 4.1-1 identifies the experimental elements included in each of the long-term strategies associated with the LTEMP alternatives. Descriptions of each alternative, including the elements included in the long-term strategies, are presented in Sections 2.2 and 4.1 of the EIS. Modeling to evaluate potential effects on aquatic resources was conducted similarly for each long-term strategy and results were compared using various performance metrics to evaluate how

inclusion of experimental elements as part of an alternative affected the modeled outcome for the resources of concern. As discussed in Section 4.1 of the EIS, the long-term strategies used to represent the alternatives in Section 4.5 are A, B1, C1, D4, E1, F, and G.

A full range of potential hydrologic and sediment conditions were modeled for a 20-year period (water years 2013–2033) that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell inflow scenarios (known as hydrology traces) for the 20-year LTEMP period were sampled from the 105-year historic record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth sequence of 20 years. Using this approach, the first 20-year period considered was 1906–1925, the second was 1911–1930, and so forth. As the start of traces reach the end of the historic record, the years needed to complete a 20-year period are obtained by wrapping back to the beginning of the historical record. For instance, the trace beginning in 1996 consists of the years 1996–2010 and 1906–1910, in that order. This method produced 21 hydrology traces for analysis that represented a range of possible conditions from dry to wet.

In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record (water years 1964–2013) were analyzed that represented low (water years 1982 to 2001), medium (water years 1996 to 1965), and high (water years 2012 to 1981) sediment input conditions. In combination, the 21 hydrology traces and 3 sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions for each alternative and long-term strategy.

Section F.2 of this appendix describes analyses conducted to evaluate impacts of alternatives on the aquatic food base. Section F.3 presents methods, results, and conclusions from modeling conducted to evaluate population-level effects of alternatives on rainbow trout and humpback chub. Section F.4 presents methods, results, and conclusions for modeling conducted to evaluate how alternatives would affect the suitability of mainstem water temperatures for sustaining populations of humpback chub and other native fish species, nonnative fish species, and fish parasites.

F.2 AQUATIC FOOD BASE ASSESSMENT

This section provides information on flow and temperature effects of LTEMP alternatives on the aquatic food base. It serves as the basis for descriptions and conclusions provided in Sections 3.5.1 and 4.5 of this EIS.

F.2.1 Description of the Aquatic Food Base Downstream from Glen Canyon Dam

Determining the impacts of LTEMP alternatives on the aquatic food base requires an evaluation of changes in the aquatic food base from pre-dam years through various post-dam operations, changes in the food base that occur with increasing distance from the dam, and the effects of intentional and unintentional species introductions. The following discussion provides this information and supplements the aquatic food base information presented in Section 3.5.1.

F.2.1.1 The Aquatic Food Base Prior to Construction of Glen Canyon Dam

Prior to the construction of Glen Canyon Dam, the productivity of the Colorado River was low due to scouring and high turbidity levels that limited the colonization and growth of benthic macroalgae and invertebrates (Woodbury 1959; Stevens et al. 1997; Ward et al. 1986). Generally, the more productive habitats for algae and invertebrates occurred at the lower edge of deltas formed at the mouths of tributaries, on and behind boulders, and on woody debris carried by floodwaters (Woodbury 1959). A pre-dam survey of 171 mi of the Colorado River between Dirty Devil River, Utah, and Lees Ferry, Arizona (collections made along the banks of the Colorado River and in tributaries or side canyons), included 28 species of green algae, 5 species of cyanobacteria, 20 species of diatoms, and 91 species of insects including mayflies, dragonflies, true bugs, fishflies, caddisflies, aquatic snout moths, beetles, and true flies (Woodbury 1959). Sixteen insect species were collected from sites along the river bank while 77 species were collected from tributary streams. From a sample of fish stomachs, it appeared that organisms derived from tributaries and terrestrial habitats played an important role in the diet of river fishes (Woodbury 1959). Pre-dam reports of invasive aquatic food base species in the Grand Canyon are limited. In 1932, 50,000 amphipods (*Gammarus lacustris*) were introduced into Bright Angel Creek. They apparently washed into the mainstem of the Colorado River where they became abundant (Carothers and Minckley 1981), particularly within the Glen Canyon reach, where they are associated with *Cladophora* beds (Blinn and Cole 1991; Blinn et al. 1992; Hardwick et al. 1992).

Stanford and Ward (1986) suggested that the lower Green and Colorado Rivers in Canyonlands National Park, Utah, may provide the best examples of the pre-regulated Colorado River, as these reaches retain similar hydrographs to pre-dam conditions and are the farthest downstream from the large dams in the upper Colorado River basin. High suspended sediment concentrations limited the growth of primary producers; thus, the primary carbon source for benthic invertebrates was terrestrial organic matter. The invertebrate community was composed of 49 taxa, mostly mayflies, caddisflies, and true flies. Stoneflies and dragonflies comprised a smaller portion of the community (Haden et al. 2003).

F.2.1.2 The Aquatic Food Base of the Colorado River Downstream from Glen Canyon Dam

Section 3.5.1 of the EIS provides an overview of the aquatic food base of the mainstem of the Colorado River following installation of Glen Canyon Dam. The following supplements that information. Glen Canyon Dam altered the primary carbon source from terrestrial (e.g., leaf litter) to aquatic (e.g., algae and detritus), the temperature regime from seasonally warm to stenothermically cool, and discharge patterns from low daily variations to high daily variations (Benenati et al. 2002). Nevertheless, riparian and upland vegetation still contribute energy to the impounded river system, particularly during flood events (Blinn et al. 1998, 1999). The large quantity of driftwood that occurred in the pre-dam river is now replaced by lower quantities of woody debris derived from tributaries during floods, or from occasional scouring flows of the vegetated post-dam shoreline (Stevens et al. 1997). Benthic detrital standing mass is generally low and variable, increasing through the more turbid downstream reaches (Shannon et al. 1996).

The Paria and Little Colorado Rivers, the primary sediment delivery systems downstream from Glen Canyon Dam, divide the Colorado River into three distinct turbidity zones that have a significant impact on mainstem aquatic food base communities (Stevens et al. 1997). The first 16 mi downstream from Glen Canyon Dam account for 60% of the total phytobenthic standing biomass throughout the remaining 242 mi of the river corridor (Blinn et al. 1995). Algae production decreases from Glen to Marble Canyon and is even lower in the Grand Canyon (Hall et al. 2010) because of the increasing suspended sediment loads that reduced light availability (Kennedy et al. 2013). *Cladophora* grows best in continuously submerged clear-water stable habitats, whereas *Oscillatoria* forms dense mat-like matrices of filaments and sand in the varial zone and other habitats with high suspended sediments that are more typical of many southwestern streams (Shaver et al. 1997).

Oscillatoria tends to colonize relatively early in disturbed or newly inundated zones, while colonization by *Cladophora* is reduced or occurs more slowly (McKinney et al. 1997). As *Oscillatoria* supports tenfold fewer invertebrates than *Cladophora*, the input of terrestrially derived carbon has become vital to support the aquatic food base organisms. However, the leaves of the common nonnative *Tamarix ramosissima* along the river are an inferior food source for macroinvertebrates due to their high tannin content and slower decomposition rate compared to leaves of native cottonwoods and willows (Bailey et al. 2001).

Zooplankton is an important food resource for larval and juvenile native fish in the Colorado River system. The zooplankton found in regulated rivers is composed of both plankton derived from the reservoir (lentic species) and those derived from the streambed, backwaters, and tributaries of the river (lotic species) (Haury 1986). Lotic zooplankton and detritus are positively correlated with distance downriver from Glen Canyon Dam, increased discharge, and nearshore versus midchannel locations. Lentic zooplankton abundance also increases at higher discharges and in nearshore habitats, but is negatively correlated with distance downriver. It is possible that lentic zooplankton cannot survive and reproduce under the cold temperatures in the mainstem, although nearshore habitats provide a more stable environment than the mainstem, which may enhance rearing and development of lentic zooplankton (Benenati et al. 2001). Copepods are the most abundant zooplankton species in the Colorado River (AZGFD 1996). The biomass, productivity, and abundance of zooplankton (cladocerans, copepods, and ostracods originating primarily from Lake Powell) are highest in the Glen Canyon reach and drop sharply downstream (Tables F-2 through F-4).

There is evidence that Lake Powell zooplankton can survive downstream passage to Diamond Creek with only a small mortality rate due to abrasion. Thus, the zooplankton derived from Lake Powell has the potential of contributing to the aquatic food base throughout the river system to Lake Mead (Haury 1986). However, the Colorado River between Lake Powell and Lake Mead has a highly constricted channel and for the most part lacks backwaters of any significant area, which may account for the limited importance of zooplankton drift in the river (Blinn et al. 1995). Zooplankton may also have an affinity for *Cladophora* and other algae in the Glen Canyon reach, and are consumed by macroinvertebrates and fish in that reach (Benenati et al. 2001). These factors may also account for the diminished importance of zooplankton in the Marble and Grand Canyon reaches.

Generally, the responses of macroinvertebrates downstream of dams depend largely on the depth of the reservoir, the depth from which water is drawn, and on the ratio of low to high discharges (Jones 2013). Information on macroinvertebrates collected before and after closure of the Flaming Gorge Dam on the Green River in northeastern Utah is applicable to events that may have occurred in the Colorado River below Glen Canyon Dam (Blinn and Cole 1991; Pearson et al. 1968). Following closure of the Flaming Gorge Dam, macroinvertebrate genera declined from >70 to <30, while the mean macroinvertebrate abundance increased from 1,000 to 10,000/m^2 (Vinson 2001). Mayflies declined from 30 species to a single common species and two rare species. Midges and blackflies were the only other common post-dam insect taxa (Vinson 2001). Colonization of tailwaters by insects can be somewhat limited by lack of drift and small downstream insect population sizes that may limit recruitment from upstream flying adults (Vinson 2001).

River regulation by Glen Canyon Dam decreases turbidity in the tailwaters and permits increased algae growth on bottom substrates (Angradi 1994; Shannon et al. 1994), leading to an increased expansion of macroinvertebrate populations in the tailwater reach of Glen Canyon Dam (Blinn et al. 1992; Stevens et al. 1997). Algae biomass and production decrease downstream as water clarity decreases (Carothers and Brown 1991; Stevens et al. 1997; Hall et al. 2010). As is evident in Table F-1, this drives a downstream decrease in aquatic invertebrate biomass (e.g., *Gammarus*, midges, snails, and aquatic worms) (Carothers and Brown 1991; Stevens et al. 1997; Kennedy and Gloss 2005; Rosi-Marshall et al. 2010).

Various studies in the 1990s demonstrated that over 80% of the invertebrate biomass below Glen Canyon Dam was composed of *Gammarus*, midges, aquatic worms, and snails, many of which graze on epiphytes and other fine particulate matter (Blinn et al. 1998). Predation on insect eggs (e.g., by *Gammarus*) may contribute to the absence of mayflies and stoneflies below dams (Vinson 2001). In Glen Canyon, blackflies and midges support more than half of rainbow trout (*Oncorhynchus mykiss*) production but represent under 10% of total invertebrate production and abundance (Tables F-3 and F-4) (Kennedy et al. 2013). Midges and blackflies dominate invertebrate production in Marble and Grand Canyons (Table F-2); cobble bars are "hotspots" for midge and blackfly production (e.g., 2 to 10 times higher than other habitat types) (Kennedy et al. 2013). New Zealand mudsnails (*Potamopyrgus antipodarum*), *Gammarus*, aquatic worms, and midges dominate the current composition of the benthic community at Lees Ferry (Table F-3). In cobble substrates, New Zealand mudsnails and aquatic worms dominate the benthic biomass. They also dominate depositional habitats, although these areas tend to support lower benthic biomass (Cross et al. 2013). *Gammarus* dominates talus slopes and cliff faces, but these habitats generally have the lowest benthic biomass in the Lees Ferry reach. Blackflies (*Simulium arcticum*) are present in the Lees Ferry reach, but their biomass and abundance are generally low (Tables F-2 and F-4).

Cold water temperatures and daily fluctuations in discharge associated with hydropower production are likely responsible for the low diversity and abundance of aquatic insects downstream of the Paria River (Stevens et al. 1997; Kennedy et al. 2016). The decrease in stream clarity lowers primary production and favors the growth of the less nutritious *Oscillatoria* in the

TABLE F-1 Average Mean Habitat-Weighted Invertebrate Biomass at Select Sites in the Colorado River, July 2006–June 2009

	Habitat-Weighted Biomass (mg AFDM/m^2)[a]					
Taxon	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Acari (water mite)	<1	1	<1	<1	1	<1
Blephariceridae (net-winged midge)	0	0	0	2	<1	0
Ceratopogonidae (biting midge)	<1	<1	0	<1	<1	<1
Chironomidae (midge or chironomid)	163	113	58	30	43	45
Cladocera (water flea)	5	<1	<1	0	<1	0
Collembola (springtail)	0	<1	0	0	<1	0
Copepoda (copepod)	4	<1	<1	<1	<1	<1
Corixidae (water boatman)	0	0	0	<1	<1	0
Elmidae (riffle beetle)	0	<1	<1	6	3	3
Empididae (dagger or balloon fly)	0	<1	2	<1	1	<1
Ephemeroptera (mayfly)	0	0	0	0	<1	0
Gammarus (scud)	1,053	30	5	2	3	5
Hydropsychidae (net-spinning caddisfly)	0	0	2	3	2	<1
Hydroptilidae (microcaddisfly)	0	16	30	0	8	9
Molophilus (crane fly)	0	0	0	<1	<1	0
Nematoda (roundworm)	15	13	2	<1	<1	<1
New Zealand mudsnail	3,170	45	3	35	8	7
Oligochaetes (earthworm/bloodworm)	2,077	218	65	28	42	25
Ostracoda (seed shrimp)	25	<1	0	<1	<1	0
Physidae (bladder snail)	122	<1	0	1	<1	<1
Planariidae (planarian or flatworm)	114	9	<1	<1	<1	<1
Pyralidae (snout moth)	0	<1	0	<1	<1	3
Rhyacophilidae (free-living caddisfly)	0	42	0	0	<1	0
Simuliidae (blackfly)	100	858	35	50	49	44
Sphaeriidae (pea or fingernail clam)	14	<1	0	0	0	0
Zygoptera (damselfly)	0	0	0	0	<1	0
Total	6,862	1,345	202	155	160	141

[a] AFDM = ash-free dry mass. Site 1 is 16 mi downstream of Glen Canyon Dam (GCD, upstream of Paria River confluence), Site 2 is 45 mi downstream of GCD (downstream of Little Colorado River confluence), Site 3 is 78 mi downstream of GCD, Site 4 is 142 mi downstream of GCD, Site 5 is 180 mi downstream of GCD, and Site 6 is 240 mi downstream of GCD (upstream of Diamond Creek confluence).

[b] Biomass values <0.1 mg AFDM/m^2 for a taxon not included in total productivity value.

Source: Cross et al. (2011, 2013).

TABLE F-2 Average Mean Habitat-Weighted Invertebrate Production at Select Sites in the Colorado River, July 2006–June 2009

	Habitat-Weighted Productivity (mg AFDM/m^2/yr)[a]					
Taxon	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Acari (water mite)	0.3	5.0	4.9	3.7	7.0	4.5
Blephariceridae (net-winged midge)	0.0	0.0	0.0	12.4	1.6	0.0
Ceratopogonidae (biting midge)	0.3	4.1	1.4	0.2	1.1	3.6
Chironomidae (midge or chironomid)	717.6	1,103.2	549.0	437.8	634.6	575.7
Cladocera (water flea)	45.2	0.3	<0.1	0.0	<0.1	0.0
Collembola (springtail)	0.0	<0. 1	0.0	0.0	<0.1	0.0
Copepoda (copepod)	33.8	2.2	0.7	<0.1	1.6	0.5
Corixidae (water boatman)	0.0	0.0	0.0	<0.1	<0.1	0.0
Elmidae (riffle beetle)	0.0	2.3	2.6	24.9	17.7	18.3
Empididae (dagger or balloon fly)	0.0	7.3	11.7	4.4	12.2	6.7
Ephemeroptera (mayfly)	0.0	0.0	0.0	0.0	0. 7	0.0
Gammarus (scud)	6,113.8	129.1	18.1	13.5	36.7	68.9
Hydropsychidae (net-spinning caddisfly)	0.0	0.0	15.3	0.0	11.5	0. 7
Hydroptilidae (microcaddisfly)	0.0	134.0	159.2	17.9	41.9	58.6
Molophilus (crane fly)	0.0	0.0	0.0	0. 5	2.2	0.0
Nematoda (roundworm)	152.6	133.5	24.9	6.6	11.6	8.1
New Zealand mudsnail	8,637.0	74.4	8.3	27.8	32.1	27.5
Oligochaetes (earthworm/ bloodworm)	6,019.5	753.3	249.3	86.0	158.6	121.6
Ostracoda (seed shrimp)	124.9	0.3	0.0	<0.1	<0.1	0.0
Physidae (bladder snail)	690.2	4.0	0.0	8.2	0.6	4.6
Planariidae (planarian or flatworm)	571.2	45.9	1.2	0.1	4.2	0.8
Pyralidae (snout moth)	0.0	11.0	0.0	<0.1	0.5	19.0
Rhyacophilidae (free-living caddisfly)	0.0	316.4	0.0	0.0	3.8	0.0
Simuliidae (blackfly)	539.4	5,240.8	266.3	367.2	540.2	488.0
Sphaeriidae (pea or fingernail clam)	69.0	<0.1	0.0	0.0	0.0	0.0
Zygoptera (damselfly)	0.0	0.0	0.0	<0.1	0.0	0.0
Total[b]	23,714.8	7,967.1	1,312.9	1,011.2	1,520.4	1,407.1

[a] AFDM = ash-free dry mass. Site 1 is 16 mi downstream of Glen Canyon Dam (GCD, upstream of Paria River confluence), Site 2 is 45 mi downstream of GCD (downstream of Little Colorado River confluence), Site 3 is 78 mi downstream of GCD, Site 4 is 142 mi downstream of GCD, Site 5 is 180 mi downstream of GCD, and Site 6 is 240 mi downstream of GCD (upstream of Diamond Creek confluence).

[b] Productivity values <0.1 mg AFDM/m^2/yr for a taxon not included in total productivity value.

Source: Cross et al. (2011, 2013).

TABLE F-3 Average Mean Habitat-Weighted Invertebrate Abundance at Select Sites in the Colorado River, July 2006–June 2009

	Habitat-Weighted Abundance (number/m^2)[a]					
Taxon	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Acari (water mite)	20	455	423	324	562	318
Blephariceridae (net-winged midge)	0	0	0	<1	<1	0
Ceratopogonidae (biting midge)	2	52	11	1	25	31
Chironomidae (midge or chironomid)	6,814	9,814	4,602	2,929	3,716	3,172
Cladocera (water flea)	2,497	13	2	0	3	0
Collembola (springtail)	0	<1	0	0	<1	0
Copepoda (copepod)	4,973	404	118	2	174	62
Corixidae (water boatman)	0	0	0	<1	<1	0
Elmidae (riffle beetle)	0	48	38	41	41	19
Empididae (dagger or balloon fly)	0	5	21	11	25	5
Ephemeroptera (mayfly)	0	0	0	0	1	0
Gammarus (scud)	2,930	50	11	8	20	33
Hydropsychidae (net-spinning caddisfly)	0	0	5	0	1	<1
Hydroptilidae (microcaddisfly)	0	42	81	17	22	20
Molophilus (crane fly)	0	0	0	<1	<1	0
Nematoda (roundworm)	1,199	1,846	276	67	113	62
New Zealand mudsnail	74,033	382	110	229	187	120
Oligochaetes (earthworm/bloodworm)	32,988	7,270	2,774	533	1,117	922
Ostracoda (seed shrimp)	1,023	4	0	<1	3	0
Physidae (bladder snail)	279	<1	0	4	4	2
Planariidae (planarian or flatworm)	987	81	5	<1	21	2
Pyralidae (snout moth)	0	<1	0	<1	1	5
Rhyacophilidae (free-living caddisfly)	0	15	0	0	3	0
Simuliidae (blackfly)	419	3,180	316	327	476	352
Sphaeriidae (pea or fingernail clam)	122	<1	0	0	0	0
Zygoptera (damselfly)	0	0	0	0	<1	0
Total[b]	128,286	23,661	8,793	4,493	6,515	5,125

[a] AFDM = ash-free dry mass. Site 1 is 16 mi downstream of Glen Canyon Dam (GCD, upstream of Paria River confluence), Site 2 is 45 mi downstream of GCD (downstream of Little Colorado River confluence), Site 3 is 78 mi downstream of GCD, Site 4 is 142 mi downstream of GCD, Site 5 is 180 mi downstream of GCD, and Site 6 is 240 mi downstream of GCD (upstream of Diamond Creek confluence).

[b] Abundance values <0.1/m^2 for a taxon not included in total productivity value.

Source: Cross et al. (2011, 2013).

TABLE F-4 Distribution, Ecological Importance, and Favorable Temperature Range for Select Primary Producers

Taxa	Distribution	Ecological Importance	Favorable Temperature Range
Upright epiphytic diatoms	Throughout the river, but most abundant in the Glen Canyon Dam–Paria River reach	High, easily consumed by grazers	10–15°C (50–59°F)
Adnate epiphytic diatoms	Throughout the river, but most abundant in the Glen Canyon Dam–Paria River reach	Medium, not as easily consumed by grazers	15–20°C (59–68°F)
Cladophora glomerata	Throughout the river, but most abundant in the Glen Canyon reach	High, substrate for epiphytic diatoms	13–17°C (55–63°F)
Oscillatoria spp.	Throughout the river, but most abundant below Little Colorado River	Low, not generally consumed directly, poor substrate for diatoms	18–21°C (64–70°F)
Egeria densa	Glen Canyon reach	Medium-high, substrate for epiphytic diatoms, cover for fish	15–21°C (59–70°F)
Potamogeton spp.	Throughout the river, but most abundant in the Glen Canyon reach	Medium-high, substrate for epiphytic diatoms, cover for fish	20–22°C (68–72°F)
Fontinalis spp.	Glen Canyon reach	Medium-high, secondary substrate for epiphytic diatoms	10–15°C (50–59°F)
Chara spp.	Throughout the river, but most abundant in the Glen Canyon reach	Medium-high, substrate for epiphytic diatoms, cover for fish	18–25°C (64–77°F)

Source: Valdez and Speas (2007) and references cited therein.

lower reaches of the Colorado River (Blinn et al. 1999). Macroinvertebrates are not generally associated with *Oscillatoria* because it is very compact, has little surface area for colonization, and largely lacks epiphytic diatoms (Blinn et al. 1995). For example, *Gammarus*, a major food source for trout and other fishes, prefers *Cladophora* due to its epiphytic diatoms. This relationship is strong from Glen Canyon Dam to Lees Ferry and weak from Lees Ferry to Diamond Creek (Patten 1998). This relationship does not exist between *Gammarus* and *Oscillatoria*. If *Cladophora* declines, then the contribution of *Gammarus* to the aquatic food base also declines, except perhaps in the drift (Patten 1998).

Drifting macroinvertebrates provide an important food resource for rainbow trout and other native and nonnative fish species. Flow regime, discharge, and distance from the dam influence drift of macroinvertebrates in the Colorado River (Shannon et al. 1996; Stevens et al. 1998; Sublette et al. 1998; McKinney et al. 1999). In general, a positive correlation exists between stream drift and discharge; however, reduced flows can increase stream drift through behavioral factors such as crowding, reduced oxygen concentrations, and avoidance of desiccation (Blinn et al. 1995). Kennedy et al. (2014) concluded that benthic density is the primary control on drift concentrations over long timescales (e.g., weeks to months), because increased benthic production will also increase drift. In contrast, changes in flow such as those

occurring from hydropeaking have an important control on drift concentrations, but primarily on a shorter timescale (e.g., days) (Kennedy et al. 2014).

Tributary and terrestrial insects comprise a small portion of the stream drift in the Colorado River (Shannon et al. 1996). It is possible that terrestrial invertebrate drift increases during and immediately after rainstorms and is therefore an uncommon but locally important resource for river fishes through Grand Canyon (Shannon et al. 1996). Terrestrial and tributary insects contribute <0.001 and <0.1% of the total invertebrate biomass in the mainstem drift, respectively (Blinn et al. 1995). Fish production throughout Glen and Grand Canyon appears to be limited by the availability of midges and blackflies, and fish may exert top-down control over them (Carlisle et al. 2012). While blackflies and midges support between 43 and 50% of trout production, they only comprise a small percentage of total invertebrate secondary production and abundance in the Glen Canyon reach (Tables F-3 and F-4) (Cross et al. 2011).

Generally, physical, chemical, and biological attributes in the lower reaches of the Colorado River peak at or immediately downstream of tributaries. The connection between tributaries and the mainstem is important for the flow of nutrients, sediment, and wood that contribute to habitat heterogeneity and biodiversity in the mainstem (Kiffney et al. 2006). However, tributary sediment inputs can limit light availability and reduce algal production, thereby reducing food for aquatic invertebrates. High sediment loads may also limit the ability of fish to see their prey (Coggins and Yard 2011).

The Colorado River between Glen Canyon Dam and Lake Mead contains more than 400 ephemeral and 40 perennial tributaries; however, as many of the Colorado River tributaries are dry except during heavy summer rains, they contribute little to the mainstem aquatic food base (Haury 1986). All of the tributary streams have a natural seasonal range of temperatures and discharges unaffected by Glen Canyon Dam (NPS 2005). Oberlin et al. (1999) indicated that primary productivity and detritus, the major food resource for macroinvertebrates, are higher overall in clear-water tributaries and highest in those originating inside the Grand Canyon. Phytoplankton species richness also increases in clear-water tributaries (Crayton and Sommerfield 1979; Oberlin et al. 1999), increasing primary productivity and food quality in those environments (Henery 2005).

Common macroinvertebrates in the tributary streams include caddisflies, mayflies, stoneflies, midges, and blackflies. Drift of tributary macroinvertebrates into the mainstem contributes, at least locally, to the aquatic food base in the Colorado River. Macroinvertebrate productivity and diversity in the tributaries are lowest in the spring and summer, as flash floods in these seasons disrupt the benthic invertebrate communities (Oberlin et al. 1999). Tributaries provide ≤25% of the total organic stream drift in the Colorado River through Grand Canyon National Park (Blinn et al. 1995).

Tributary streams with travertine deposits (e.g., Havasu Creek) or those dominated by bedrock (e.g., Matkatamiba Creek) have little inhabitable substrate for macroinvertebrates. Steep channel gradients and erosional habitat also limit benthos in some tributaries. Overall, standing biomass of the Little Colorado River macroinvertebrate community was an order of magnitude lower (0.056 g/m^2 ash-free dry mass [AFDM]) than at the confluence with the Colorado River

(0.25 g/m^2 AFDM). A high discharge with increased suspended sediment loads negatively affects macroinvertebrate biomass (Haden et al. 1999). Even extended periods of base flow (which tends to increase macroinvertebrates and algae) do not increase productivity for the areas of the Little Colorado River that contain most of the river's humpback chub population (Haden et al. 1999).

Some of the tributaries also contain New Zealand mudsnails, probably spread by recreationists (NPS 2005). Shannon et al. (2003a) reported the New Zealand mudsnail in cobble bars of 5 of 18 tributaries they sampled, but the snail did not extend more than 32 m upstream in those streams. Since New Zealand mudsnails prefer habitats with constant temperatures and flows and high primary productivity, flash floods may diminish their long-term establishment in tributaries (Shannon et al. 2003a). The risk of quagga mussel (*Dreissena rostriformis bugensis*) introduction to tributaries also appears low. Reservoirs on the upper reaches of the Little Colorado River may eventually support the quagga mussel. Establishment of the quagga mussel in many of the tributaries is unlikely due to high summer water temperatures above the mussel's upper lethal limit (Kennedy 2007).

F.2.1.3 Influence of New Zealand Mudsnail on the Aquatic Food Base

In addition to changes brought about by Glen Canyon Dam, the loss of native species and the addition of numerous nonnative species modified the aquatic ecosystem of the Colorado River within Grand Canyon (Johnson and Carothers 1987). This applies to the aquatic food base and fish species. Nonnative species, including those intentionally introduced, are often better competitors in the homogeneous habitats of regulated rivers (Stanford et al. 1996). To date, nonnative periphyton and rooted aquatic macrophytes have not caused adverse impacts on the aquatic food base in the Colorado River below Glen Canyon Dam. Section 4.17.3.4 discusses potential impacts that could occur if the diatom *Didymosphenia geminata* ("didymo") becomes established in the Colorado River.

The New Zealand mudsnail can tolerate a wide range of water temperatures (except freezing), salinity, and turbidity. It can also withstand short periods of desiccation. Densities of New Zealand mudsnail are usually highest in systems with high primary productivity, constant temperatures, and constant flow. It occurs in all types of aquatic habitats, from eutrophic mud bottom ponds to clear rocky streams (USGS 2002; Sorensen 2010). Fitness of the New Zealand mudsnail peaks at 18°C (64°F), declining at cooler and warmer temperatures (NZMMCPWG 2007).

Numerous adaptations of the New Zealand mudsnail aid its spread within watersheds. For instance, adults can pass through the digestive systems of some fish species alive, adults can float on masses of algae, and juveniles can float freely on the water surface (Kerans et al. 2005; NZMMCPWG 2007). While the New Zealand mudsnail is not common in streams prone to periods of sediment-moving flood flows, its tough shell, small size, and hydrodynamic shape make it likely to survive scouring flows (Holomuzuki and Biggs 2006; NZMMCPWG 2007). Most New Zealand mudsnails in North America are asexually reproducing females that are born with developing embryos already present in their reproductive system (Sorensen 2010). Clonal

reproduction increases the probability of success of introduction as only a single female can establish a new population (NZMMCPWG 2007). One female can carry up to 20 embryos and under proper conditions may account for over one million snails within one year (Shannon et al. 2003a).

Vinson et al. (2007) suggest that the New Zealand mudsnail introduction into the Green River below Flaming Gorge Dam may have led to a decline of total invertebrate abundance by over 25%. They concluded that decreases in mayflies due to competition from New Zealand mudsnails may jeopardize mayfly recolonization of the Green River following implementation of a more natural springtime flood flow regime. Where the New Zealand mudsnail dominates invertebrate production, it could become the dominant forage base for fishes that prey on macroinvertebrates (Vinson and Baker 2008). Field survey data in the Green River below Flaming Gorge Dam showed a sharp annual increase in the number of brown trout (*Salmo trutta*) and rainbow trout that consumed New Zealand mudsnail between 2001 and 2005 (Vinson and Baker 2008). Bioenergetic simulations suggest that fish diets high in New Zealand mudsnail would not meet energy requirements of fish, resulting in reduced growth and weight loss (Vinson et al. 2007; Vinson and Baker 2008) as discussed previously. For example, when the New Zealand mudsnail comprised between 71 and 81% of brown trout diet, the trout did not gain weight, and when the diet consisted of more than 81% New Zealand mudsnails, brown trout lost weight. Rainbow trout fed a diet of 42% New Zealand mudsnail began losing weight over the course of the experimental study (Harju 2007).

The New Zealand mudsnail represents a trophic dead end in Glen Canyon because it has a high production and consumption of primary producers, but it does not support a substantial amount of production for higher trophic levels (i.e., fish). Minnows and suckers that possess pharyngeal teeth may be capable of consuming and crushing the shells of New Zealand mudsnails (NZMMCPWG 2007). However, the New Zealand mudsnail offers little or no energy compared to other common food items in those fish successful in crushing its shell (Ryan 1982).

F.2.2 Impacts of LTEMP Alternatives on the Aquatic Food Base

The desired future conditions (DFCs) for the Colorado River ecosystem domain (Appendix A of the EIS) include these two DFCs for the aquatic food base goals:

- The aquatic food base will sustainably support viable populations of desired species at all trophic levels.

- Assure that an adequate, diverse, productive aquatic food base exists for fish and other aquatic and terrestrial species that depend on those food resources.

Attaining these DFCs while meeting existing water delivery requirements is complex. Biological resources in regulated rivers are subject to a number of spatial and temporal changes in conditions downstream from a dam: reductions in seasonal flow variability, alterations in the timing of extreme flow events, pulses in flow during periods of peak power demands, reduced turbidity and increased water clarity, diel and seasonal constancy of water temperatures,

armoring of substrates in the tailwaters, modified nutrient regimes, and the appearance of lentic plankton below the reservoir (Blinn and Cole 1991; Blinn et al. 1995; McKinney and Persons 1999). Flow and temperature are the two major factors that influence the condition and availability of the aquatic food base in the Colorado River between Glen Canyon Dam and Lake Mead. The following discussion supplements the analyses presented in Sections 4.5.2.1 and 4.5.3 of the EIS.

F.2.2.1 Flow Effects on the Aquatic Food Base

Hydropeaking is the mode of hydroelectric generation that most alters the quantity and quality of habitats available to aquatic organisms. Effects can be direct (e.g., stranding, mortality, and habitat loss) or indirect (e.g., downstream displacement, depleted food production, increased stress) (Clarke et al. 2008). Impacts of flow fluctuations are typically greatest within the tailwaters of a dam and decline with distance downstream due to flow attenuation and the increasing influence of tributaries (Clarke et al. 2008; Patterson and Smokorowski 2011). Flow attenuation occurs downstream of Glen Canyon Dam; however, because of the constrained nature of the channel through most of Marble Canyon and the Grand Canyon, flow fluctuations from dam releases are still apparent in the lower Grand Canyon near Lake Mead (see Section 3.2.1.2 of the EIS). The following sections discuss flow effects on the aquatic food base with respect to the elements of base operations, adjustments of base operations, and trout management actions for the LTEMP alternatives.

Effects of Base Operations

Potential alternative-specific effects of base operations (i.e., operations in those years when no condition-dependent or experimental actions are triggered) on the aquatic food base depend on the differences in the monthly pattern in release volumes, minimum and maximum flows, daily flow ranges, and ramp rates. Monthly increases in release volumes may increase the permanently wetted zone, which could increase benthic production, if the increased monthly flows last long enough for benthic development to occur (e.g., weeks to months). Months of higher release volumes would also improve hydraulic connectivity with and maintenance of backwater habitats. Backwaters with more permanency potentially support increased planktonic and benthic communities. A decrease in the permanently wetted zone would occur when decreases in monthly release volumes occur (Reclamation 1995; Hoffnagle 2001; Melis et al. 2006; Behn et al. 2010). Pools of water left after high spring or summer flow months potentially provide habitat for mosquitoes (Blinn et al. 1995). While mosquitoes may contribute to the aquatic and terrestrial food base, they pose a potential health concern to humans.

Daily minimum flow is an important determinant of benthic standing crop because of the strong negative effects of desiccation on algae and invertebrates (Melis et al. 2006). Periods of low steady summer/fall releases (e.g., 5,000 to 8,000 cfs) are expected to result in warmer and more stable nearshore and backwater habitats and longitudinal river warming, while similar flows in winter are likely to produce greater overwinter algal and macroinvertebrate production (Blinn et al. 1995; Valdez et al. 2000). Wet channel area in low-angle habitats within the Glen

Canyon reach is reduced by about 10% at 5,000 cfs compared to 8,000 cfs. This area reduction consists of about 16 ha; however, the effects on the aquatic food base from this habitat reduction may not be detectable (Melis et al. 2014).

Restricted minimum and maximum flows and reduced ramping rates of the Modified Low Fluctuating Flow regime adopted in the Glen Canyon Dam Record of Decision (Reclamation 1996) were intended to stabilize the area available for colonization by benthic algae, thereby decreasing losses through desiccation or freezing while increasing primary and secondary production (Blinn et al. 1995). Midges, blackflies, and *Gammarus* were not observed in the varial zone above the 10,600-cfs stage (Blinn et al. 1995).

The interactions between cycles of inundation and dewatering in varial zones play a major role in structuring algal communities in regulated desert rivers (Blinn et al. 1998). Periodic exposure of nearshore and backwater habitats can result in loss of invertebrates and primary producers through desiccation, while inundation can impact the aquatic food base through sediment deposition (Valdez et al. 1998). Atmospheric exposure of benthos can be more severe than flooding because organisms are directly killed rather than displaced or buried (Blinn et al. 1995). Fluctuating flows (>10,000 cfs/day) can fragment *Cladophora* from its basal attachment and increase its occurrence in the drift. Consuming drifting *Cladophora* (with its attached epiphytes and any invertebrates) allows rainbow trout to expend less energy in searching for food (Leibfried and Blinn 1987). Daily range in flows >10,000 cfs only occur during December and January (12,000 cfs) for Alternative B.

A stabilized discharge regime could increase algae production downstream of Glen Canyon Dam. In turn, this may have positive effects on invertebrate and fish production (Kennedy et al. 2013). Basal holdfasts of *Cladophora* can dry following periods of exposure as short as 4 hours in summer (Pinney 1991). Exposure to subzero winter air temperatures for only one night resulted in ≥50% loss of chlorophyll a and mass of *Cladophora* (Blinn et al. 1995). Recovery time may take several months (Blinn et al. 1992). Since algal communities provide the dominant food resource below dams, restricting the extent of the varial zone and maintaining wetted perimeter can be important to maintaining the overall food base (Blinn et al. 1998). Potential differences among alternatives based on daily range in flows are provided in Section 4.5.3 of the EIS.

Warm or subfreezing air temperatures could cause mortality of invertebrates stranded in the varial zone (Gislason 1985). The varial zone provides poor habitat for species with multiple life history stages (Jones 2013) by dewatering of emergence and oviposition sites (Vinson 2001; Kennedy et al. 2016). High rates of egg mortality due to exposure may partially explain the rarity of mayflies in the Colorado River. For example, adult female *Baetis* species land on rocks protruding from the water surface and then crawl underwater to lay their eggs on the underside of the rocks. These rocks may become dry for possibly 12 hours during the hydropeaking cycle, causing egg mortality (Kennedy et al. 2016). The fact that midges and blackflies have more generalized egg laying behaviors that are not strictly dependent on river edges may explain why they are the predominant insects in the mainstem. Nevertheless, hydropeaking still appears to limit egg survival and thus recruitment for midges in the mainstem (Kennedy et al. 2016). In the Glen Canyon Dam tailwaters, *Gammarus* standing stock and fecundity are lower, seasonal

recruitment of young is briefer, and fewer young are recruited into the population in the varial zone compared to the permanently wetted zone. In addition, *Gammarus* mortality increases in the varial zone (Angradi and Kubly 1993; Ayers and McKinney 1996; Ayers et al. 1998).

Invertebrates are continually moving and drifting to different positions in the river, thus stranding of a significant number of invertebrates in the varial zone would reduce the overall abundance in the river including that in the permanently wetted zone (Smokorowski 2010). However, there may be little colonization of shoreline areas during daily high flows, and as discharge decreases, large numbers of insects may not be present to enter the drift from areas being dewatered (Perry and Perry 1986). Nevertheless, reduction in the amplitude and duration of power peaking flow fluctuations may be an effective management strategy for enhancing aquatic insect biomass with the potential for increasing the survival and growth of fishes dependent on them (Gislason 1985).

Flow fluctuations may increase the amount of organisms available to drift-feeding fish, although this may only occur for a short period (e.g., a few days or less), depending on the density and replacement capacity of benthic invertebrates. For example, a twofold daily variation in discharge resulted in a greater than tenfold increase in drift concentrations of *Gammarus* and New Zealand mudsnails while blackfly drift concentrations decreased by more than 80% as discharge doubled. Midge drift concentrations increased proportional to discharge (Kennedy et al. 2014).

As the daily range in flows increases, there is greater divergence in habitat conditions between low and high flows, and there will likely be fewer taxa that can withstand such variability. Consequently, the ratio of the regulated high and low flows may become as important as the base flow as an influencing factor determining biotic composition (Jones 2013). Ramping rate restrictions may allow sufficient time for aquatic macroinvertebrates to respond to daily flow fluctuations (Patterson and Smokorowski 2011). Rapid up-ramping can result in rapid increases in shear stress, potentially causing catastrophic drift or the large-scale displacement of invertebrates from the sediment (Gibbins et al. 2007). Perry and Perry (1986) observed a greater number of aquatic invertebrates stranded when the down-ramping rate was rapid; indicating that unlimited down-ramping is a potential cause of increased invertebrate mortality (Smokorowski 2010). In addition, high ramping rates potentially favor adnate diatom species over the more upright species, the latter of which macroinvertebrates and fishes more readily consumed (Hardwick et al. 1992; Pinney 1991; Biggs 1996).

Miller and Judson (2014) observed that, during a daily hydropeaking schedule, macroinvertebrate drift biomass below Flaming Gorge Dam in the Green River increased during the rising limb of the daily hydrograph and declined prior to the cessation of the peak. Macroinvertebrate drift increases were correlated with the biomass of drifting vegetation. As the study by Miller and Judson (2014) occurred over winter, the rate of vegetation export declined over time due to senescence caused by decreased light levels and cooler temperatures. This at least partly accounted for the observed declines in macroinvertebrate drift after 30 to 60 days (Miller and Judson 2014).

During base operations, up-ramping rates are the same at 4,000 cfs for all alternatives except for Alternatives F and G that would not have a daily range in flows. Down-ramping rates would be highest for Alternative B (4,000 cfs for November through March and 3,000 cfs in the other months), followed by the Alternatives C, D, and E (2,500 cfs) and Alternative A (1,500 cfs). Alternatives F and G both feature steady flows in all months.

Experimental Treatments

High-Flow Experiments. Most experimental adjustments of base operations relate to high-flow experiments (HFEs). The existing HFE protocol calls for spring HFEs to occur in March–April and fall HFEs to occur in October–November, with magnitudes ranging from 31,500 to 45,000 cfs (Reclamation 2011a). Most HFEs would last from less than 1 hour to 96 hours, although HFEs longer than 96 hours could occur under Alternatives C, D, and G. There is a potential for more than one HFE to occur within the same year or between years, with a potential for up to 40 HFEs during the LTEMP period (Alternatives C, F, and G). Food webs close to Glen Canyon Dam are more energy inefficient and are expected to exhibit lower resistance to experimental flood perturbations compared to food webs downstream of major tributaries (Cross et al. 2013).

HFEs conducted in the spring and fall represent contrasting conditions, particularly with regard to light, temperature, and invertebrate biomass. Plant and macroinvertebrate recovery times may be shorter for spring HFEs than for fall HFEs as a result of longer day lengths and warmer river temperatures in spring and summer. Spring HFEs can cause ponding of tributary flows that enter the Colorado River, creating temperature refuge areas within the mainstem (Valdez et al. 2000). Spring HFEs can also re-suspend organic material stored along the shoreline and redistribute it into the mainstem (Valdez et al. 2000). The majority of the aquatic food base taxa would recover within 1 to 4 months after a spring HFE as observed for the spring 1996 and 2008 HFEs (Blinn et al. 1999; Rosi-Marshall et al. 2010), although some taxa may recover more slowly (Cross et al. 2011). Shannon et al. (2001) reported high rates of invertebrate drift for 2 months after the spring 1996 HFE. A post-flood increase in production and drift of midges and blackflies is expected after a spring HFE (Cross et al. 2011), likely due to the flushing of fines in the interstitial spaces between gravel and around macroalgae holdfasts used by these invertebrates for cover. *Gammarus* is expected to be slower to recover because of its greater susceptibility to being exported by river currents than most invertebrate species (Reclamation 2011a). In addition, slow-growing taxa such as *Gammarus* take longer to recover to pre-flood levels relative to faster growing taxa with aerial life stages such as blackflies and midges (Robinson and Uehlinger 2008).

Fall HFEs precede winter months of minimal insolation, low temperatures, and reduced gross primary productivity. Thus, recovery times for aquatic food base organisms take longer than for spring HFEs (Melis et al. 2006). Following the fall 2004 HFE, *Gammarus* was extremely scarce for many months in Lees Ferry (Melis et al. 2006). Even longer recovery times could occur if a fall HFE is followed by a spring HFE. The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. The

following spring HFE could scour the remaining primary producers and susceptible invertebrates and further delay recovery. A spring HFE followed by a fall HFE may not have as great an impact because of the rapid recovery of the food base expected over the summer (Reclamation 2011a).

The 2008 spring HFE reduced annual invertebrate production in the Lees Ferry tailwater by >50%, driven primarily by significant reductions in production of New Zealand mudsnails and *Gammarus*. Large numbers of *Gammarus* dislodged during high flows are transported considerable distances downstream, making them available to fishes. Windrows of stranded *Gammarus* carcasses along some shorelines following the spring 1996 controlled flood (Valdez 1999) became available to terrestrial consumers such as shorebirds, lizards, and spiders. Reductions in mudsnails and *Gammarus* persisted at least 15 months after the HFE (when the study concluded) and coincided with a significant decline in the annual production of these taxa (e.g., New Zealand mudsnail production declined from 11 to 13 g AFDM/m^2/yr to 2 g AFDM/m^2/yr and *Gammarus* production from 7 to 8 g AFDM/m^2/yr to 3 g AFDM/m^2/yr). Reductions in aquatic worms recovered in about 4 to 6 months (Rosi-Marshall et al. 2010). However, midges and blackflies increased by 30 and 200%, respectively, in the year following the HFE, and they supported a 200% increase in rainbow trout production (Cross et al. 2011). During the flood, the concentrations of invertebrate prey available in the drift increased from an average of 0.093 mg/m^3 AFDM before the flood to an average 0.163 mg/m^3 after the flood (Rosi-Marshall et al. 2010; Cross et al. 2011).

The concentrations of midges and blackflies in the drift increased 400 and 800%, respectively, after the 2008 HFE, and this effect persisted for at least 15 months. Biomass and production of both groups also increased after the HFE (Rosi-Marshall et al. 2010; Cross et al. 2011). The March 2008 HFE resulted in an increase in the area of backwater habitat that persisted for at least two months, but returned to conditions similar to those before the HFE by about 6 months after the HFE (Melis 2011). In addition to scouring benthic algae and invertebrates, high flows can capture large quantities of terrestrial organic matter that may temporarily increase the amount of food base available for drift-feeding fish (Valdez and Hoffnagle 1999; Gloss et al. 2005).

Generally, more frequent HFEs may cause a shift to more resistant taxa or to new taxa that would colonize the river. However, if such taxa are not present, more frequent HFEs may reduce macroinvertebrate diversity and possibly abundance, resulting in a reduction in the aquatic food base (Reclamation 2011a). Any benefits from HFEs along downstream segments of the Colorado River (particularly the lower portion of the Grand Canyon reach) will likely be smaller in magnitude than in the Lees Ferry reach (Melis 2011; Kennedy et al. 2013). The average number of HFEs during the LTEMP period would be 39.3 under Alternative F; range from 17.1 to 24.5 under Alternatives C, D, E, and G; and be only 7.2 under Alternative B and 5.5 under Alternative A.

The most notable differences among the alternatives is for Alternative A, which would not have HFEs after 2020; Alternative B, which would not exceed one spring or fall HFE every other year; and Alternative E, which would not have spring HFEs during the first 10 years (Table 2-2 of the EIS).

A comprehensive study on the ecological effects of repeated HFEs in the River Spöl in Switzerland indicated that one or two high-flow events per year can enhance and sustain long-term ecological integrity (Scheurer and Molinari 2003) and that such releases must be repeated on a regular basis (annually) to maintain their benefits (Robinson and Uehlinger 2008). The first experimental flood in the River Spöl reduced macroinvertebrate abundance by about 50%. However, subsequent experimental floods had less effect, indicating that a new assemblage had established that was more resilient to flood disturbance. The response of macroinvertebrates to experimental floods occurs over a period of years, rather than months, as species composition adjusts to the new flow conditions (Robinson and Uehlinger 2008). Robinson et al. (2003) observed that the abundance of amphipods and planarians decreased while the abundance of baetid mayflies, blackflies and midges increased. Some mayfly, stonefly, and caddisfly taxa initially decreased in abundance but subsequently increased. The results of experimental floods in the River Spöl imply that the experimental flood regime needs maintaining to sustain the development of a more natural macroinvertebrate assemblage (Robinson et al. 2003). While three to five consecutive HFEs from Glen Canyon Dam may alter the aquatic food base composition, the absence of an HFE for one or more seasons might reset the current aquatic food base community (Reclamation 2011a). It is anticipated that, regardless of the HFE regimen, midges and blackflies would remain important components of the aquatic food base downstream of Glen Canyon Dam.

A large portion of the aquatic food base in the Lees Ferry reach would likely be scoured by an HFE of 41,000 to 45,000 cfs regardless of the time of year. The initial hydrostatic wave produces the scouring effect, and the duration of the flow is an important factor in transporting the material downstream (Rosi-Marshall et al. 2010). The HFE conducted in March 1996 (7-day discharge of 45,000 cfs) resulted in benthic scour and entrainment of both primary and secondary producers at all study sites along the 239-mi river corridor. Over 90% of the benthos was removed by the hydrostatic wave or within 24 hr from the start of the test flood. In addition, drift mass reached highest levels during the first 2 days of the HFE (an order of magnitude higher than under normal dam operations) and subsided after that period (Shannon et al. 2001). Recovery rates to pre-flood levels were fast for benthic algae (1 month) and invertebrates (2 months) (Blinn et al. 1999). Recovery of the macrophytes *Chara*, *Potamogeton*, and *Elodea* to pre-flood conditions took 1 to 7 months (Shannon et al. 2001).

It is hypothesized that mucilaginous algae found in miscellaneous algae, macrophytes, and bryophytes (MAMB) can outcompete *Cladophora* under the combination of reduce nutrient conditions and elevated discharge regimes of about 25,000 cfs. However, if discharge increases to 45,000 cfs or more, MAMB will scour, allowing *Cladophora* to recolonize regardless of nutrient conditions because of strong holdfast attachment and lack of competition (Benenati et al. 2000). HFEs up to 45,000 cfs may occur under Alternatives C, D, and G.

HFEs longer than 96 hours may also occur under Alternatives C, D, and G. These longer-duration HFEs could scour much of the aquatic food base, especially within the Glen Canyon reach, and reduce the standing crop of benthic invertebrates. The extended-duration HFEs may increase the aquatic food base available for drift-feeding fishes, particularly during the initial hours of the flood. An extended-duration HFE may also help to control the abundance of

New Zealand mudsnails in the Glen Canyon reach, but it may possibly contribute to their downstream abundance. Potential effects of sustained spring flows include:

- High, turbid main-channel flow and a surge of increased macroinvertebrate drift, increased feeding opportunities for non-sight feeders, and increased density of terrestrial invertebrates washed from shoreline.

- Rebuilt backwater habitats and increased primary and secondary production in backwaters following redistribution of organics (Valdez et al. 1998).

Steady Flows. Steady flows (or nearly steady flows with some instantaneous fluctuations associated with ancillary services) would occur prior to or following spring and/or fall HFEs (prior to spring and fall HFEs under Alternative C and before fall HFEs only for Alternatives D and E; Alternatives F and G already feature steady flows). Potential effects of steady flows include (1) warmer shoreline and backwaters and an increase in backwater production; (2) warmer main channel and an increase in primary and secondary production and potential for parasite maturation and proliferation; and (3) stable main channel and less turbidity and an increase in shoreline primary and secondary production and reduced macroinvertebrate drift as food for fish (Valdez et al. 1998). However, mainstem warming, particularly in the Glen Canyon and Marble Canyon reaches, would be limited. Ralston et al. (2007) observed that biological and physical parameters were unaffected by daily fluctuations in flow of 2,700 cfs and steady-flow releases. Reduced flow fluctuations prior to an HFE could increase production of primary producers and consumers. The HFE could increase drift biomass. Reduced flow fluctuations following an HFE could hasten benthic recolonization.

Low Summer Flows. Low summer flows may be tested under Alternatives C, D, and E; and are an annual component of Alternative F. Low summer flow tests would involve flows between 5,000 and 8,000 cfs to warm the Colorado River at the confluence with the Little Colorado River to at least 13°C (55°F), 14°C (57°F), or 16°C (61°F) under Alternatives C, D, and E, respectively. Dropping to low flows in the summer would necessitate increasing mean daily flows in other months relative to base operations. Low summer flow tests may increase primary and secondary benthic production but reduce macroinvertebrate drift. In particular, the density of New Zealand mudsnails may increase under low summer flows. However, the opposite conditions, compared to base operations without low summer flow tests, may occur in non-summer months. Potential impacts on the aquatic food base from low summer flows under Alternative F are described in Section 4.5.3.6 of the EIS.

Hydropower Improvement Flows. Hydropower improvement flows (increased fluctuation levels proposed as an experiment under Alternative B) would entail a daily change from a minimum flow of 5,000 cfs to a maximum flow of 15,000 to 25,000 cfs (depending on season). This could decrease primary and secondary production, although macroinvertebrate drift may increase. Down-ramp rates of 5,000 cfs/hr may increase stranding of organisms in the varial zone compared to base operations that range from 1,500 cfs/hr (Alternatives A, F, and G) to 4,000 cfs/hr (Alternative B from November through March). Conversely, higher up-ramp rates of 5,000 cfs/hr coupled with sustained high flows may flush increased amounts of terrestrial invertebrates (and other items such as leaf litter) from shoreline areas into the drift compared to base operations for all alternatives (up-ramp rates of 4,000 cfs/hr).

Sustained Low Flows for Benthic Invertebrate Production. An aquatic resource-related experiment unique to Alternative D would be to test the effects of macroinvertebrate production flows in May through August on benthic invertebrate production and diversity. It has been demonstrated that the large varial zone created by fluctuating flows limits recruitment of mayflies (order Ephemeroptera), stoneflies (order Plecoptera), and caddisflies (order Trichoptera), collectively referred to as EPT, due to high egg mortality. Because EPT taxa cement eggs principally along the river edge habitats, eggs laid during stable low flows over the weekend would not be subjected to drying prior to hatching. Depending on the findings from the first test, this experiment may be conducted two to three times during the LTEMP period, but not during the first 2 years. In addition to potentially increasing EPT, macroinvertebrate production flows may benefit other aquatic food base organisms that have terrestrial adult life stages such as dragonflies and true flies (including midges and blackflies). Some loss of benthic production is possible in the shoreline areas that remain dewatered over the weekend. If this results in an unacceptable risk (e.g., decreased benthic production), the experiment would not be repeated. There is also the possibility that this experimental procedure may result in confounding interactions with trout management flow (TMF) experiments, which are also expected to be conducted during the LTEMP period.

Trout Management Flows. The 2003 Ecological Restoration Flows that began on January 1, 2003, consisted of daily fluctuations between 5,000 and 20,000 cfs in an attempt to disadvantage nonnative fish, particularly trout, during their winter spawning period. Overall, the 2003 Ecological Restoration Flows caused a drop in benthic biomass at cobble bars in Glen Canyon during the January to March flows followed by recovery through the summer (Shannon et al. 2003b). The flows did not have a long-term adverse impact on New Zealand mudsnail biomass and densities throughout the river. For example, at –3 Mile Bar, mudsnail biomass dropped by 70% between December and January collections; however, by June, New Zealand mudsnails had recovered to 90% of the December estimate (Shannon et al. 2003b).

TMFs conducted in spring and summer months (May–July), featured in all alternatives but Alternative A, would consist of several days at relatively high sustained flows (e.g., 20,000 cfs) followed by a rapid drop to low flows (e.g., 5,000 cfs), which would be held for a brief period (e.g., <24 hr). This pattern would be repeated for a number of cycles. Conditions for primary production should decrease slightly with increased turbidity during the higher

discharge portion of TMFs (Reclamation et al. 2002). Although a temporary increase in total wetted area would occur under TMFs, areas would not be inundated for sufficient time to allow for benthic colonization (Benenati et al. 1998; Blinn et al. 1995). Thus, desiccation losses due to substrate exposure from dewatering of the varial zone would be minimal. Aquatic food base drift may increase during up-ramping to 20,000 cfs/hr associated with TMFs. Drift biomass has been observed to increase during the rising limb of the hydrograph (Miller and Judson 2014).

F.2.2.2 Temperature Effects on the Aquatic Food Base

One of the primary effects of dams, particularly those with hypolimnetic releases, is a change in water temperature, which is primarily responsible for the decline in invertebrate biodiversity. Warmer winter water temperatures can impact invertebrates in a number of ways including loss of physiological signals; disruption of normal growth, fecundity, and emergence; lack of winter chill to break insect egg or larval diapause; and early emergence. Cooler summer water temperatures can also impact invertebrates. For example, water temperatures high enough to complete development may not occur. Other impacts may include decreased fecundity, temporal separation of male and female emergence, delayed emergence, and prolonged emergence. The greater thermal constancy in annual and diel stream water temperatures downstream from dams also tends to decrease food base biodiversity (Vinson 2001).

Seasonal variation in water temperatures decreased gradually from Glen Canyon Dam closure in 1963 until about 1971, when water began to be drawn from the hypolimnion of Lake Powell. Main channel temperatures are now relatively isothermal at 7.2 to 10°C (45 to 50°F), but warm somewhat downstream in summer. There is an estimated maximum warming of the Colorado River mainstem of about 1°C (1.8°F) for every 35 mi, and water released at 10°C (50°F) from Glen Canyon Dam is expected to warm to about 17°C (62.6°F) near Diamond Creek (RM 225) in May or June (Benenati et al. 2002; Valdez 1994). Backwater habitats near the channel margins are one of the few aquatic habitats that warm above these levels. Backwater temperatures tend to warm with distance downstream from the dam (Valdez et al. 1998).

In winter, the mainstem water temperature near Diamond Creek is only about 1°C (1.8°F) higher than at Glen Canyon Dam (Cross et al. 2013). From 1988 to 2005, the average temperature of water released from Glen Canyon Dam was 9°C (48.2°F), and annual high temperatures at Diamond Creek between 1990 and 2002 were about 18°C (64.4°F). A drought that began in 2003 reduced water levels in Lake Powell and resulted in water temperatures that reached an annual high of 21°C (69.8°F) at Diamond Creek in 2005 (Hamill 2009).

In a two-week laboratory study, epiphytic diatom communities from the cold tailwaters of Glen Canyon Dam (12°C [54°F]) were incubated at 18 and 21°C. No change occurred in diatom composition between 18 and 21°C (64 and 70°F), but a significant change occurred between 12 and 18°C (54 and 64°F). At the higher water temperatures, smaller and closely adnate taxa became more important numerically than larger, upright diatoms (Blinn et al. 1989). This shift in diatom species composition may affect macroinvertebrates that feed on diatoms (Lechleitner 1992). Table F-4 provides the distribution, ecological importance, and favorable temperature range for select primary producers in the Colorado River, while Table F-5 provides temperature requirements for common zooplankton taxa.

TABLE F-5 Temperature Requirements for Common Zooplankton

	Temperature, °C (°F)		
Species	Minimum	Maximum	Optimum
Daphnia pulex (cladoceran)	10 (50)	28 (82)	20 (68)
Daphnia galeata (cladoceran)	10 (50)	25 (77)	20 (68)
Daphnia lumholtzi (cladoceran)	10 (50)	30 (86)	25 (77)
Leptodora sp. (cladoceran)	15 (59)	30 (86)	20 (68)
Bosmina sp. (cladoceran)	6 (43)	28 (82)	20 (68)
Diaphanosoma sp. (cladoceran)	10 (50)	30 (86)	25 (77)
Rotifers	15 (59)	30 (86)	25 (77)
Calanoid copepods	10 (50)	30 (86)	25 (77)
Cyclopoid copepods	10 (50)	30 (86)	25 (77)

Source: Valdez and Speas (2007).

If stream temperatures are raised by only a few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in February or March and face death by freezing or will be prevented from mating because they are inactivated by low air temperatures. In addition, increases in stream temperatures may exaggerate the separation between the emergence of males and females (e.g., males may emerge and die before females emerge) (Nebeker 1971). Overall, temperatures above or below the optimum can lead to the production of small adults and lower fecundity (Vannote and Sweeney 1980). Slower warming of streams throughout the summer can reduce fecundity of emerging adults, exaggerate the separation of male and female emergence, prolong the emergence period of individual generations (which reduces the number of insects emerging at any given time, which may increase the individual risk of predation by trout or other fish), and reduce the growth rate such that emergence might occur later in the year when air temperatures are suboptimal for mating (Rader et al. 2008; Vinson 2001).

The lack of temperature variability in the Colorado River downstream of Glen Canyon Dam has selected for macroinvertebrates that do not require temperature cues to complete their development. This may at least partially account for the low levels of mayflies and caddisflies and the absence of stoneflies in the mainstem of the Colorado River (Oberlin et al. 1999). Fecundity of *Gammarus* in the tailwaters of Glen Canyon Dam is lower than that reported in other locations, probably due to water temperatures being well below the optimum of 18°C (64°F) for reproduction (Ayers et al. 1998). Table F-6 provides the distribution, importance to higher trophic levels, and temperature range for common benthic macroinvertebrates that occur in the Colorado River.

There is the possibility of an increase in the distribution and prevalence of fish diseases and parasites from river warming (Hoffnagle 2001; Valdez et al. 2000). Warmer, more stable backwaters could provide additional habitats for the Asian tapeworm (*Bothriocephalus acheilognathi)* and anchor worm (*Lernaea cyprinacea*) to substantially increase in abundance,

TABLE F-6 Distribution, Importance to Higher Trophic Levels, and Temperature Range for Common Benthic Macroinvertebrates Downstream of Glen Canyon Dam

Taxa	Distribution in Project Area	Importance to Higher Trophic Levels	Temperature Range in Project Area[a]	Favorable Temperature Range[a]
Gammarus lacustris (amphipod)	Glen Canyon Dam–Paria River (also important component of drift below this reach)	High	7–10 (45–50)	7–29 (45–84)
Simulium (blackfly)	RM 1.0 to Lake Mead and various tributaries	Medium-high	5–31 (41–88)	10–26 (50–79)
Cricotopus (midge)	Glen Canyon Dam–Paria River (also important component of drift below this reach)	Medium	7–10 (45–50)	15–21 (59–70)
Eukiefferiella (midge)	Glen Canyon Dam–Paria River (also important component of drift below this reach)	Medium	7–10 (45–50)	12–18 (54–64)
Orthocladius (midge)	Glen Canyon Dam–Paria River (also important component of drift below this reach)	Medium	7–10 (45–50)	8–18 (46–64)
Chironomus (midge)	RM 1.0 to Lake Mead	Medium	4–23 (39–73)	9–25 (48–77)
Aquatic worms	Glen Canyon Dam–Paria River (also important component of drift below this reach)	Low	4–23 (39–73)	8–25 (46–77)
Aquatic snails	Glen Canyon Dam–Paria River	Low	7–10 (45–50)	7–39 (45–102)
Potamopyrgus antipodarum (New Zealand mudsnail)	Glen Canyon Dam–Paria River	Low	4–23 (39–73)	7–28 (45–82)
Pisidium (pill clam)	Glen Canyon Dam–Paria River	Low	7–10 (45–50)	2–20 (36–68)
Dugesia (planarian)	Glen Canyon Dam–Paria River	Low	7–10 (45–50)	5–16 (41–61)
Baetis (mayfly)	Various tributaries	High	3–31 (37–88)	4–18 (39–86)
Hydropsyche (caddisfly)	Various tributaries	High	3–3 (37–88)	7–30 (45–86)
Megaloptera: Corydalidae (dobsonflies)	Various tributaries	High	5–28 (41–82)	5–30 (41–86)

[a] Temperature in °C (°F).

Source: Valdez and Speas (2007) and references cited therein.

resulting in their spread along the mainstem and into additional warmwater tributaries. Reported maximum temperature warming above those in the main channel for nearshore habitats ranges from 2.2°C (4.0°F) in eddies to 13°C (23.4°F) in backwaters (Vernieu and Anderson 2013). Warming of nearshore areas is somewhat ephemeral (e.g., decreases at night and during day under windy or cloudy conditions) (Vernieu and Anderson 2013). Temperatures greater than 20°C (68°F) would allow maturation of the Asian tapeworm, while temperatures greater than 15°C (59°F) would allow maturation of the anchor worm (Valdez et al. 1998). Section 4.5.2.4 of the EIS discusses fish parasite and disease incidence for mainstem locations. Table F-7 presents temperature requirements of the Asian tapeworm, anchor worm, and trout nematode. Whirling disease infection prevalence and disease severity reaches its highest levels at 10–15°C (Steinbach Elwell et al. 2009).

As analyzed in Section 4.5.3 of this EIS, temperature differences among alternatives would be minimal. Therefore, no significant changes in the aquatic food base due to elements of the base or condition-dependent operations are expected.

F.2.3 Conclusion

Table 4.5-1 of this EIS summarizes the impacts from the alternatives on the aquatic food base, while Section 4.5.3 presents the impacts of each alternative in more detail. Under Alternative A, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base are expected to persist over the LTEMP period. The cessation of HFEs after 2020 may result in a shift to a food base community not dominated by midges and blackflies (important contributors to the diet of trout). Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base, would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

TABLE F-7 Temperature Requirements for the Asian Tapeworm, Anchor Worm, and Trout Nematode

	Host Activity Temperature Requirements[a]			Infestation Temperature Requirements[a]		
Species	Minimum	Maximum	Optimum	Minimum	Maximum	Optimum
Asian tapeworm	18 (64)	20 (68)	19 (66)	20 (68)	30 (86)	25 (77)
Anchor worm	20 (68)	30 (86)	25 (77)	18 (64)	30 (86)	25 (77)
Trout nematode	16 (61)	20 (68)	18 (64)	16 (61)	20 (68)	18 (64)

[a] Temperature in °C (°F).

Source: Valdez and Speas (2007).

Under Alternative B, benthic food base production would be similar to that under Alternative A. HFEs conducted less often than annually may lower the potential to establish a food base adaptable to flood conditions (i.e., one dominated by midges and blackflies). Hydropower improvement flows could decrease benthic food base production, which over the long term may also decrease drift (Kennedy et al. 2014). Over the short term, TMFs could also cause short-term increases in drift rates and slightly decreased primary production compared to Alternative A. Temperature impacts on the aquatic food base under Alternative B would be similar to those under Alternative A.

Under Alternative C, benthic food base productivity may be higher in December through June compared to Alternative A due to higher volumes and larger wetted area, but lower from August through November compared to Alternative A due to lower volumes and smaller wetted area. The more frequent HFEs compared to Alternative A would favor midge and blackfly production. Low summer flows are expected to lower food base production compared to higher flow conditions. Over the short term, TMFs could increase drift rates and slightly decrease primary production compared to Alternative A. Slightly warmer water temperatures for August and September at RM 225 under Alternative C may slightly increase food base production compared to Alternative A, although this could be offset by changes in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

The relatively consistent monthly release volumes under Alternative D compared to Alternative A would produce a more consistent and stable aquatic food base. The more frequent HFEs under Alternative D are expected to favor midge and blackfly production compared to Alternative A. Over the short term, TMFs could increase drift rates and slightly decrease primary production compared to Alternative A. Macroinvertebrate production flows in May through August under Alternative D would be tested to determine whether they increase benthic food base production and diversity including the recruitment of mayflies, stoneflies, and caddisflies (important food base organisms currently rare to absent throughout much of the mainstem below Glen Canyon Dam). Low summer flows would provide ideal egg laying conditions for aquatic insects throughout the summer growing season and would therefore be expected to increase food base production; however, the lower magnitude of discharge might lead to lower drift concentrations of invertebrates. Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C.

Under Alternative E, relatively consistent monthly release volumes would favor aquatic food base productivity, but this effect would be offset by larger daily fluctuations. The frequent HFEs under Alternative E will favor midge and blackfly production, although the number of HFEs would be less than under Alternatives C, D, F, and G. Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternatives C and D.

Because of the comparatively lower flow volumes under Alternative F, food base biomass from July through the following March would be low compared to all other alternatives. Flow stabilization may allow for high benthic densities of New Zealand mudsnails. Over the long term, increased benthic production from flow stabilization may increase drift rates of food base organisms (Kennedy et al. 2014). Higher flow volumes in April through June may increase benthic food base biomass compared to Alternative A. The frequent HFEs will favor blackfly

and midge production. The warmer water temperatures for August and September at RM 225 under Alternative F may slightly increase food base production even more than Alternative D, although this could similarly be offset by changes in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Under Alternative G, consistent and stable aquatic food base conditions would persist throughout the year. Benthic food base biomass would probably be greater under Alternative G, compared to Alternative F, because flows from July through the following February would be higher. However, stable flows may favor dominance by the New Zealand mudsnail. Potentially higher drift rates from spring flows under Alternative F would not occur under Alternative G. However, increased benthic production may increase drift rates over the long term (Kennedy et al. 2014). The frequent HFEs are expected to favor blackfly and midge production. Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternatives C, D, and E.

F.3 MODELING EFFECTS OF LTEMP ALTERNATIVES ON RAINBOW TROUT AND HUMPBACK CHUB

This section describes the methodology, results, and conclusions from a model developed in support of the LTEMP EIS by Yackulic (Grand Canyon Monitoring and Research Center [GCMRC]), Coggins (U.S. Fish and Wildlife Service [FWS]), and Korman (EcoMetrics) to evaluate effects of alternatives on rainbow trout and humpback chub populations. Although other models were considered for use, the combined rainbow trout-humpback chub model described here was developed to incorporate recent information from the Natal Origins, Juvenile Humpback Chub Monitoring, and Near-Shore Ecology projects being conducted by GCMRC and to utilize newer approaches to modeling humpback chub population demographics. In addition, there was a need to develop the model in a software environment in which batch processing of model runs for multiple hydrologic and sediment input scenarios for each alternative would be feasible and computationally efficient. The model used existing data to inform parameter estimates whenever possible.

F.3.1 Model Overview

The trout-chub model consists of three combined submodels: (1) a model of rainbow trout population dynamics in the Lees Ferry reach, (2) a model of rainbow trout movement and survival downriver from Lees Ferry (trout routing model), and (3) a model of the response of humpback chub population dynamics in the Little Colorado River and Colorado River to monthly mainstem temperatures and monthly trout abundances. The model of the Lees Ferry rainbow trout population dynamics is similar to previous models used for the Glen Canyon reach. The trout movement and humpback chub models, on the other hand, were developed for this application to reflect recent advances, with an emphasis on deriving parameter values from data. The following paragraphs give a brief overview of the three submodels, with more detailed descriptions of each submodel available in subsequent sections (Sections F.3.1.1, F.3.1.2, and F.3.1.3).

Output from a flow model drives the Lees Ferry rainbow trout submodel. This model can be run independently from the trout routing and humpback chub submodels, as it does not include any feedbacks. Simulations include interannual variability in recruitment, outmigration, and growth based both on regression-derived predictions and variation around these predictions. Simulations also include parameter uncertainty, which includes a critical uncertainty related to the effectiveness of TMFs. The parameter associated with the critical uncertainty was fixed at two values (0.10 and 0.50) encompassing a hypothesized range of effectiveness, while all other parameters were drawn from the multivariate distribution estimated from data. Outputs from this submodel include four performance metrics, including simulated outmigration, which was used as input to the trout routing submodel.

The trout routing submodel includes a single biological parameter describing movement, as well as multiple inputs related to implementation of mechanical removal, all of which are fixed. The trout routing submodel model is run a year at a time, after which it passes monthly rainbow trout abundances to the humpback chub submodel.

The humpback chub submodel simulates the impacts of rainbow trout and temperature (forecasted by a temperature model) on humpback chub population dynamics at a monthly time step. It returns the adult population abundance at the end of the year, which is used as one of the performance metrics and is also used by the trout routing model to determine whether mechanical removal would be triggered in the next year. The humpback chub submodel includes parametric uncertainty including levels for a critical uncertainty related to the effect of rainbow trout on humpback chub survival and growth, as well as variation in other parameters. The humpback chub submodel also includes interannual variability in recruitment and outmigration.

More detailed information about each of the submodels is provided in the following sections.

F.3.1.1 Glen Canyon Trout Submodel

An age-structured population dynamics model was used to predict the abundance and growth of rainbow trout in Glen Canyon and the number of those fish that migrate into Marble Canyon. The model makes predictions on an annual time step for ages 1–6 yr. Annual recruitment, which was defined as the number of age-0 fish (i.e., fish hatched in the current year) that enter the population in a given year, is predicted based on flow statistics, and growth is predicted as a decreasing function of overall rainbow trout abundance. Abundance, in combination with age-specific angling vulnerabilities, is used to make predictions of angler catch per hour of effort. Predicted abundance and size distributions are used to compute the number of high-quality fish (trout ≥16 in. total length) potentially available for capture. The number of fish migrating from the Glen Canyon reach into Marble Canyon each year (out-migrants) is predicted as a proportion of the previous year's recruitment, and is used to determine the potential number of fish that eventually migrate down to the confluence of the Little Colorado River (RM 61), where their effects on humpback chub are simulated. Basic simulation parameters and those for key functional relationships were derived or fitted to values from the Korman et al. (2012) stock

synthesis model. This model used 21 years of electrofishing-based catch-per-effort data for Glen and Marble Canyons, in conjunction with length frequencies and other information, to estimate annual recruitment, survival rate, von Bertalanffy growth parameters, and outmigration patterns (numbers, size, and timing). Specifics of the Glen Canyon trout simulation model are provided below.

Recruitment

The annual recruitment of age-0 trout in Glen Canyon was predicted based on a multiple linear regression driven by flow-derived independent variables. The model predicted log annual recruitment as a function of annual Glen Canyon Dam release volume, the range in mean daily flows during the critical early life history rearing period (May–August), and the presence of a spring HFE in each year or in the previous year (Korman et al. 2011c; Avery et al. 2015). The model explained 55% of the annual variation in the recruitment estimates from the Korman et al. (2012) stock synthesis model between 1990 and 2010 (Figure F-1). The flow-dependent regression model predicted that recruitment would be higher in years with greater annual volumes, reduced daily variation in flow between May and August, and when spring HFEs occur. In the simulation model, log recruitment each year is predicted from a random normal distribution, with the mean determined by linear regression parameters and hydrologic statistics, and the extent of error determined by the residual error in the regression model.

Recruitment for a given year was predicted to be higher if a spring HFE occurred in that year or in the previous year, based upon empirical relationships reported by Korman et al. (2011c). However, there is insufficient information to draw a conclusion about whether HFEs that occur in the fall would have a similar effect on recruitment of trout. The model considered this uncertainty about the effect of fall HFEs on recruitment of rainbow trout in the Glen Canyon reach by examining two hypotheses: (1) fall HFEs would have no effect on recruitment and (2) recruitment would increase at the same rate as seen with spring HFEs, but for only one year instead of two.

As described in Section 2.3.3.2 of this EIS, TMFs are a special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging young-of-the-year (YOY) trout. TMFs have been proposed and developed on the basis of research described in Korman et al. (2005). TMFs are included as elements of some alternatives evaluated in the LTEMP EIS, and the Glen Canyon trout submodel incorporated the ability to consider the effects that occurrence of TMFs could have on trout resources. For alternatives and associated long-term strategies that included TMFs, these flows were triggered in the model during years in which the initial production of YOY rainbow trout (based on hydrologic characteristics) in the Glen Canyon reach was anticipated to be greater than 200,000 individuals. Because there is uncertainty regarding how effective TMFs would be at disadvantaging YOY trout, the model was used to evaluate two different levels of effectiveness by reducing the number of YOY trout surviving to age-1 by either 10% or 50% for each 20-year simulation period.

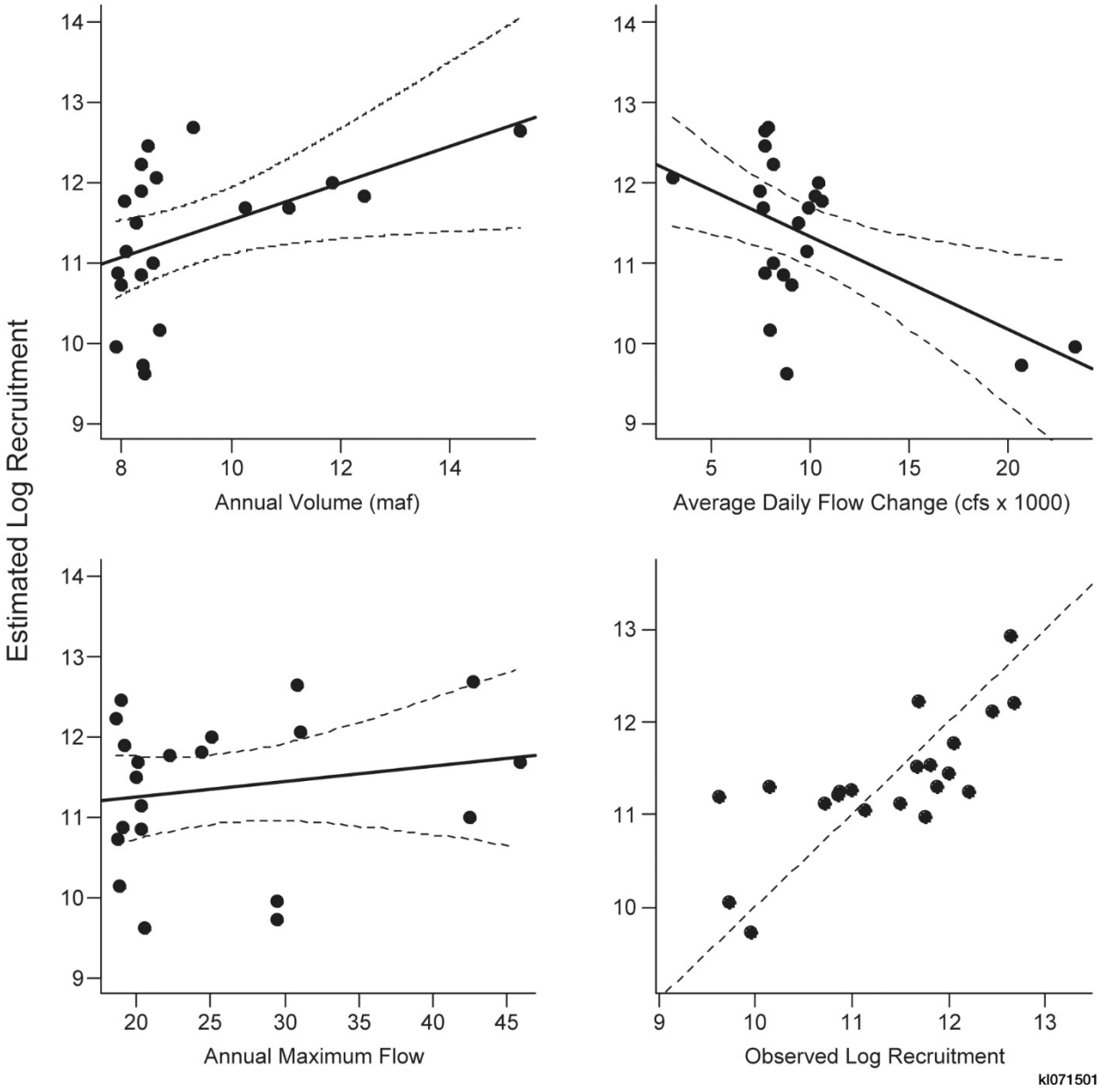

FIGURE F-1 Fit of Regressions Predicting the Log of Recruitment of Rainbow Trout in the Glen Canyon Reach Estimated by the Korman et al. (2012) Stock Synthesis Model as a Function of the Annual Release Volume from Glen Canyon Dam (million acre-feet), the Range of Mean Daily Flows during May–August (thousand cfs), and the Maximum Flow (cfs) Each Year (The bottom-right plot compares the overall fit of a multiple regression model with annual volume and range of mean daily flows during May–August as independent variables, and with the maximum annual flow independent variable replaced with a dummy variable with values of 1 for years prior to or with spring HFEs. The dashed line in the bottom-right graph indicates the 1:1 relationship and the 95% confidence interval in other graphs. The multiple regression model explained 55% of the variation in log recruitment and was statistically significant [p = 0.002].)

Growth

Length-at-age was calculated assuming a von Bertalanffy relationship that depends on the Brody growth coefficient ($vbK = 0.55$), the asymptotic length (L_{inf}, size at the terminal age), the coefficient of variation in length-at-age ($cvLen = 0.1$), and the mean size at age 1 ($L_0 = 130$ mm). Parameter estimates were derived from the stock synthesis model, which was fit to length-frequency and supplemental growth data (Korman et al. 2012, 2011a,b). Annual variation in asymptotic length was predicted as a linear function of the abundance of trout >150 mm. This model predicts only 18% of the annual variation in the annual asymptotic length estimates from the stock synthesis model (Figure F-2). To simulate interannual variation in L_{inf} in the model, annual deviates of L_{inf} in log space were added to a base value (5.89). In the simulation, predicted deviates from the $L_{inf} - N > 150$ regression model were added to the base value, and these formed the mean of a random normal distribution with a standard deviation equal to the residual error of the regression model.

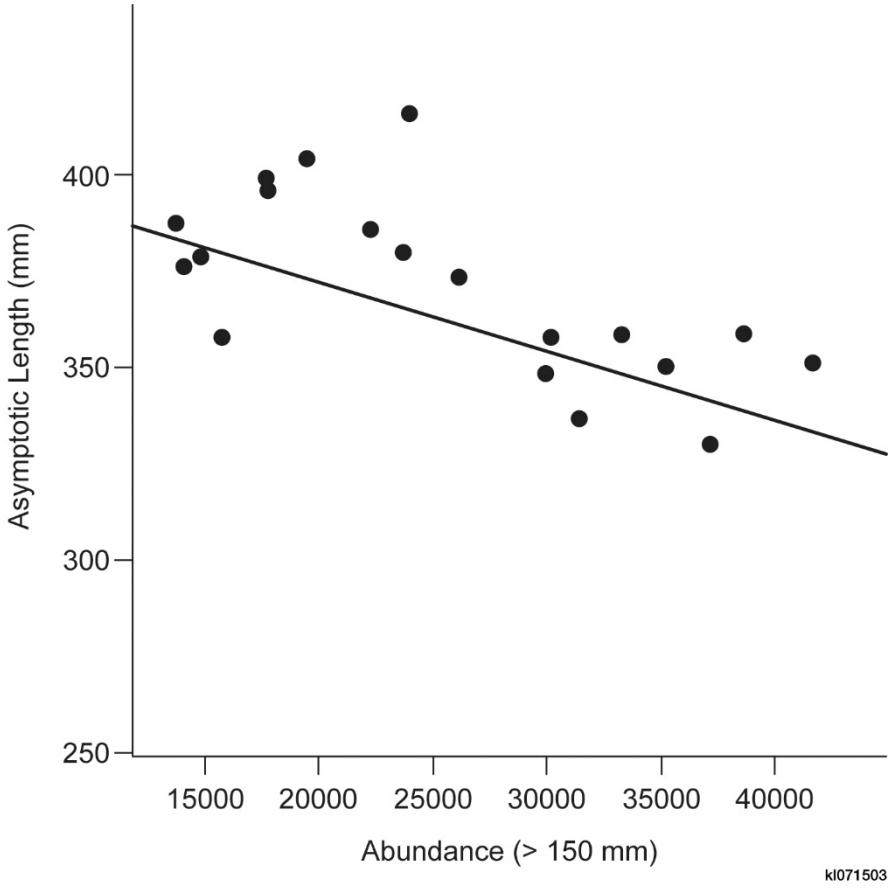

FIGURE F-2 Relationship between Annual Estimates of the Asymptotic Length of Rainbow Trout in Lees Ferry Predicted by the Stock Synthesis Model as a Function of the Estimated Abundance for Fish >150 mm (approximately age-1+) Each Year (The solid line is the best-fit relationship. This relationship explained 18% of the annual variation in asymptotic length and was not statistically significant [p = 0.056].)

Performance Metrics from Glen Canyon Trout Submodel

Four performance metrics were derived from the trout submodel in order to evaluate the relative degree to which the various alternatives would achieve a healthy high-quality recreational trout fishery in Glen Canyon National Recreation Area and reduce or eliminate downstream trout migration consistent with National Park Service fish management and Endangered Species Act (ESA) compliance needs. These four trout performance measures were:

1. Glen Canyon trout abundance index (for age-1+ fish)

2. Catch rate index (number/hr) for age-2+ fish

3. Number of trout >16 in. total length

4. Trout emigration estimate (number of age-0 trout moving into Marble Canyon from Glen Canyon)

The Glen Canyon trout abundance index was calculated as the average of modeled annual abundance of trout that were 1 year of age or older during each 20-year simulation period. The model used an age-structured population dynamics model to calculate the annual abundance for age classes 1 through 6 based upon annual recruitment rates and density-dependent survival rates.

The catch rate index was calculated as the average annual angling catch per unit of effort (number of fish per hour) during the 20-year simulation period. Only fish 2 years of age or older were considered vulnerable to angling. The annual angling catch per effort in the fishery (CPE_{yr}) was predicted as the sum of products of an overall catchability coefficient ($q = 4.25e^{-05}$), age-specific vulnerabilities ($V_1 = 0$, $V_2 = 0.5$, and V_3 *to* $V_6 = 1$), and the predicted age-specific abundance for the year ($N_{yr,a}$):

$$CPE_{yr} = \sum_{a=0}^{6} \left(q \times V_a \times N_{yr,a} \right)$$

To estimate q, the simulation model was run using the recruitment estimates from the stock synthesis model to predict age-specific abundance between 1990 and 2010. The value for q was then calculated from the back-transformed average of the log of the ratio of the observed CPEs to the estimates of the vulnerable population each year. Thus, q represents the average scalar required to convert predicted vulnerable abundance to the observed CPE.

In order to evaluate the potential for large trout to be present in the population under a given alternative, a performance metric was calculated as the average of the annual modeled number of fish equal to or greater than 16 in. that would be present in the Glen Canyon reach. The number of trout in the population with total lengths equal to or greater than 16 in. during a given year was predicted as the sum of the products of the abundance-at-age and the proportion of the age with lengths greater than or equal to 16 in. That proportion meeting the length

criterion is predicted based on a normal distribution (*pnorm*) with a mean predicted by expected length-at-age ($Len_{yr,a}$) determined using the von Bertalanffy relationship and a standard deviation determined by the coefficient of variation in length-at-age (*cvLen*):

$$N_{qual,yr} = \sum_{a=0}^{6} \left[N_{yr,a} \times pnorm\left(16, Len_{yr,a}, cvLen \times Len_{yr,a}\right) \right]$$

The trout emigration performance metric was calculated as the average of the annual modeled number of trout migrating from Glen to Marble Canyon during a 20-year simulation period. The Glen Canyon Trout submodel computes the number of trout migrating to Marble Canyon as a fraction of the recruitment estimate from the previous year (Figure F-3). A linear model with a zero intercept explained about 70% of the estimated outmigration from Korman et al. (2012). The model predicts that on average, the number of out-migrants is 42% of the recruitment value from the previous year; however, there is considerable interannual variation in this percentage (95% of values are between 0 and 91%). A normal distribution (*rnorm*) with a mean equal to the mean of the logit-transformed annual proportions and a standard deviation equal to the standard deviation of the transformed proportions was used to simulate the proportion of fish out-migrating in each year of the simulation. The back-transformed proportions were then multiplied by the previous year's recruitment ($Rec_{\text{yr-1}}$) to calculate the out-migration each year:

$$Out_{yr} = Rec_{yr-1} \times \text{logit}[rnorm(\text{mean} = -0.35, \text{sd} = 1.65)]$$

Parameter estimates for the key linear models (recruitment-flow, out-migration-recruitment, asymptotic length-abundance) were estimated by linear regression. The variance-covariance matrices for these models, which represent the extent of uncertainty in parameter estimates and their covariation, were used to generate 1,000 different parameter values for each relationship. The simulation model integrated over these values to incorporate uncertainty in key functional relationships when making predictions for any long-term strategy and hydrologic trace.

In addition to the performance metrics that were used to evaluate the potential effects of alternatives and long-term strategies on the trout fishery and downstream migration of trout, the trout submodel also kept track of the number of TMFs expected to be triggered during each 20-year simulation period. The number of TMFs during a 20-year period was used as one indicator of how American Indian Tribes—some of which consider lethal actions to fish an adverse effect if there is no beneficial use—could be affected by alternatives and long-term strategies (see Appendix I), rather than as a measure of effects on the trout fishery itself.

Evaluation of Trout Submodel

Annual flow statistics for Glen Canyon Dam were computed from the historical record between 1990 and 2010 and used as input to the Glen Canyon trout model to compare predictions with observations and best estimates of key state variables such as recruitment,

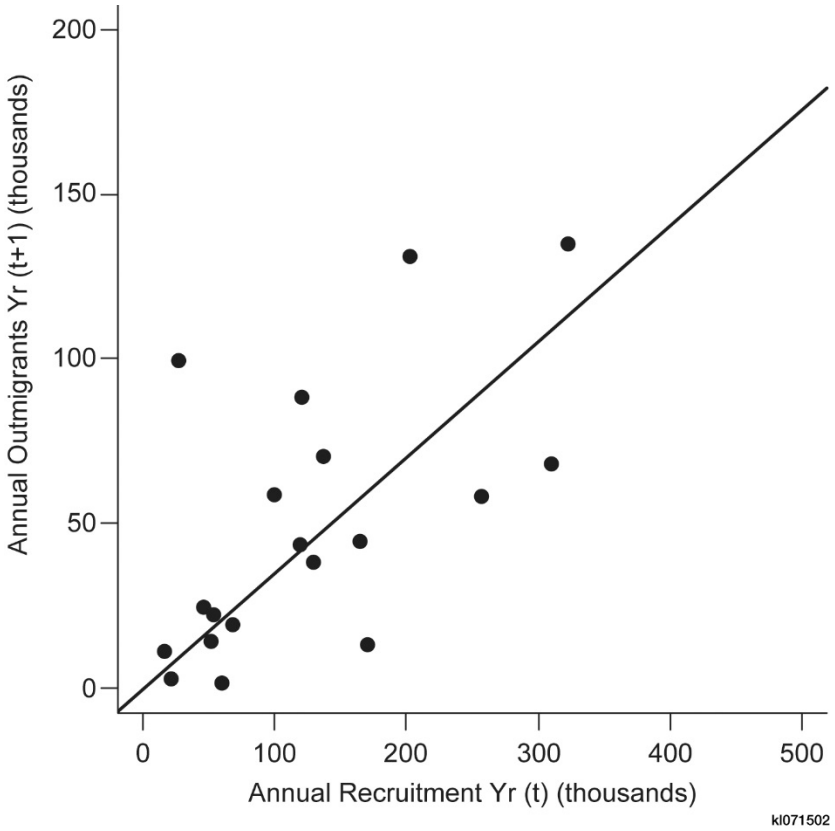

FIGURE F-3 The Relationship between Annual Recruitment of Rainbow Trout in Lees Ferry Estimated by the Korman et al. (2012) Stock Synthesis Model and the Number of Trout That Emigrate from Lees Ferry into Marble Canyon the Following Year (The solid line represents the best-fit relationship, which assumes no out-migration when there is no recruitment in the previous year [i.e., the line is forced through the origin]. This relationship predicted 72% of the annual variation in estimated out-migration and was statistically significant [$p < 0.001$].)

out-migration, and size at the terminal age. Predictions of angler CPE were compared to estimates of annual CPE from the Arizona Game and Fish Department (AZGFD) creel survey (Makinster et al. 2011). Simulations were based on most likely parameter estimates from the key regression models (recruitment-flow, outmigration-recruitment, asymptotic length-abundance) and did not include interannual variation in predictions to facilitate comparisons of predictions and data. Predictions of abundance were compared to the interannual trend in AZGFD electrofishing surveys. Other predictions (recruitment, asymptotic length, and out-migration) were compared to best-fit estimates from the Korman et al. (2012) stock synthesis model.

The historical flow-driven predictions of recruitment made by the simulation model produced an interannual trend quite similar to the estimates produced by Korman et al. (2012; Figure F-4, top-left panel). However, the model substantially over-predicted recruitment in 1996 and under-predicted recruitment in 2007–2009. The effects of high annual volumes and spring

floods on recruitment may be confounded with other variables in the multiple regression model due to the low frequency of these events in the period of record.

The trend in predicted abundance from the model generally matched the trend in electrofishing-based CPE (Figure F-4, middle-left panel). The model over-predicted abundance in 2005–2007, perhaps because it did not account for a number of unusual events in earlier years that likely affected recruitment and adult mortality (e.g., a sudden change in minimum flow due to an emergency shutdown of Glen Canyon Dam generators, very few spawners in 2006, mortality of adults due warm water and low dissolved oxygen in releases during the fall of 2004). The trend in asymptotic length predicted by the model did not provide a good fit to the trend from the Korman et al. (2012) stock synthesis model. This is not surprising, as trout abundance was a relatively poor predictor of asymptotic length (Figure F-3), especially in years when other factors (e.g., low food availability, high mud snail abundance) appeared to have strong effects. Factors such as food availability and quality and long-term trends in reservoir productivity are likely more important drivers of growth than abundance.

The model was only partially able to reproduce the observed trend in angling CPE (Figure F-4, top right). It correctly predicted an increase with abundance between 1992 and 1997. However, observed CPE for the following 3 years was relatively stable, while model predictions indicated that CPE increased by about threefold. As the model provided a relatively good fit to the observed trend in electrofishing CPE over the majority of the historical period, this likely indicates that catchability (q) declined beginning in 1999. Possible mechanisms include a reduction in q at higher trout densities, as a greater fraction of fish use less vulnerable habitats, or reduced q at lower flows (which began in 1999). The predicted number of quality-sized fish in the population (dashed line, top right) has been low over the entire historical period (<1000) and declined from maximum values at the start of the period due to increasing abundance (top left), which reduced asymptotic length (bottom left).

The trend in simulated out-migration estimates was reasonably close to the historic trend estimated by the stock synthesis model (Figure F-4, bottom right). The proportion of recruitment that out-migrates each year is not constant (Figure F-2), and this simplification in the application of the simulation model to historical data leads to some of the error in out-migration estimates. Departures between the best recruitment estimates (Korman et al. 2012) and those derived from the flow regression (Figure F-4, top left) increases the extent of error in out-migration estimates.

F.3.1.2 Trout Movement Submodel

One component of the LTEMP trout/humpback chub simulation model is the movement of rainbow trout from Glen Canyon to near the confluence of the Little Colorado River. The trout movement model predicts the monthly abundance of trout within each mile segment of the Colorado River from RM 0 to RM 150 and reports monthly abundance over broader river reaches as required for the humpback chub population dynamics model. While the LTEMP rainbow trout-humpback chub model is not focused on locations below approximately RM 66, the trout movement model extends below this location to avoid problems with modeling boundary conditions near the Little Colorado River. Key inputs to the trout movement model

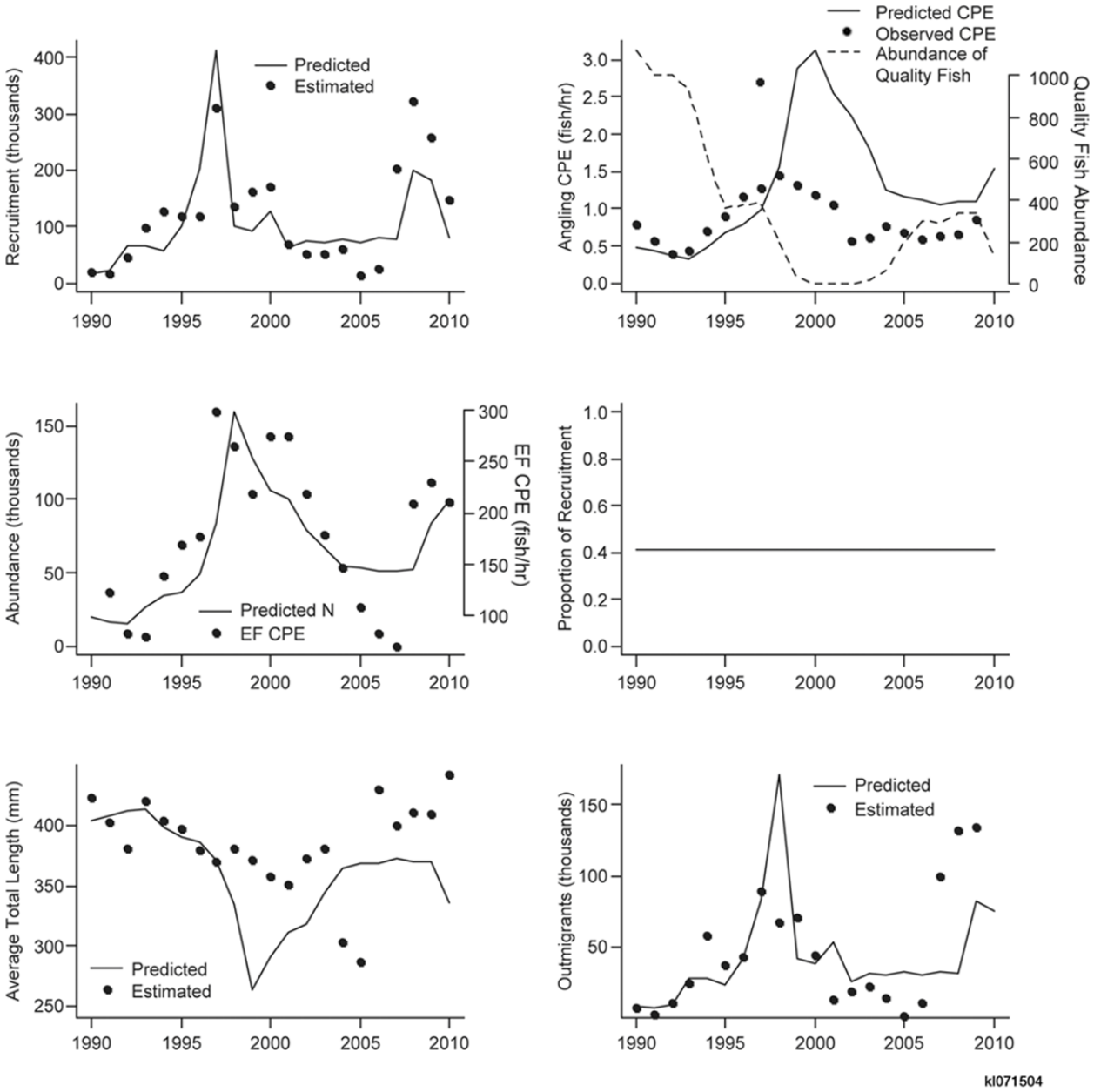

FIGURE F-4 Fit of the Glen Canyon Rainbow Trout Simulation Model to Predictions of Recruitment (top left), Asymptotic Length (bottom left), and the Number of Out-migrants (bottom right) Predicted by the Korman et al. (2012) Stock Synthesis Model (Also shown is the predicted abundance relative to catch per effort [CPE] from AZGFD electrofishing surveys [middle left], the predicted angling CPE compared to AZGFD creel survey estimates [top right], and the average proportion of recruitment that migrates from Glen to Marble Canyon each year [middle right].)

include the monthly number of age-0 trout out-migrating from the Glen Canyon reach, parameters that control the movement and dispersion of rainbow trout in Marble/Grand Canyons, the natural mortality rate of rainbow trout, and the number, intensity, and timing of nonnative mechanical removal trips conducted each year. The rules governing the implementation of

mechanical removal were specified based on the Biological Opinion on nonnative fish control (Reclamation 2011b). Monthly movement and dispersion do not depend on trout density and are modeled as a random process following a Cauchy distribution of movement distances. To allow parameter estimation and to evaluate the ability of the model to reconstruct historic trout abundance patterns, model-predicted catch of rainbow trout from sampling efforts in 2000–2009 was compared to the observed catch.

The trout movement model accounts for the abundance of rainbow trout at a monthly time step and in 1-mi-long river segments (RM segments) from RM 0 to RM 150. The age and size structure of the population was not modeled, although all immigrants from Glen Canyon are assumed to be YOY. At the end of each month, trout within each RM segment are diminished by some survival rate and then distributed to other RM segments according to a RM segment-specific movement distribution. This calculation is accomplished via matrix operations as:

$$n(t+1) = MSn(t),$$

where n is a vector containing the abundance of rainbow trout within each RM segment, M is the movement matrix specifying how the abundance at a particular RM segment is distributed to other segments, S is the survival matrix where the diagonal contains the survival of fish within each RM segment and all other elements are zero, and t is the month of the year.

Number of Trout from the Glen Canyon Reach

The number of fish entering the upstream-most RM segment in the model (RM 1) each month equals the number of annual emigrants calculated by the Glen Canyon trout submodel. The monthly number of trout entering the reach was assumed to be 1/12 of the annual total emigrants, as migration timing was assumed to be uniform across months.

Survival

Instantaneous natural mortality rate (M = 0.49/year) was assumed to be temporally and spatially constant and corresponded to a monthly survival rate of 0.96 based on mark recapture-based methods from the Natal Origins project (Korman et al. 2015). In the RM segments RM 56 to RM 66, monthly survival is also potentially influenced by mechanical removal operations. Survival rate associated with mechanical removal was modeled as:

$$MR_{surv} = (1-p),$$

where MR_{surv} is survival from mechanical removal, p is the electrofishing capture probability, and D is the number of times fish are removed from each RM segment (number of passes). Thus monthly survival rate in RM segments where mechanical removal is not conducted was 0.96, and in RM segments where mechanical removal was conducted, it was $0.96 \times MR_{surv}$. The diagonal elements of the survival matrix S contained these RM segment survival rates and non-diagonal

elements were zero. Capture probability (p) was assumed to be 0.10, based on recent work from the Natal Origins project (Korman et al. 2015).

Mechanical Removal

Mechanical removal in RM 56–66 was triggered in a particular year when three conditions were simultaneously met: (1) mechanical removal was authorized under the alternative being modeled, (2) the estimated abundance of rainbow trout in the trigger reach (RM 63–64.5) during September of the previous year was greater than 760 individuals, and (3) the estimated number of adult humpback chub (from humpback chub submodel, see Section F.3.1.3) was less than 7,000 individuals. When the triggering conditions were met, mechanical removal was implemented as six removal trips that occurred from February through July. Occurrence of removal trips reduced the number of trout in the vicinity of the Little Colorado River during the month, based upon the abundance of trout and electrofishing capture probability estimated from past removal efforts.

Trout Movement

The movement of fish between RM segments was assumed to be a diffusion process in which the probability of a fish moving from each RM segment to every other RM segment followed a truncated Cauchy distribution. The distribution is said to be truncated as movement upstream of the RM 0 segment or downstream of the RM 150 segment was disallowed. The probability distribution for each RM segment was assumed to represent the proportions of fish that would move to every other segment and formed a row vector in a movement matrix.

Performance Metrics from Trout Movement Submodel

The principal purpose of the trout movement submodel was to provide inputs to the humpback chub population submodel pertaining to monthly estimates of the number of rainbow trout that would be present in the vicinity of the Little Colorado River, and to calculate the number of trout that would be removed by mechanical removal efforts. Although no aquatic ecology performance metrics were generated, the trout movement submodel was used to calculate the numbers of years in which mechanical removal trips were triggered for each 20-year simulation, and that calculation was used as an indicator of how Tribal resources could be affected by alternatives and long-term strategies (see Appendix I).

Two factors must coincide to trigger mechanical removal trips in the submodel: (1) there must be more than 760 adult rainbow trout projected for the test reach in the vicinity of the Little Colorado River confluence (RM 63–RM 64.5) and (2) the projected adult humpback chub population must be less than 7,000 individuals. The number of adult humpback chub is calculated by the humpback chub population submodel and provided as input to the trout movement submodel. Once triggered, the model assumes that six mechanical trip passes would occur during the year.

Estimating Model Parameters and Evaluating Model Predictions

Rainbow trout electrofishing catch data from 2000 through 2009 and between RM 0 and RM 65.7 were used to estimate the Cauchy scale distribution parameter and the catchability coefficient (q). These data were composed of the annual electrofishing catch and effort by the 10-mi reaches between RM 0–50 and by the reaches RM 50–61.5 and RM 61.5–65.7 (Makinster et al. 2011). The annual predicted catches (C_i) for each reach (i) were computed as:

$$C_i = n_i \times E_i \times q,$$

where n_i is the model-predicted abundance of rainbow trout within reach *i* during the month of June and E_i is AZGFD electrofishing effort in June.

The observed catch was assumed to be distributed as a Poisson random variable with mean equal to the model-predicted catch. Estimation of the Cauchy scale (γ = 3.38) parameter and the catchability coefficient ($q = 3.4e^{-06}$) was accomplished via the method of maximum likelihood and the function "optim" within R (R Core Team 2013). These estimates provided a reasonably good fit to the data (Figure F-5), providing confidence that the simulation model would accurately portray movement dynamics of rainbow trout. A more complex parameterization of the Cauchy distribution was tested, where the location parameter (which specifies the most probable movement distance) was estimated as a free parameter. The maximum likelihood estimate of the location parameter was approximately $5.0\ e^{-03}$, confirming that most fish do not change location on a monthly basis. A normal distribution also was considered to describe movement distance, but there was a better fit to the data using the Cauchy distribution. In addition, the Cauchy distribution of movement implies a smaller probability of fish moving long distances within a month than the normal distribution (Figure F-6) and is more biologically reasonable, considering the observed movement of tagged trout.

F.3.1.3 Humpback Chub Population Submodel

A size- and location-structured population dynamics model was used to predict the size of the adult population of humpback chub over time. The model assumes five size classes of humpback chub (40–99 mm, 100–149 mm, 150–199 mm, 200–249 mm, and >250 mm, size classes 1–5, respectively) and two locations (Little Colorado River and Colorado River) for a total of 10 "states" (where a state is a unique combination of size and location; for example, a fish in the Little Colorado River that is 40–99 mm is in state 1; Figure F-7). The structure of this model is based on recent modeling work (Yackulic et al. 2014) as well as a new set of candidate models developed specifically to address the effects of temperature and rainbow trout on humpback chub survival (see "Model Selection and Development" below). The model uses a monthly time step and assumes constant survival for all states except for state 6, corresponding to juveniles in the Colorado River. Survival for this state depends on rainbow trout abundance. Growth of size class 1 (40–99 mm) humpback chub depends on both water temperature and rainbow trout abundance. Growth for all other size classes in the Colorado River is temperature-dependent, while Little Colorado River growth is assumed to be constant. Movement between

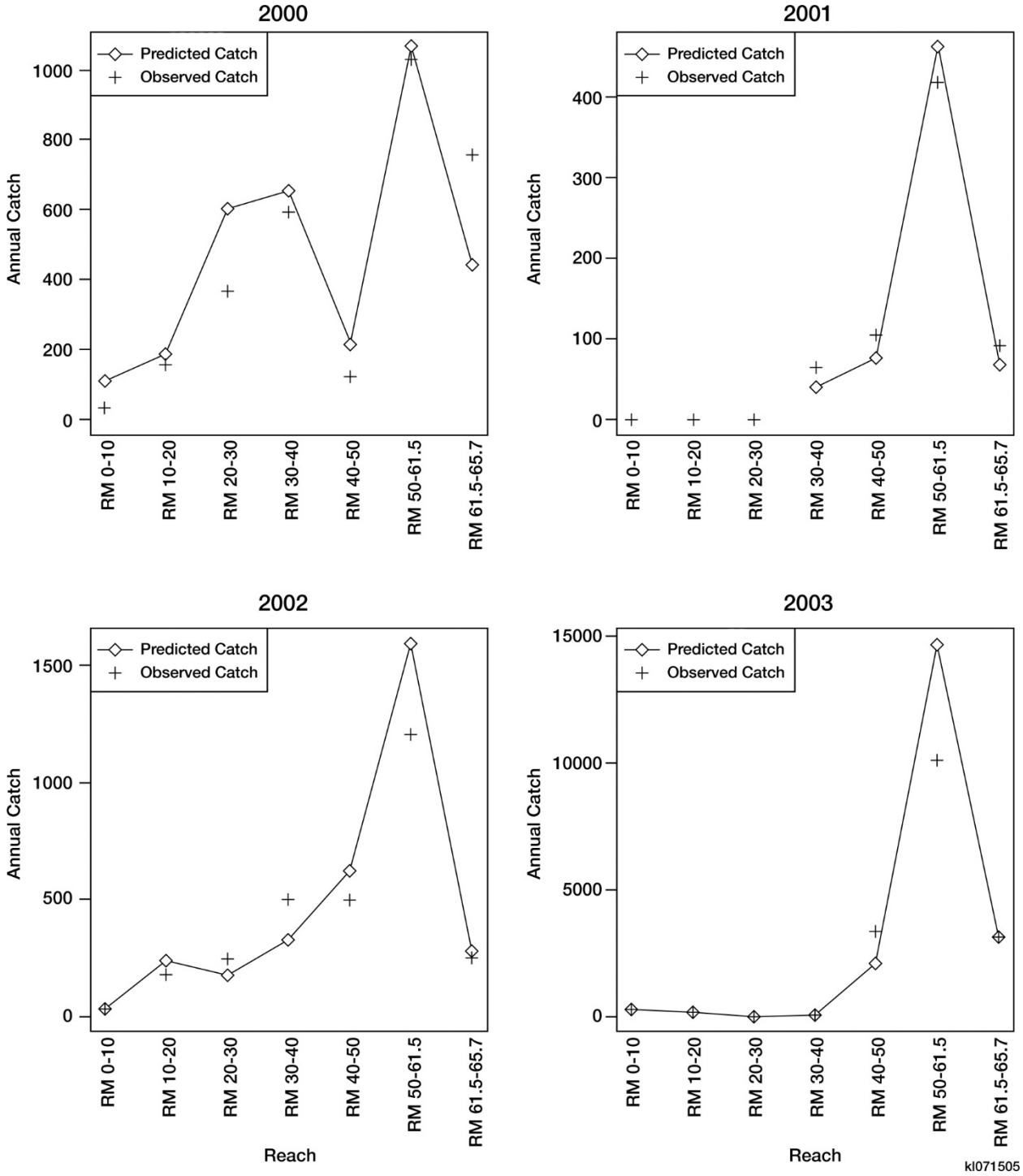

FIGURE F-5 Predicted and Observed Annual Catch of Rainbow Trout by Year and River Reach

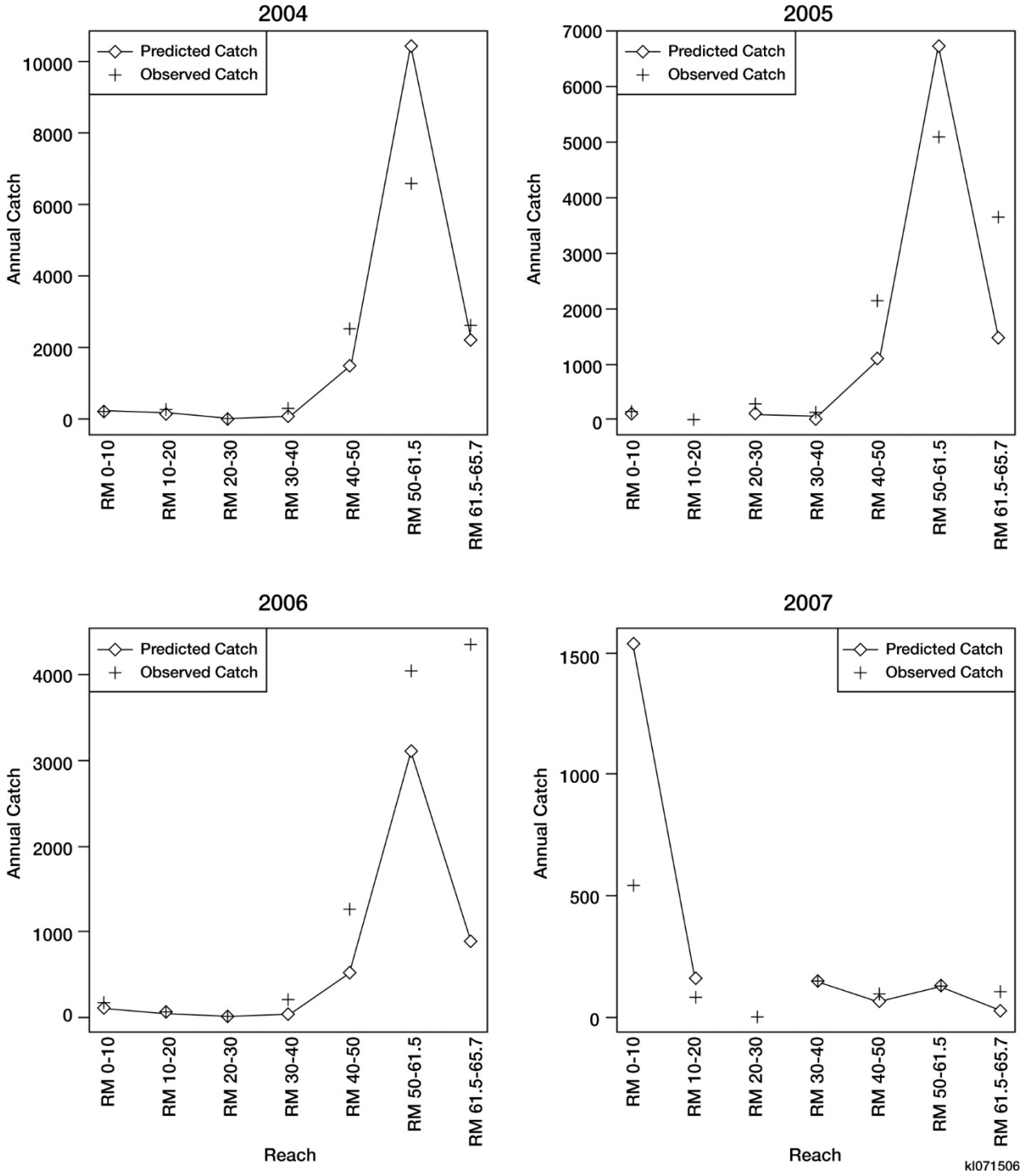

FIGURE F-5 (Cont.)

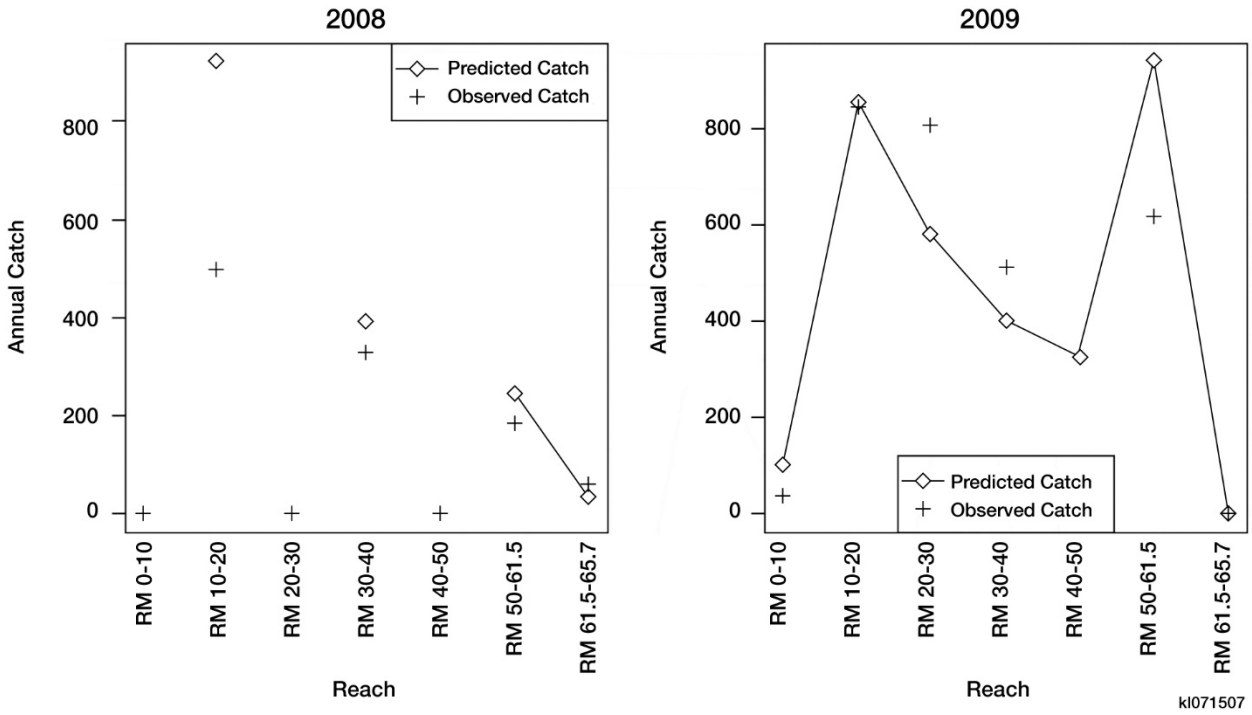

FIGURE F-5 (Cont.)

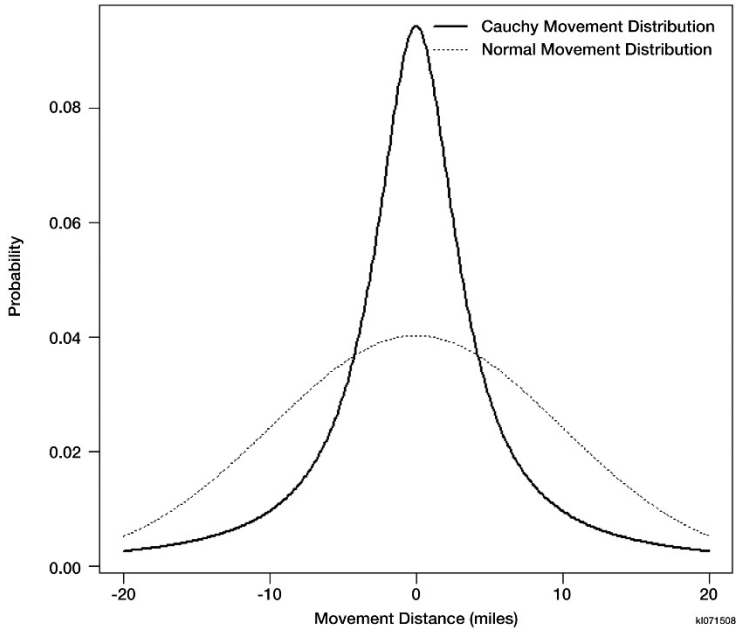

FIGURE F-6 Best-Fitting Distributions Describing Monthly Movement of Rainbow Trout in Marble Canyon Assuming Either a Normal or Cauchy Distribution (The Cauchy distribution implies a lower probability of large monthly movements and agrees better with movement observations from tagging data.)

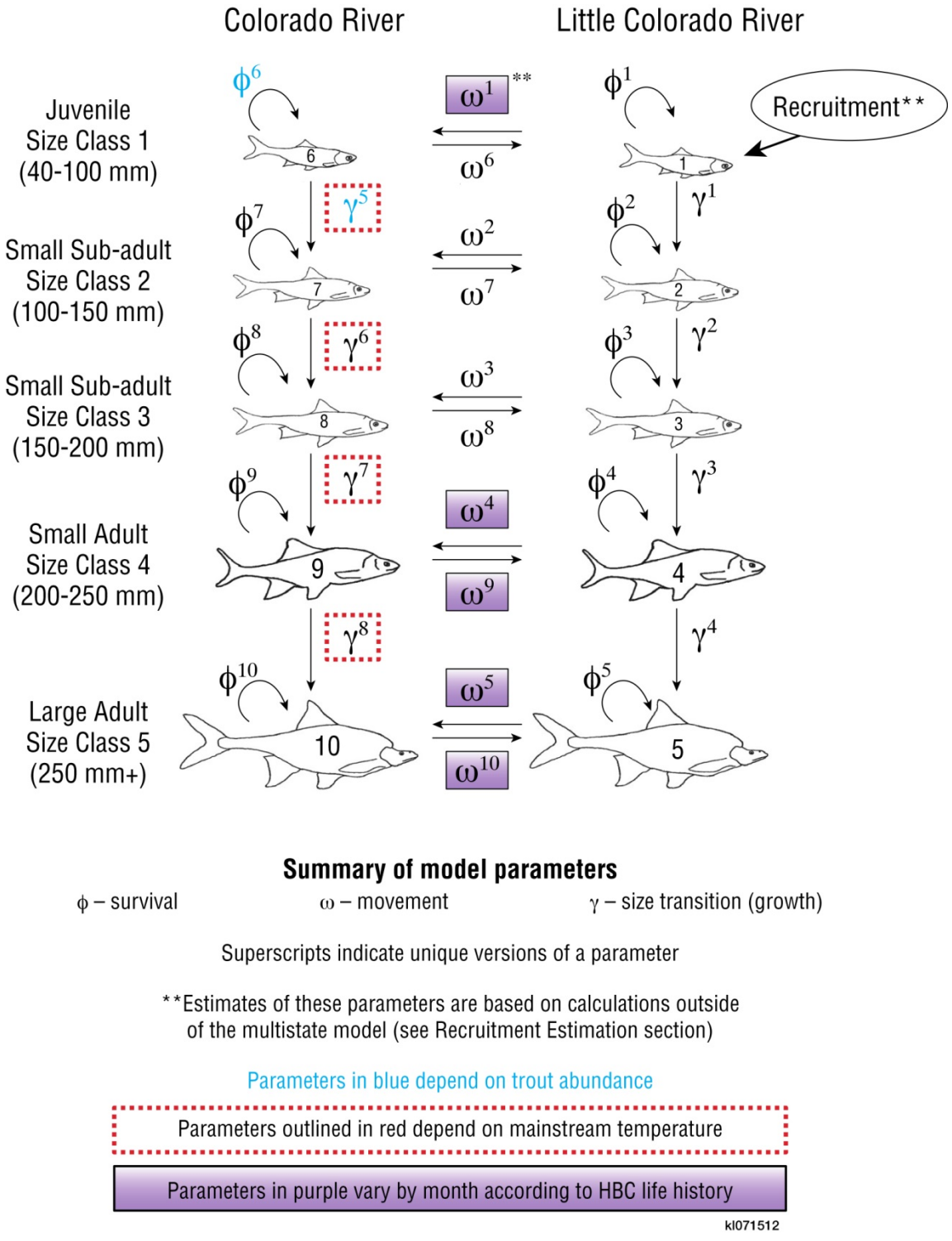

FIGURE F-7 Visual Summary of Humpback Chub Population Model Structure (The number on each fish represents its state number. Modified from Yackulic et al. [2014].)

the Little Colorado River and Colorado River is modeled via movement parameters that vary depending on the month and size class (see Yackulic et al. 2014, for more details regarding movement parameters). In addition to parameters describing survival, movement, and growth, the simulation model also relies on estimates of the starting abundance in each of the 10 states, as well as assumed annual recruit abundance.

All YOY fish recruit to state 1 (i.e., size class 1 fish in the Little Colorado River) in July. Most parameters were estimated directly from data collected during 2009–2013 in the Colorado River and 2009–2012 in the Little Colorado River. Recruitment was approximated by comparing estimated juvenile abundances in the Colorado River and Little Colorado River between 2009 and 2012. This analysis also led to modification of the value for the movement parameter associated with juvenile out-migration from the Little Colorado River (see "Recruitment Estimation" below). Yackulic et al. (2014) had previously speculated that this parameter might be biased, since July marking of juveniles has, until recently, been limited to a small section of the Little Colorado River proximate to the Colorado River that is likely to experience higher overall out-migration than the Little Colorado River as a whole. Recruitment estimates were also influenced by recent research suggesting severely diminished recruitment in years with little winter runoff in the Little Colorado River (Van Haverbeke et al. 2013).

Having estimated the maximum likelihood ("best") values of parameters based mainly on data collected from 2009 to 2013, the simulation model was run using a 20-year sequence of observed temperatures near the Little Colorado River between 1990 and 2009, as well as predictions of rainbow trout abundance for this period from the Glen Canyon and trout movement submodels. These outputs were compared to trends reported in Coggins and Walters (2009), as discussed in "Evaluating Model Predictions," below. Potential uncertainties in model predictions are discussed in "Model Uncertainties" below.

Model Selection and Development

The primary objective for the humpback chub population model was to estimate the effects of mainstem temperature and trout abundance on humpback chub population dynamics (i.e., growth and survival). Six candidate models that represent different a priori hypotheses concerning potential effects were evaluated:

- Model A: Rainbow trout and temperature have no effect on growth and survival.

- Model B: Survival of size class 1 humpback chub in the Colorado River is a logit linear function of rainbow trout abundance. Growth of all size classes in the Colorado River are logit linear functions of temperature with independent intercepts for each size class and a shared slope (a model with different slopes for each size class was considered, a posteriori, but this did not improve the fit considerably). Model B was based on the hypotheses that temperature is a primary control on growth rates and that rainbow trout mainly affect humpback chub by lowering the survival of juvenile humpback chub. This

does not mean that rainbow trout effects are solely predatory, as competition with trout could lead to lowered survival if humpback chub were forced to forage longer or in suboptimal habitat, leading to increased predation risk by species other than rainbow trout.

- Model C: As in Model B, but growth of size class 1 fish is a function of rainbow trout abundance in addition to temperature. Rainbow trout are hypothesized to affect humpback chub growth by forcing them into suboptimal habitats and directly consuming food resources that might otherwise be consumed by young humpback chub. This effect is likely to be greatest in young fish because they are frequently found in the nearshore environments that rainbow trout also prefer.

- Model D: As in Model C, but growth of size class 2 humpback chub is also a logit linear function of rainbow trout abundance in addition to temperature.

- Model E: As in Model B, but survival of size class 1 fish is a function of temperature in addition to rainbow trout abundance. Increased temperature is expected to increase the swimming ability of juvenile humpback chub, which should in turn aid them in avoiding predation by a variety of fish species in the system.

- Model F: A combination of Models C and E.

A general model structure modified from Yackulic et al. (2014) was used to fit a series of mark-recapture multistate models using maximum likelihood. For more technical details, see Yackulic et al. (2014). Yackulic et al. (2014) suggested three important features of humpback chub movement between the Little Colorado River and Colorado River:

1. Juveniles out-migrate from the Little Colorado River at a different and higher rate during July through September compared to the rest of the year,

2. Smaller and larger adults spawn at different rates, and

3. There is evidence for a resident Little Colorado River population.

The models that were considered include the first two of these elements, but ignore the third element. The third element is ignored because it would make simulations more difficult and is likely to only apply to a relatively small portion of the adult population (about 15%). Moreover, since the model only considers those fish that move into the mainstem, the movement dynamics of the system can be well represented without this detail.

Monthly temperatures were calculated using data from U.S. Geological Survey (USGS) gage 09383100 located on the Colorado River above the confluence with the Little Colorado River. Rainbow trout abundance in 2012 and 2013 was calculated by averaging trip estimates from the Natal Origins project within each year. Rainbow trout estimates for 2009–2011 were

back-calculated based on the relationship between the catch between RM 63.4 and RM 64.8 and the estimated abundance in the same area.

Models were fit using general-purpose optimization algorithms provided by "optim" in R (version 3.0.2) using the BFGS (Broyden, Fletcher, Goldfarb and Shanno) method[1] and were run until convergence of all models was obtained. The variance inflation factor (c-hat) was calculated based on model F, and models were compared using the quasi-Akaike's Information Criterion (qAIC) calculation.[2] Model selection based on qAIC favored model C (summarized in Figure F-7), and estimates from this model were used for further steps. Figure F-8 illustrates the estimated relationships between temperature and trout and various survival and growth parameters. The maximum likelihood estimates from these relationships were used for backcasting, while combinations of the draws from the multivariate normal and critical uncertainties were used to characterize these relationships in simulations conducted to compare LTEMP alternatives.

Recruitment Estimation

The one value needed for simulation that was not estimated in the model selection section is the mean annual recruitment, along with the variability around this mean. Annual recruitment is defined here as the number of YOY humpback chub present in the Little Colorado River in July. By July, most YOY are typically above 40 mm in total length. While some YOY will have left the Little Colorado River before this, several lines of evidence suggest that fish that leave the Little Colorado River before July do not contribute appreciably to population growth, given the temperature typically found in the Colorado River during May and June (Robinson and Childs 2001). Unfortunately, direct estimates of July YOY abundance in the Little Colorado River are not available. However, estimates from the Little Colorado River during September–October are available for 2001 through 2012 in Van Haverbeke et al. (2013), and were used here. The parameters estimated in the model should allow back-calculation of July YOY abundance in the Little Colorado River from the September abundance using the following formula:

$$N_J^1 = \frac{N_S^1}{\left[\emptyset^1\left(1-\omega_{JS}^1\right)\right]^2}$$

where N_J^1 is recruitment to state 1 in July, N_S^1 is recruitment to state 1 in September, ϕ^1 is the probability of survival during state 1 in the Little Colorado River, and ω_{JS}^1 is the probability of moving from the Little Colorado River to the mainstem Colorado River during the July-to-September period.

1 For details regarding the "optim" function in the "stats" package for Program R, see http://www.inside-r.org/r-doc/stats/optim.

2 For additional information, refer to http://www.inside-r.org/packages/cran/MuMIn/docs/QAIC.

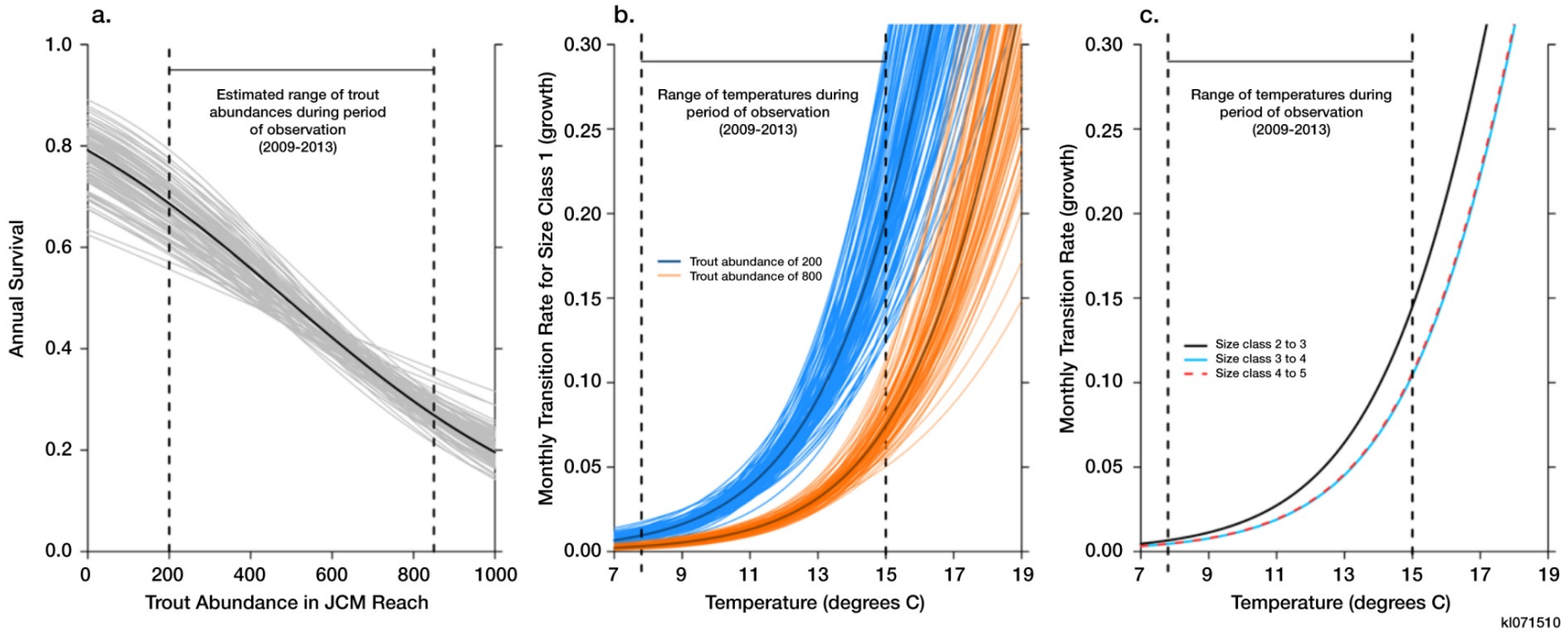

FIGURE F-8 Modeled Effects of Trout Abundance and Temperature on Humpback Chub Survival and Growth ([a] Annual survival of juvenile humpback chub [40–99 mm] declines relative to estimated trout abundance in the Colorado River; gray lines are based on 100 draws from a multivariate normal distribution based on maximum likelihood estimates and associated covariance matrix and give an indication of uncertainty around the maximum likelihood estimates in black. [b] Monthly size transition rates [proportional to growth] as a function of temperature with trout abundance set at either 200 or 800; as in panel [a], dark lines indicate best estimates and lighter lines are draws from a multivariate normal distribution giving an indication of uncertainty. [c] Dependence of size transition rates [growth] for larger fish on temperature. Note that relationships have a common slope but different intercepts. Uncertainty in these rates is comparable to the uncertainty around either of the curves in panel [b], with slightly more uncertainty around the intercept associated with the transition from size class 4 to size class 5.)

However, this approach is based on estimates of the monthly probability of size class fish moving from the Little Colorado River during the July–August and August–September intervals, ω_{JS}^1. Unfortunately, this is the parameter in the multistate model that is most likely to be biased because of details of sampling. In short, until 2013, all July and August marking of humpback chub at the Little Colorado River was limited in its spatial extent to an area near the confluence, which is likely to have a higher rate of export than the Little Colorado River as a whole. Moreover, over two-thirds of the marked fish were marked in 2011 and 2012, years that exhibited large increases in the abundance of size class 1 humpback chub in the juvenile chub monitoring (JCM) reach, thereby suggesting higher export (see Yackulic et al. [2014] for a full discussion). Last, both July recruitment, N_J^1, and movement out of the Little Colorado River, ω_{JS}^1, may exhibit substantial interannual variability (in comparison to, say, adult survival), even though the limited number of marked fish released in July and August into the Little Colorado River in 2009 through 2012 does not allow us to estimate interannual variability in our models.

Therefore, a different approach was taken that is based on the estimated increase in size class 1 abundance in the JCM reach between July and September, as well as the estimated proportion of humpback chub in the JCM reach, τ, and survival rates in both the Little Colorado River, ϕ^1, and Colorado River, ϕ^6. (Note that humpback chub in size class 1 in the Colorado River are frequently 2 or more years old, whereas almost all size class 1 fish caught in the Little Colorado River in the fall are YOY fish). This approach involved solving the following equations for N_J^1 and ω_{JS}^1 for each year:

$$N_J^1 = \frac{N_S^1}{\left[\emptyset^1\left(1-\omega_{JS}^1\right)\right]^2}$$

and

$$N_J^1 = \frac{N_S^6 - N_J^6 \times \emptyset^6 \times \emptyset^6}{\left[\emptyset^1 \times \omega_{JS}^1 \times \emptyset^6 + \emptyset^1 \times \left(1-\omega_{JS}^1\right) \times \emptyset^1 \times \omega_{JS}^1\right] \times \tau}$$

This approach was applied to abundance estimates from 2009 to 2012 and resulted in estimated values of ω_{JS}^1 of 0.15, 0.28, 0.45, and 0.52 (mean, 0.35), with associated values of N_J^1 of 5,000, 17,000, 45,000, and 35,000 (mean, 25,000). Another aspect of recruitment highlighted in Van Haverbeke et al. (2013) is that in years with low runoff between January 1 and May 31, there appears to be weak recruitment, at least in terms of the number of YOY remaining in the Little Colorado River in the fall. Six years between 1990 and 2013 meet this criterion (1990, 1996, 1999, 2000, 2002, and 2006).

When backcasting historical trends, the mean values across years for both ω_{JS}^1 and N_J^1 were used, with the exception of "weak recruitment years" in which recruitment was assumed to be 2,500, based on an examination of estimates in Van Haverbeke et al. (2013). For forecasting, "weak" versus "strong" recruitment years were modeled as a Bernoulli process in which weak years occur with a probability of 0.25 (based on the observed frequency of these hydrologic conditions in the Little Colorado River from 1990 to 2013). For "strong" years, annual

recruitment values were drawn from a uniform distribution between 0 and 50,000. For both "strong" and "weak" years, out-migration was chosen randomly from a uniform distribution between 0.15 and 0.55.

Performance Metrics from Humpback Chub Population Submodel

The resource goal identified for humpback chub is to "meet humpback chub recovery goals including maintaining a self-sustaining population, spawning habitat, and aggregations in the humpback chub's natural range in the Colorado River and its tributaries below the Glen Canyon Dam" (EIS Section 1.4). The humpback chub population submodel was used to calculate an estimate of the number of adult (i.e., >200 mm total length) humpback chub that would be present in the aggregation associated with the Little Colorado River for each year of a 20-year simulation period. In order to evaluate and compare the potential for alternatives and long-term strategies to lead to extinction or improvement of the humpback chub population in the Grand Canyon, the modeled minimum number of adult humpback chub that would occur during each 20-year simulation period was used as the performance metric.

Evaluating Model Predictions

Humpback chub population dynamics were backcasted using maximum likelihood estimates of parameters (see "Model Selection and Development" section), with the exception of the parameters related to recruitment and juvenile out-migration from the Little Colorado River (see "Recruitment Estimation" section) and an initial vector of abundances by state. Initially dynamics were simulated using a monthly time step; however, the time scale was coarsened to 6-month intervals so as to minimize potential issues related to numerical diffusion. This was accomplished by calculating a 6-month transition matrix and then removing any transitions of more than one size class and adding these to the cells corresponding to a one size class transition. The initial structure of the population was based roughly on estimates from 2009 to 2012. For the Little Colorado River, abundance by size classes 1–5 was 4,000, 2,500, 1,800, 1,200, and 800, respectively, while corresponding Colorado River abundances by size were 20,000, 7,000, 5,500, 4,000, and 5,000. The simulation model was also provided a 20-year sequence of observed temperature near the Little Colorado River between 1990 and 2009, as well as predictions of trout abundance for this period that resulted from the Glen Canyon trout and trout movement submodels (Sections F.3.1.1 and F.3.1.1, respectively). While the backcasted simulation (Figure F-9) suggests a later decline than the Age-Structured Mark Recapture (ASMR) estimates (Coggins and Walters 2009), followed by a quicker recovery, the patterns are remarkably similar, given that parameters from the simulation model were derived primarily from a more recent period (2009–2013). Moreover, the ASMR estimation method is known to have some biases (Coggins and Walters 2009), so minor discrepancies are expected.

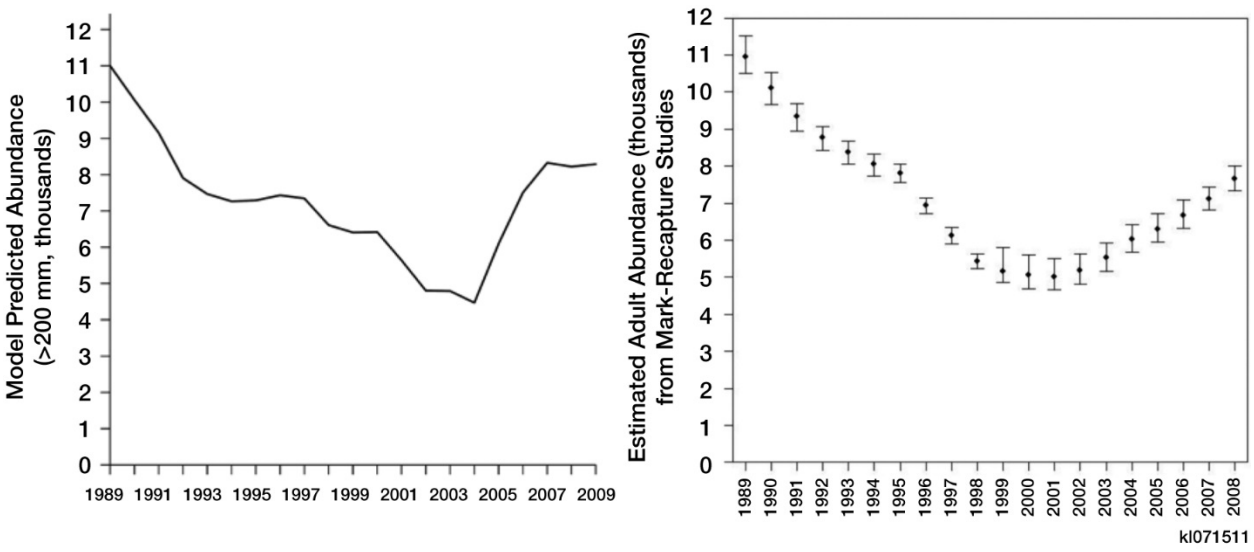

FIGURE F-9 Simulated Adult Abundances from Backcasted Model (left) Compared to Patterns Reported in Coggins and Walters (2009) (right)

Model Uncertainties

The model described here is based on the best available information and does a good job of backcasting the dynamics of humpback chub populations for a period of time (1990–2008) that is separate from the period of time (2009–2012) over which most parameters were estimated. However, like all models, it is only a representation of the actual system it seeks to describe. There are a number of conditions that could lead to dynamics in humpback chub populations that are different from those predicted with the model. Some of these conditions are listed here, in no particular order:

- No portion of this model explicitly models short- or long-term impacts of flows or temperature on the aquatic food base. Flow, particularly an increased frequency of flooding, has the potential to permanently change the composition of the invertebrate assemblage, as has been observed in other regulated rivers (Robinson 2012; also see Section F.2). This shift could be beneficial for both rainbow trout and humpback chub resources, positive for one and negative for the other, or detrimental to both, and initial impacts may differ from long-term consequences. Similar, unpredictable shifts in the invertebrate assemblage could also occur because of long-term changes in release temperatures associated with climate change and lower Lake Powell reservoir elevations.

- Temperature–growth relationships estimated here are based on a relatively short period of record and do not consider seasonal patterns in food availability, light, and turbidity. As such, the humpback chub submodel assumes a temperature of 11°C (52°F) observed in clear water in June during

midge emergence will lead to the same growth as a temperature of 11°C (52°F) in August in turbid water. Moreover, monthly mean temperatures at the Little Colorado River confluence from 2009 to 2013 peaked at roughly 15°C (59°F), suggesting that modeling the effects of substantially warmer temperatures on humpback chub populations represents an extrapolation. On the other hand, the model did a reasonable job of backcasting dynamics during the 1990–2009 era, even though monthly temperatures reached 16.7°C (62°F) in one year (2005).

- The humpback chub model does not consider the potential effects of other fish species besides rainbow trout that are already relatively common in the system and known to eat humpback chub (e.g., brown trout and various catfish species), nor does it attempt to account for the negative effects of other warmwater nonnative fishes that could become prevalent if temperatures above 16°C (61°F) become common. Potential effects of cannibalism by humpback chub are also not directly considered by the model.

- Climate change could lead to increases in the proportion of "weak" recruitment years in the Little Colorado River, particularly if winter precipitation in the Little Colorado River watershed becomes less frequent.

F.3.2 Results for LTEMP Alternatives

The results for the rainbow trout-humpback chub model for each of the alternatives (including associated long-term strategies) are summarized in the following sections. Values for the means of the six metrics resulting from the model are summarized in Table F-8. The magnitude of effects on rainbow trout and humpback chub populations are estimated using the performance metrics identified in Sections F.3.1.1, F.3.1.2, and F.3.1.3.

F.3.2.1 Rainbow Trout Performance Measures

This section summarizes the results for the performance measures for rainbow trout that were derived from the rainbow trout-humpback chub model.

Rainbow Trout Population Estimates

The rainbow trout population estimates for the 19 LTEMP alternatives and associated long-term strategies are summarized in Figure F-10. Among all of the long-term strategies evaluated, the modeled average abundance of age-1 (i.e., individuals that are 1 year old) and older rainbow trout during the simulations of 20-year LTEMP periods ranged from about 48,000 to 242,000 individuals in the Glen Canyon reach. Overall means (i.e., mean abundance for all simulations) for the various long-term strategies ranged from approximately 61,000 individuals under long-term strategy E6 to approximately 160,000 individuals under Alternative F

(Table F-8; Figure F-10). The differences among the modeled population levels for rainbow trout reflect the estimated levels of annual recruitment based on the empirically derived flow-dependent regressions in the model that predict that annual recruitment of rainbow trout will increase as a function of greater annual volumes, reduced daily variation in flow between May and August, the occurrence of spring HFEs, and implementation of management actions (i.e., TMFs) that would decrease annual survival of YOY trout (see "Recruitment" in Section F.3.1.1) in high-recruitment years. Table 4.1-1 identifies the experimental elements included in the various long-term strategies, and Appendix E of this EIS describes the number and duration of HFEs that would be expected under the various long-term strategies.

Although there is a considerable amount of overlap in the ranges of the estimates for some long-term strategies, the overall modeled average rainbow trout abundance in the Glen Canyon reach was greatest under long-term strategies C2, C4, and D3, and Alternatives F and G. With the exception of Alternative G, all of these long-term strategies implement spring HFEs and would have steadier flows (at least for the May–August portion of the year) than Alternative A and would not include implementation of TMFs. Although Alternative G would include implementation of TMFs, the annual production of trout would be expected to be very high due to a high proportion of years with HFEs and the steady pattern of flows that would be

TABLE F-8 Summary of Metrics Values from the Rainbow Trout-Humpback Chub Model[a]

Alternatives and Long-Term Strategies	Trout Abundance	Number of Trout ≥16 in. Total Length	Catch Rates (fish/hr)	Number of Out-migrants (fish/year)	Number of Years with Trout Management Flows	Number of Years with Mechanical Removal	Minimum Humpback Chub Population
A	94,667	769	2.11	36,699	0.0	0.07	4,991
B1	74,078	867	1.67	29,586	3.0	0.44	5,392
B2	62,822	920	1.46	24,172	3.1	0.30	5,541
C1	102,342	748	2.23	43,683	6.5	0.00	5,016
C2	150,285	640	3.18	66,890	0.0	0.00	4,527
C3	85,181	830	1.90	33,559	0.0	0.74	5,335
C4	127,129	707	2.72	55,076	0.0	2.80	4,874
D1	92,854	811	2.02	40,784	3.9	1.67	5,247
D2	99,452	796	2.15	43,981	6.9	2.02	5,181
D3	123,448	711	2.63	55,811	0.0	2.95	4,876
D4	93,312	810	2.03	40,936	3.8	1.69	5,241
E1	87,812	826	1.93	37,614	2.6	0.00	5,269
E2	108,046	761	2.33	47,450	0.0	0.00	5,015
E3	73,727	891	1.68	28,499	0.0	0.47	5,477
E4	100,330	781	2.19	42,806	0.0	1.73	5,103
E5	73,848	890	1.68	28,561	0.0	0.00	5,470
E6	60,600	956	1.42	22,415	2.4	0.00	5,708
F	160,297	592	3.37	71,869	0.0	0.00	4,450
G	131,816	702	2.81	58,533	11.0	3.05	4,741

[a] Mean values for 63 modeled hydrology–sediment conditions.

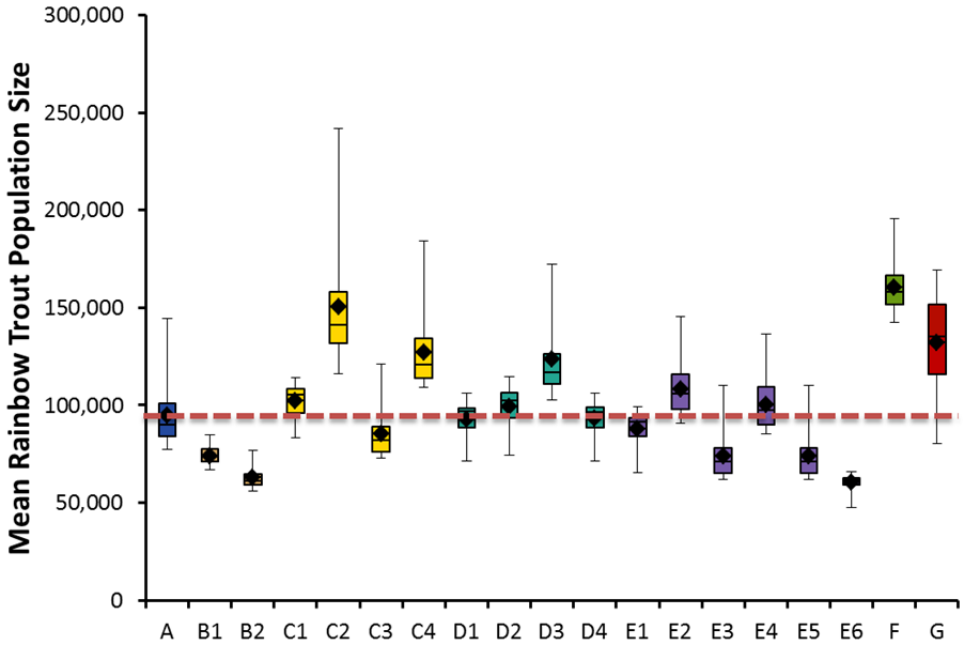

FIGURE F-10 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

maintained throughout the year without monthly differences in flow (other than those needed to adjust operations in response to changes in forecast and other operating requirements such as equalization); even at the highest evaluated levels of effectiveness for TMFs (50% reduction in age-0 trout), average annual recruitment would be expected to be quite high under Alternative G.

The overall modeled average rainbow trout abundance in the Glen Canyon reach was lowest under long-term strategies B1, B2, E3, E5, and E6. These long-term strategies generally would not allow spring HFEs (e.g., long-term strategies E3, E5, and E6) or would be expected to have considerably fewer HFEs during the LTEMP period (e.g., long-term strategies B1and B2) than other long-term strategies, would maintain levels of fluctuations in flow similar to or greater than Alternative A, and (with the exception of long-term strategies E3 and E5) would implement TMFs. Thus, average annual recruitment levels would be expected to be lowest under these alternatives.

Modeled levels of trout abundance were intermediate and similar to Alternative A under long-term strategies C1, C3, D1, D2, D4, E1, E2, and E4. These long-term strategies generally included implementation of combinations of flow actions that would be expected to result in intermediate levels of trout recruitment (e.g., no spring HFEs in all or a portion of the LTEMP

period together with higher levels of fluctuation) or included TMFs that would function to control recruitment in years with high levels of trout production (e.g., years with HFEs).

Abundance of Rainbow Trout >16 in. Total Length

The modeled abundance of large rainbow trout in the Glen Canyon reach (i.e., trout that would be larger than 16 in. total length) under LTEMP alternatives are summarized in Figure F-11. Among all the long-term strategies evaluated, the modeled abundance of these larger trout during the simulations of 20-year LTEMP periods ranged from 480 to 1,039 individuals (Figure F-11). Overall modeled means (i.e., mean number of large trout for all simulations) for the various long-term strategies ranged from 592 large fish under Alternative F to 956 large fish under long-term strategy E6 (Table F-8; Figure F-11). Compared to Alternative A, the model suggested that long-term strategies C2, C4, and D3, and Alternatives F and G would have fewer large trout; long-term strategies D1, D4, E1, and E4 would have similar numbers of large trout; and the remaining long-term strategies would have greater numbers of

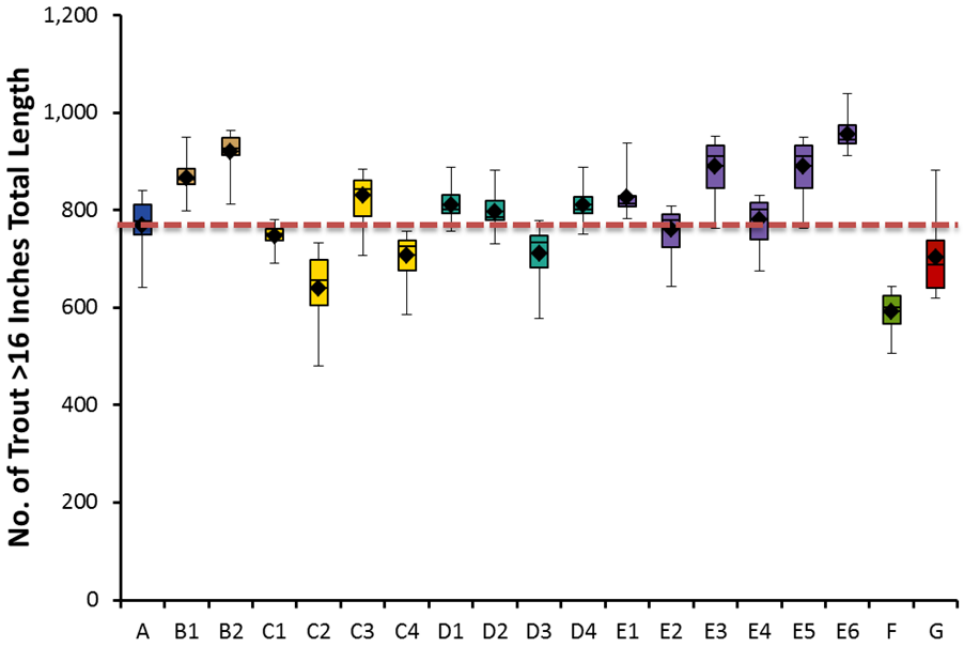

FIGURE F-11 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

large trout (Figure F-11). It is generally expected that the average size of rainbow trout in the population would be inversely proportional to the average population size because of the effects of trout density on growth rates due to competition for food and other resources; this was supported when the modeled results for average number of large trout were compared to the average number of trout in the Glen Canyon reach (Figure F-12). Because of their effect on lowering recruitment levels and population size, long-term strategies (such as long-term strategies B2 and E6) that have fewer HFEs and higher daily fluctuations, and that implement TMFs, are expected to have a greater number of large trout. Table 4.1-1 identifies the experimental elements included in the various long-term strategies, and Appendix E of this EIS describes the number and duration of HFEs that would be expected under the various long-term strategies.

Trout Catch Rates

The modeled angler catch rates for rainbow trout in the Glen Canyon reach under the LTEMP alternatives and long-term strategies are shown in Figure F-13. Modeled average catch rates during the simulations of 20-year LTEMP periods ranged from approximately 1.1 fish/hr to

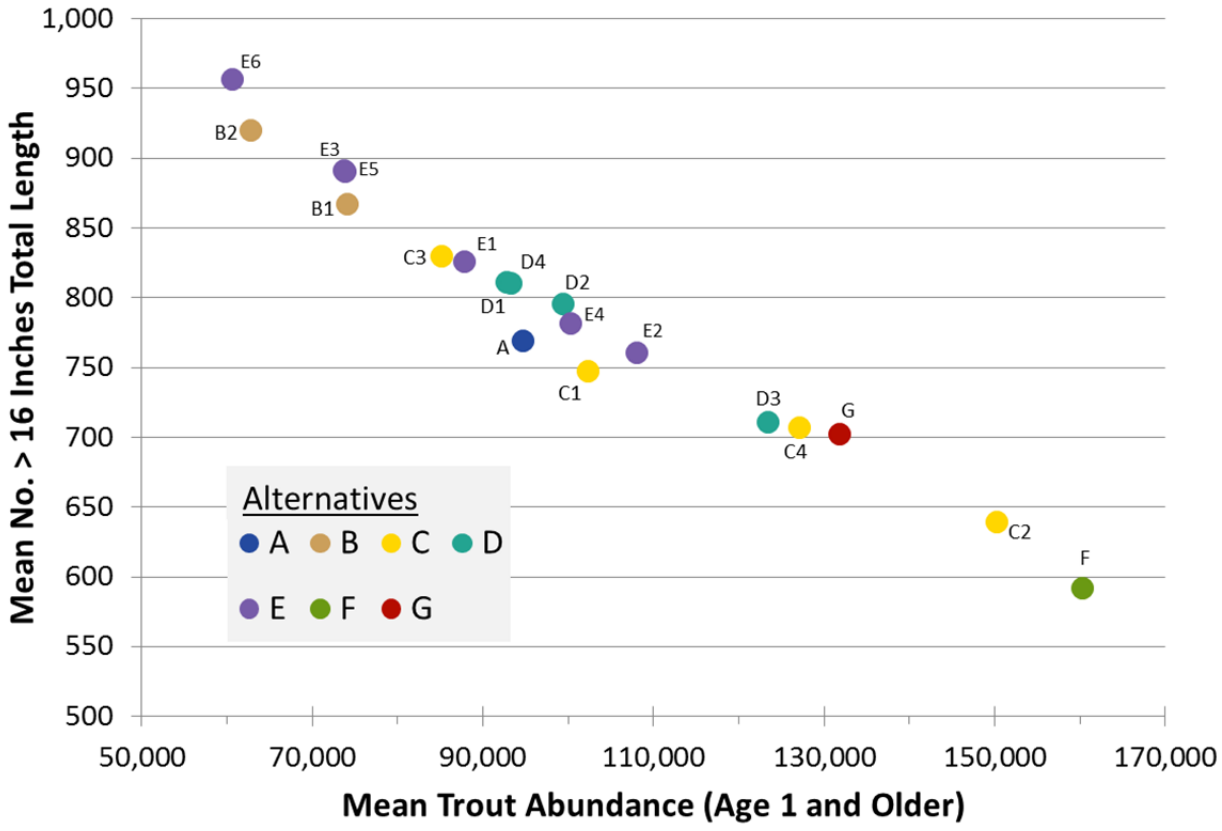

FIGURE F-12 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and the Mean Number of Rainbow Trout Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies

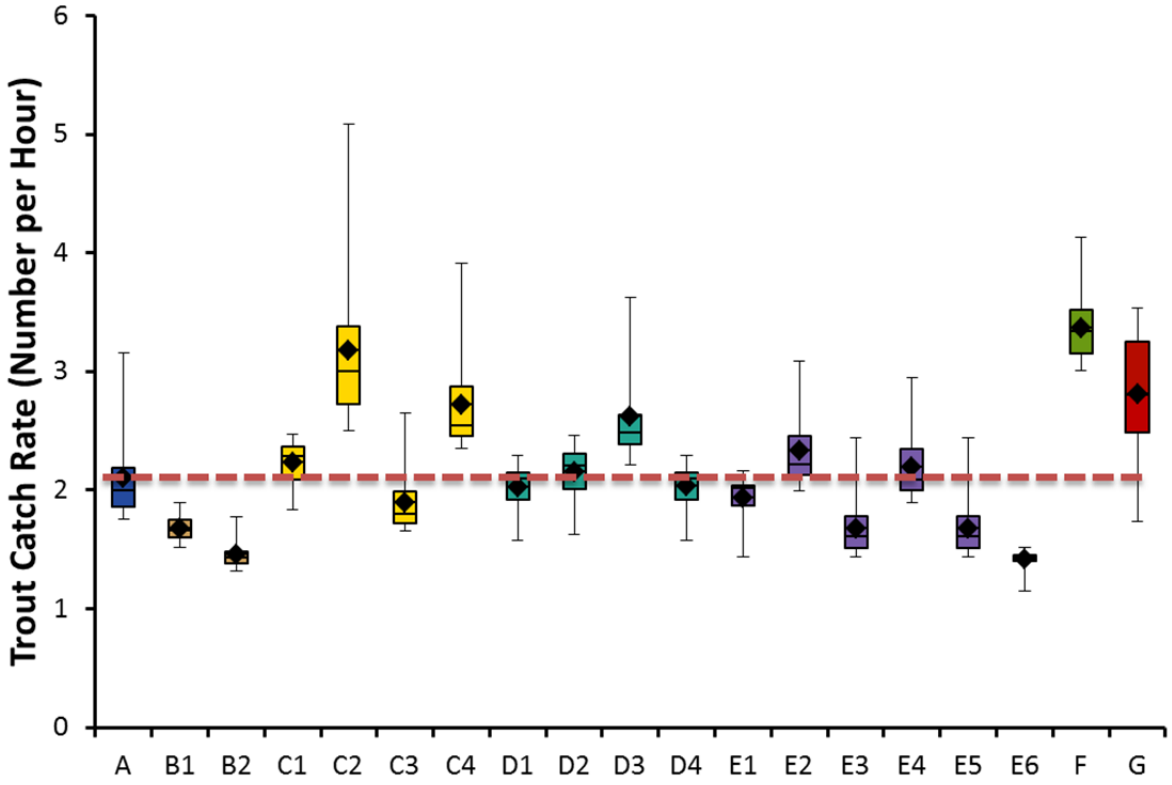

FIGURE F-13 Modeled Mean Annual Angler Catch Rate for Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

5.1 fish/hr (Figure F-13). Modeled mean catch rates (i.e., mean catch rates for all simulations) ranged from 1.4 fish/hr under long-term strategy E6 to 3.4 fish/hr under Alternative F (Table F-8; Figure F-13). Compared to Alternative A, the model indicated that long-term strategies B1, B2, C3, E1, E3, E5, and E6 would have lower catch rates; long-term strategies C1, D1, D2, D4, and E4 would have similar catch rates; and long-term strategies C2, C4, D3, and E2, and Alternatives F and G would have higher catch rates (Figure F-13). Although the modeled vulnerability of individual trout to angling varies depending on the age of the trout, modeled average angler catch rates are highly correlated with average population levels of the long-term strategies, as shown in Figure F-14.

For this reason, the same combinations of experimental elements that drive recruitment levels and affect rainbow trout abundance would be expected to drive angler catch rates (see "Recruitment" in Section F.3.1.1 and "Rainbow Trout Population Estimates" in Section F.3.2.1). Thus, long-term strategies that result in more frequent HFEs (especially spring HFEs) have steadier flows and do not include TMFs (e.g., Alternatives F and G and long-term strategies C2

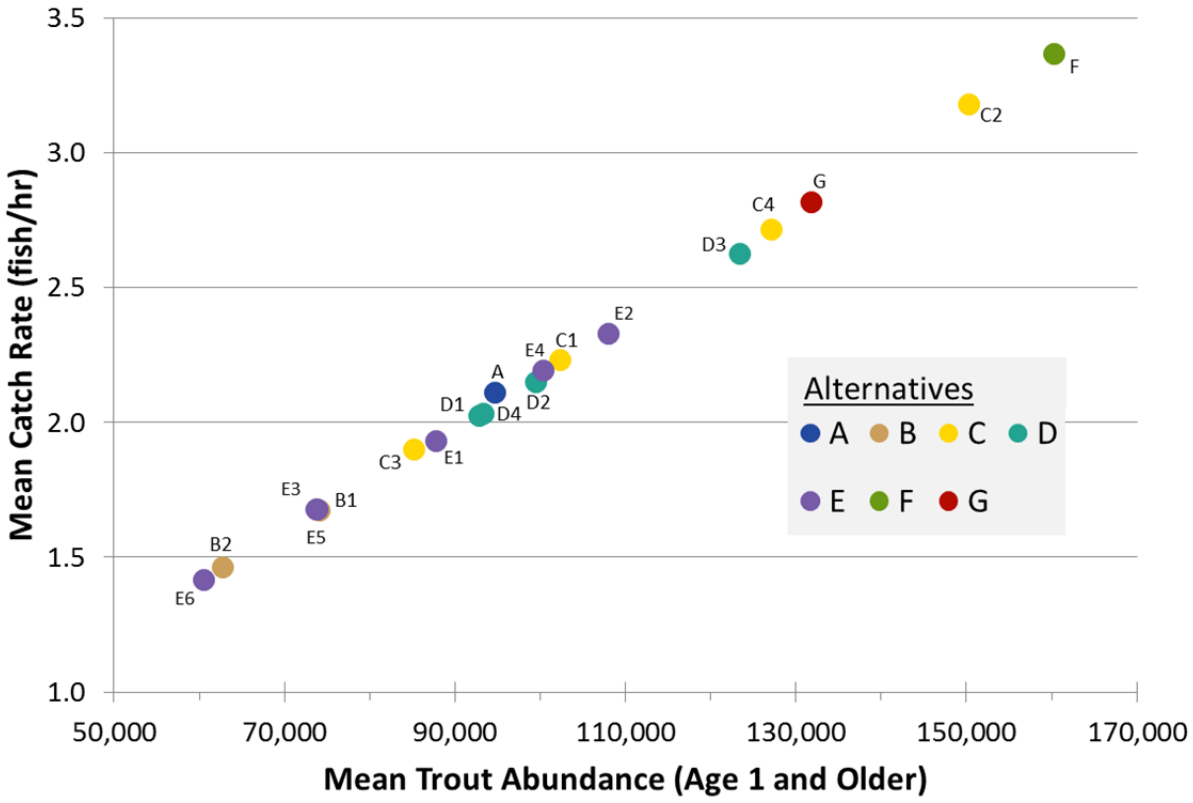

FIGURE F-14 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and Mean Angler Catch Rates during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies

and D3) would be expected to have higher trout numbers and would lead to greater angler catch rates for rainbow trout, while long-term strategies that have fewer HFEs, more variable flows, and include TMFs (e.g., long-term strategies B1, B2, and E6) would be expected to have lower trout abundance and lower mean angler catch rates. Table 4.1-1 identifies the experimental elements included in the various long-term strategies, and Appendix E of this EIS describes the number and duration of HFEs for each.

Trout Emigration

The modeled number of trout emigrating (i.e., number of out-migrants) from the Glen Canyon reach into the Marble Canyon reach of the Colorado River under the LTEMP alternatives and long-term strategies are summarized in Figure F-15. Modeled annual number of out-migrants ranged from approximately 18,200 fish/year to 114,900 fish/year (Figure F-15). The modeled mean annual number of out-migrants (i.e., mean number of out-migrants for all simulations) ranged from 22,415 fish/year under long-term strategy E6 to 71,869 fish/year under Alternative F (Table F-8; Figure F-15). Compared to Alternative A, the model indicated that long-term strategies B1, B2, E3, E5, and E6 would have lower numbers of out-migrants; long-term strategies C3 and E1 would have similar numbers of out-migrants; and long-term strategies

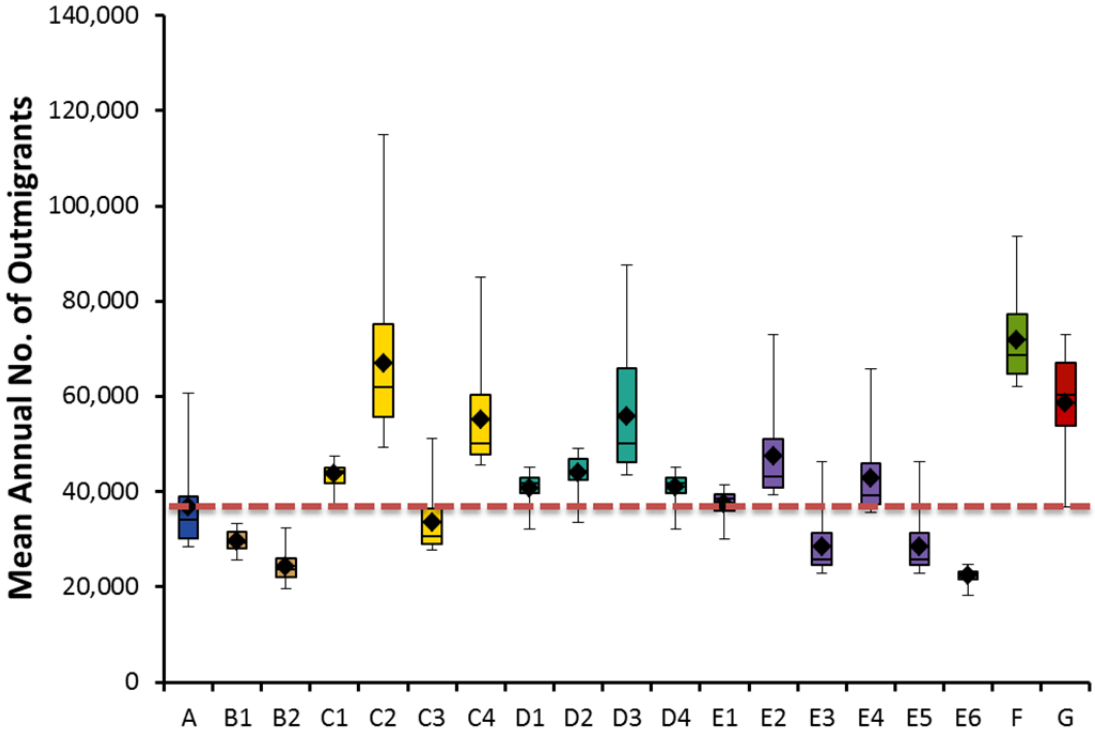

FIGURE F-15 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

C1, C2, C4, D1, D2, D3, D4, E2, E4, and Alternatives F and G would have higher numbers of out-migrants (Figure F-13).

As described in Section F.3.1.1, the annual number of trout emigrating from Glen Canyon into Marble Canyon was calculated as a function of the level of trout recruitment during the previous year. Thus, long-term strategies that result in more HFEs (especially spring HFEs), less variability in flows, and do not include TMFs (e.g., Alternatives F and G and long-term strategies C2, C4, D3, and E2) had higher modeled levels of trout emigration than long-term strategies with fewer HFEs, more variable flow regimes, and included TMFs (e.g., long-term strategies B1, B2, and E6). Table 4.1-1 identifies the experimental elements included in the various long-term strategies, and Appendix E of this EIS describes the number and duration of HFEs that would be expected under each.

Mechanical Removal of Trout in the Little Colorado River Reach

The modeled frequency of years in which mechanical removal of trout would be triggered in the Little Colorado River reach under the LTEMP alternatives and long-term strategies is summarized in Figure F-16. Mechanical removal is not included under long-term strategies C1, C2, E1, E2, E5, and E6, and Alternative F. Among the remaining long-term strategies, the average number of years in which mechanical removal was triggered ranged from approximately 0.1 under Alternative A to approximately 3.1 under Alternative G (Table F-8; Figure F-16). The average maximum number of years in which mechanical removal would be triggered is 6.3 out of 20 years under long-term strategy D3. In general, long-term strategies that result in more frequent HFEs (especially spring HFEs), have steadier flows, and do not include TMFs (e.g., Alternatives F and G and long-term strategies C2, C4, and D3) have higher levels of recruitment, increase the number of trout that move downstream to the Little Colorado River reach, and meet conditions in the model that trigger mechanical removal of trout with a greater frequency. Long-term strategies that result in fewer HFEs and more variable flow levels (e.g., long-term strategies B1, B2, and E6) have lower levels of trout recruitment on average; inclusion of TMFs acts to further decrease the potential for large recruitment events. As a consequence, these long-term strategies result in lower numbers of trout entering the Little Colorado River reach and fewer years when mechanical removal is triggered. Table 4.1-1 identifies the experimental elements included in the various long-term strategies, and Appendix E of this EIS describes the number and duration of HFEs that would be expected under each.

F.3.2.2 Humpback Chub Performance Measures

The modeled minimum population sizes for humpback chub adults under the LTEMP alternatives and long-term strategies are summarized in Figure F-17. Modeled minimum adult population sizes ranged from 1,433 to 13,478 fish (refer to upper and lower whiskers in Figure F-17). Overall modeled means (i.e., mean minimum number of adult humpback chub for all simulations) ranged from 4,450 individuals under Alternative F to 5,708 individuals under long-term strategy E6 (Table F-8; refer to diamonds in Figure F-17). The lowest modeled minimum adult population size (1,433 fish) was observed under long-term strategy C2, and the highest modeled minimum adult population size was observed under long-term strategy E6, although the lowest minimum adult population values were relatively similar among all long-term strategies (refer to lower whiskers in Figure F-17). Compared to Alternative A, the model indicated that long-term strategy C2 and Alternative F would have somewhat lower mean minimum adult population sizes; long-term strategies C1, C4, D1, D2, D3, D4, E1, E2, E4 and Alternative G would have similar mean minimum adult population sizes; and long-term strategies B1, B2, C3, E3, E5, and E6 would have higher mean minimum adult population sizes (Figure F-17). These results indicate that although there are small differences among the long-term strategies with regard to the predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all long-term strategies would likely maintain the population above at least 1,000 adults throughout the 20-year LTEMP period.

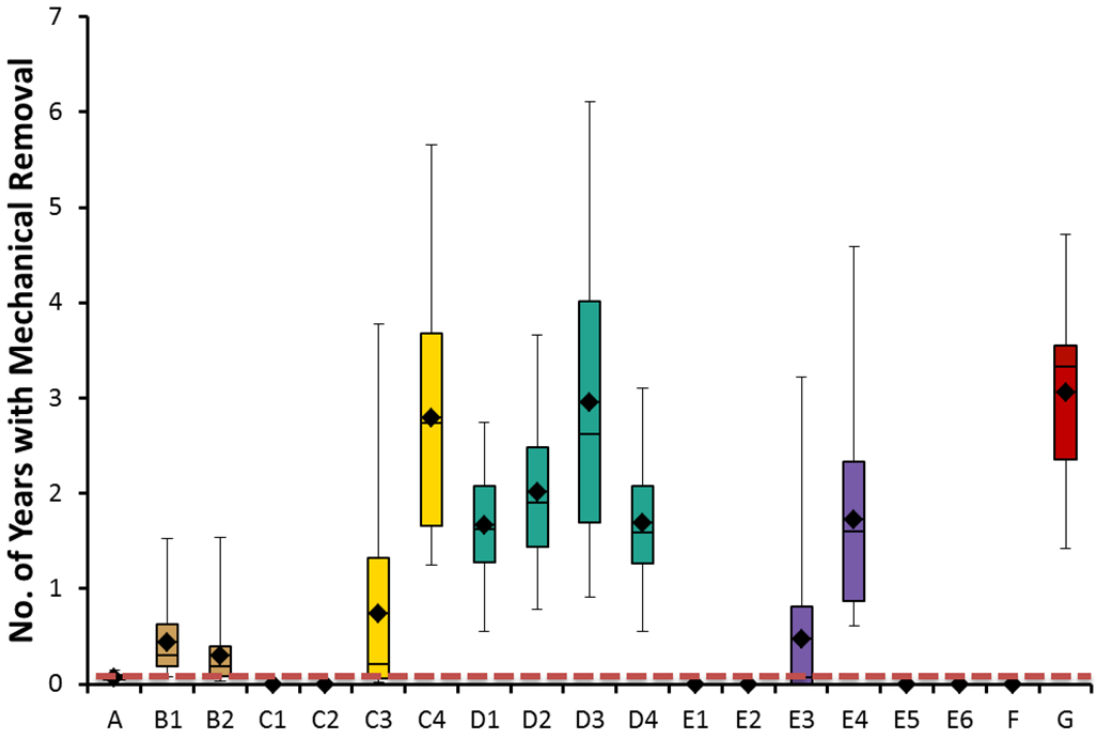

FIGURE F-16 Modeled Frequency of Triggered Mechanical Removal for Rainbow Trout in the Little Colorado River Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

In the humpback chub submodel, the factors that affect annual recruitment and survival of humpback chub are mainstem water temperatures and the number of trout in the Little Colorado River reach (Section F.3.1.3). Because there is little variation among the long-term strategies in modeled mainstem water temperatures at the confluence with the Little Colorado River, the differences in modeled numbers of adult humpback chub among the long-term strategies were primarily affected by the estimated abundance of trout in the Little Colorado River reach where survival of age-0 and juvenile humpback chub and subsequent recruitment of adult humpback chub could be affected by increased competition and predation (e.g., Yard et al. 2011). Because the modeled abundance of trout in the Little Colorado River reach is driven by modeled emigration of rainbow trout from the Glen Canyon reach, there is a strong relationship between the average adult humpback chub population size and the average number of trout emigrating from the Glen Canyon reach for the various long-term strategies (Figure F-18). Refer to the section above entitled "Trout Emigration" for information about the experimental elements of long-term strategies that affect the levels of trout emigration. Although the model predicts that

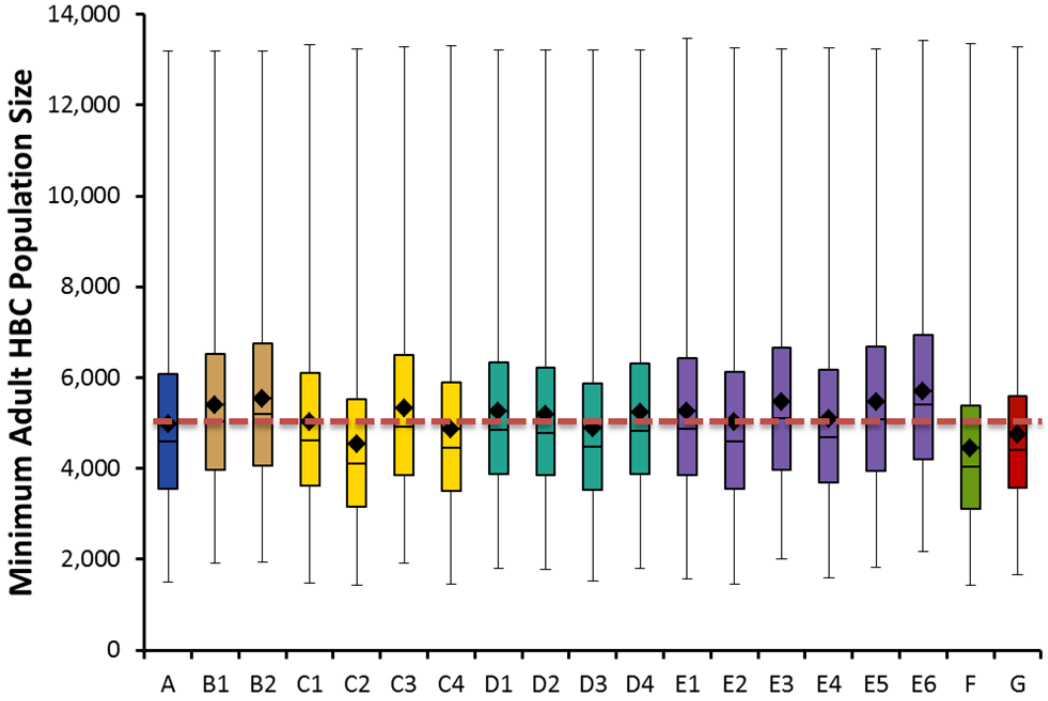

FIGURE F-17 Modeled Minimum Population Size for Humpback Chub (HBC) during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum annual value for all simulations; upper whisker = maximum annual value for all simulations; horizontal dashed line identifies mean value for Alternative A.)

the number of trout at the confluence with the Little Colorado River is related to trout recruitment in the Glen Canyon reach, the actual relationship is unclear and still under investigation.

F.4 MODELING THE EFFECTS OF LTEMP ALTERNATIVES ON TEMPERATURE SUITABILITY

This section describes the modeling approach used to evaluate the effects of LTEMP EIS alternatives on temperature suitability for fishes and invertebrate parasites in the mainstem Colorado River downstream of Glen Canyon Dam. The goal of the temperature suitability modeling was to evaluate the potential for each of the alternatives to result in temperature conditions that would promote maintenance and/or establishment of various fish and invertebrate

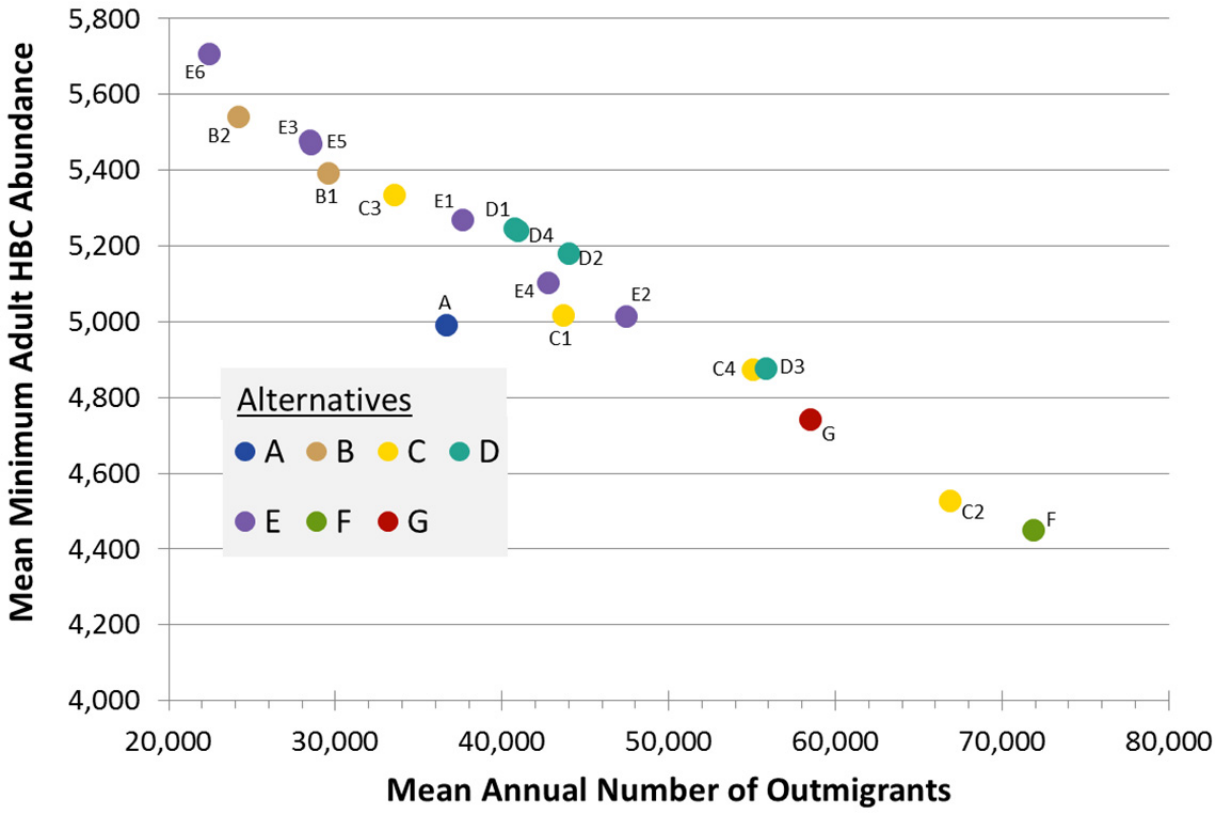

FIGURE F-18 Relationship between Modeled Mean Numbers of Rainbow Trout Out-migrants from the Glen Canyon Reach and the Modeled Mean Minimum Abundance of Adult Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies

species of management concern. In particular, the temperature suitability modeling is intended to evaluate effects of alternatives on temperature suitability for four species groups:

1. Temperature suitability for establishment and maintenance of self-sustaining aggregations of humpback chub at various river locations in the Colorado River downstream of Glen Canyon Dam;

2. Temperature suitability for establishment and maintenance of self-sustaining populations of native warmwater fish other than humpback chub at various locations in the Colorado River downstream of Glen Canyon Dam;

3. Temperature suitability for establishment and maintenance of self-sustaining populations of nonnative fish species at various locations in the Colorado River downstream of Glen Canyon Dam; and

4. Temperature suitability for establishment and maintenance of self-sustaining populations of parasitic invertebrate species at various locations in the Colorado River downstream of Glen Canyon Dam.

The following sections describe the general modeling approach for evaluating temperature suitability, specific modeling considerations applied in order to implement the modeling approach for each of the species groups to be evaluated, the input data needs and sources for each of the ecological components, and the approach for statistically evaluating the output of the models in order to compare the effects of the various operational alternatives on temperature suitability for each species group.

F.4.1 Model Overview

In general, the temperature suitability modeling considers how well mainstem water temperatures at selected locations downstream of Glen Canyon Dam would meet the temperature requirements for three life history components—spawning, egg incubation, and growth—for each species group evaluated. To accomplish this, monthly water temperature values in a multiyear time series were compared to temperature suitability profiles for life history components of each species group considered. The seasonal timing or period of the year during which the temperature needs for each life history component must be met is taken into account by the model. Possible values for temperature suitability can theoretically range from 0 (completely unsuitable for one or more life history component) to 1 (magnitude and timing of temperatures would be optimal for all life history components). However, since optimal conditions for all life history components cannot be simultaneously met in many cases due to different optimal temperatures during overlapping time frames, the maximum attainable value for a given species would generally be less than one.

The temperature suitability modeling evaluates the potential for all life history components to be met in the mainstem river, even though some species are known to sometimes use tributaries to accomplish particular needs. Thus, the model can predict relatively low temperature suitability for some areas even though species populations appear to be abundant and self-sustaining. In addition, modeled water temperatures used as inputs do not consider the potential for warming near tributary mouths, backwater habitats, or in shallow nearshore areas. Thus, the results of temperature suitability modeling are used to compare relative effects of alternatives on species-specific temperature needs in the mainstem Colorado River, rather than as an exact predictor of the potential for the presence or absence of fish or parasite species at particular locations.

For fish species, the model considers the suitability of each day's water temperature for three life history components (spawning, egg incubation, and growth). The model bases the potential for self-sustaining populations of fish species being successful on the combined temperature suitability scores for spawning, incubation, and growth, and it is assumed that some level of both mainstem spawning and egg incubation would be required to support self-sustaining populations of fish species. The annual potential for successful spawning and egg incubation is assumed to be related to the suitability of the annual temperature regimes for

spawning and egg incubation during the spawning and egg incubation periods. It was assumed that the potential for successful rearing and survival of fish species within the mainstem at each evaluation location was related to the suitability of temperatures throughout the year for growth. The suitability of various temperatures for spawning, egg incubation, and growth needs of fish was calculated using triangular probability functions[3] based upon reported suitable ranges and optimal temperatures for each life history aspect of each species (Valdez and Speas 2007).

For parasite species, the model bases the potential for unacceptable parasite conditions on the temperature suitability scores for host activity and infestation. It is assumed that both elevated host activity and infestation rates would be needed to result in unacceptable infestations of the parasite species and the annual potential for unacceptable infestations is assumed to be related to the suitability of the temperature regimes for host activity and infestation throughout the year. The suitability of various temperatures for host activity and infestation needs of a group of four parasite species was calculated using triangular probability functions based on the reported range of suitable temperatures and the reported optimal temperature for each species (Valdez and Speas 2007). The model calculates daily temperature suitability scores for the life history components based on the triangular suitability relationships and the seasonal time periods during which the temperature needs for each life history component must be met.

Annual temperature suitability for each life history component is calculated as the mean of the daily suitability values that fall within the specified seasonal time period during a given water year. The overall annual temperature suitability for each species is calculated as the geometric mean of the annual temperature suitability scores for the applicable species-specific life history components. Temperature suitability over a 20-year period is based on the mean of the annual temperature suitability values. Evaluations were conducted for each river location to be assessed or using the overall annual means for combinations of downstream locations. The mean of the annual suitability scores for multiple fish or parasite species was used as an indication of the overall suitability of each year's temperature regime for groups of native fish, nonnative fish, or parasite species.

The LTEMP temperature suitability model requires inputs pertaining to daily water temperatures for each of the downstream locations to be assessed, and it requires identification of temperature requirements for the life history aspects of each species to be evaluated. Species-specific temperature requirement information includes the minimum, optimal, and maximum suitable temperatures for important life history components and information describing the appropriate months of the year during which conditions for each life history component should be met. Table F-9 summarizes the input data needs and the anticipated sources of the input values. The model is formulated to consider daily water temperatures for multiyear periods. The daily water temperature input values were derived from external modeling (i.e., not calculated within the LTEMP temperature suitability model) following formulas developed by Wright et al. (2009) to predict mean monthly water temperatures at various locations downstream of Glen

[3] With the triangular functions used, the temperature suitability value rises linearly from 0 at the minimum suitable temperature to 1 at the optimum temperature, then falls linearly from 1 at the optimum to 0 at the maximum suitable temperature). Each of these functions was based on species-specific temperature requirements as reported by Valdez and Speas (2007). See Figure F-19 for example functions.

TABLE F-9 Description of Input Parameters for the LTEMP Temperature Suitability Model

Input Parameter	Description of Input Data	Comments
$TW_{x,y}$	Mean daily water temperature (°C) for a specific day (*x*) in a given year (*y*)	Provided by water temperature modeling. Although daily water temperatures are used as inputs into the model, modeled mean monthly water temperatures were used to provide the mean daily temperatures to be used within the months for each year. The model is formulated to accommodate multiyear traces of daily temperature data. A water temperature time series covering the same time period was developed for each downstream location.
$T_{Min(s,l)}$	The minimum suitable temperature (°C) to meet a given life history need (*l*) for a given species (*s*)	Values obtained from Valdez and Speas (2007).
$T_{Max(s,l)}$	The maximum suitable temperature (°C) to meet a given life history need (*l*) for a given species (*s*)	Values obtained from Valdez and Speas (2007).
$T_{Opt(s,l)}$	The optimum suitable temperature (°C) to meet a given life history need (*l*) for a given species (*s*)	Values obtained from Valdez and Speas (2007).
$MonthStart_{(s,l)}$	The beginning month of the water year during which a given life history need (*l*) for a given species (*s*) should be met	Used to identify the beginning of the appropriate time period for meeting each species–life history component combination.
$MonthEnd_{(s,l)}$	The ending month of the water year during which a given life history need (*l*) for a given species (*s*) should be met	Used to identify the end of the appropriate time period for meeting each species–life history component combination.

Canyon Dam based on assumed meteorological conditions, the expected magnitude of water releases, and the temperature of the water being released from Lake Powell for each of the LTEMP alternatives. The temperature suitability for each alternative/long-term strategy was evaluated using a total of 63, 20-year temperature input scenarios generated from conditions expected during operations for a range of hydrology–sediment trace combinations. The temperature suitability model was implemented using R (R Core Team 2013; see http://www.r-project.org/about.html).

The following sections provide specific information regarding implementations and results of the temperature suitability modeling approach to evaluate suitability for (1) self-sustaining aggregations of humpback chub; (2) self-sustaining populations of native warmwater fish species other than humpback chub; (3) self-sustaining populations of coldwater and warmwater nonnative fish species; and (4) establishment and maintenance of invasive parasitic invertebrate species.

F.4.2 Humpback Chub Aggregations

The temperature suitability model evaluates how well alternatives would provide mainstem water temperatures suitable for spawning, egg incubation, and growth of humpback chub at reported aggregation locations. The model based the potential for a self-sustaining aggregation of humpback chub becoming successfully established at each location on the combined potential for successful spawning, successful incubation, and successful growth of humpback chub. The time series of water temperatures was based upon estimated water temperatures for eight mainstem Colorado River locations (Table F-10) where humpback chub aggregations have been reported to occur. As described in Section F.4.1, the water temperatures used as inputs for these locations were modeled using a water temperature model developed by Wright et al. (2009).

It was assumed that mainstem spawning would be required to support self-sustaining aggregations at all locations except for the aggregation at the confluence of the mainstem and the Little Colorado River (RM 61), where successful tributary spawning is known to occur. Thus, except for the Little Colorado River aggregation, the annual potential for successful spawning is assumed to be related to the suitability of temperature regimes in the mainstem Colorado River for spawning. The potential for successful spawning at various temperatures was calculated using a triangular probability function based upon the reported range of suitable spawning temperatures (16–22°C) (61–72°F) and the reported optimal spawning temperature (18°C) (64°F) for humpback chub (Valdez and Speas 2007). The calculated suitability of various water temperatures for successful humpback chub spawning is shown in Figure F-19.

April, May, and June were identified as encompassing the possible spawning period for humpback chub aggregations (Figure F-20), based on observations of fish in spawning condition reported by Valdez and Ryel (1995) for aggregations and by Gorman and Stone (1999) for spawning in the Little Colorado River. The annual suitability values for spawning were set to a value of 1 for the Little Colorado River aggregation, since water temperature in the Little

TABLE F-10 Humpback Chub Aggregation Locations

Aggregation Location	River Mile (RM)[a]
30-mile	RM 30
Little Colorado River confluence	RM 61
Bright Angel Creek	RM 88
Shinumo Creek	RM 108
Stephen Aisle	RM 119
Middle Granite Gorge	RM 125
Havasu Creek	RM 157
Pumpkin Spring	RM 213

[a] River mile distances are calculated as the distance downstream from the Lee Ferry gage.

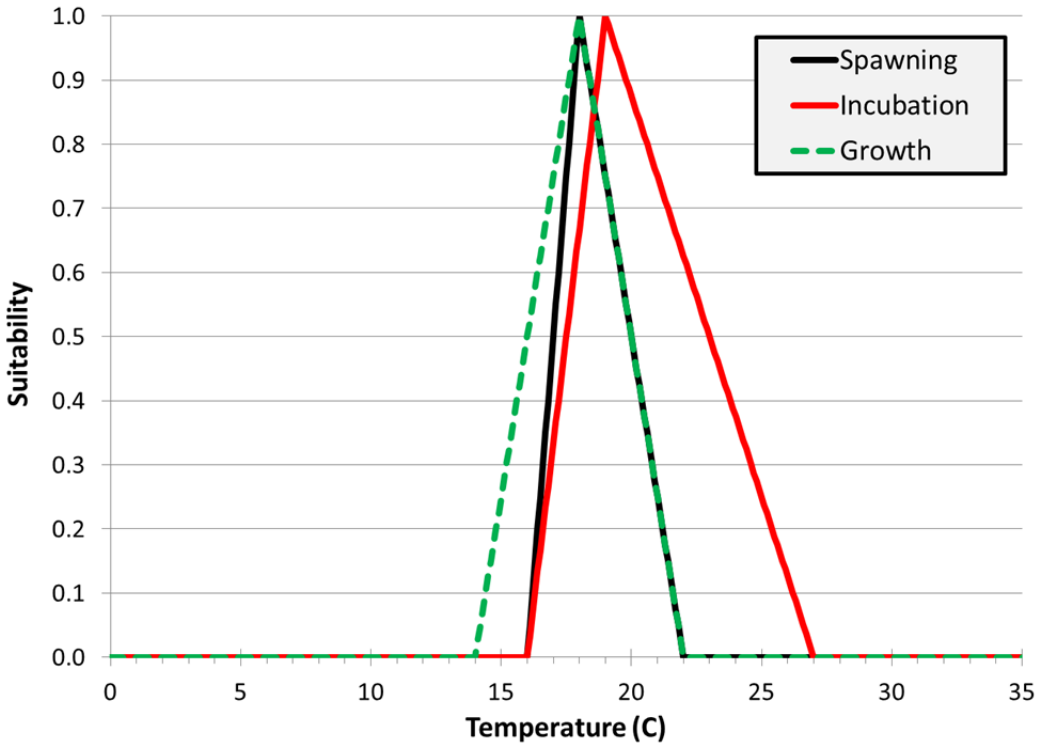

FIGURE F-19 Suitability for Spawning, Egg Incubation, and Growth of Humpback Chub as a Function of Water Temperature (based on minimum, maximum, and optimum temperature values presented in Valdez and Speas 2007)

Species	Life History Aspect	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Humpback Chub	Spawning				■	■	■						
	Incubation				■	■	■						
	Growth	■	■	■	■	■	■	■	■	■	■	■	■

FIGURE F-20 Months for Which Annual Temperature Suitability for Specific Life History Aspects of Humpback Chub Were Calculated

Colorado River is known to support spawning needs for this aggregation. The potential for successful spawning for each aggregation during a given water year was calculated as the average of the estimated suitability scores during April through June (Figure F-20).

It was assumed that mainstem egg incubation would be required to support self-sustaining aggregations at all locations except for the aggregation at the confluence of the mainstem and the Little Colorado River (RM 61), where successful tributary spawning is known to occur. The suitability for incubation in the Little Colorado River (RM 61) aggregation was assumed to be 1. At other aggregation locations, the annual potential for successful egg incubation was assumed to be related to the suitability of mainstem temperature regimes for incubation during the spawning period, because incubation of humpback chub eggs may require as little as 3 days at optimal temperatures. Thus, it was assumed that the spawning period of April, May, and June also encompassed the egg incubation period for aggregations (Figure F-20). The suitability of various temperatures for egg incubation was calculated using a triangular probability function based upon the reported range of suitable egg incubation temperatures (16–27°C) (61–81°F) and the reported optimal egg incubation temperature (19°C) (66°F) for humpback chub (Valdez and Speas 2007; Figure F-19).

It was assumed that the potential for successful rearing of humpback chub within the mainstem at each aggregation location is related to the suitability of temperatures throughout the year for humpback chub growth. The suitability of various temperatures for growth of humpback chub was calculated using a triangular probability function based upon the reported range of suitable temperatures (16–22°C) (61–72°F) and the reported optimal temperature (18°C) (64°F) for growth (Valdez and Speas 2007; Figure F-19). The annual suitability of daily temperatures for growth was calculated as the mean of daily suitability values during the entire water year (Figure F-20).

The geometric mean of the annual temperature suitability values for spawning, egg incubation, and growth was used as an indicator of the annual potential for an aggregation to be successful (and self-sustaining) at a particular location. The arithmetic mean of the annual suitability scores for each of the eight aggregation locations was used as an indication of the overall relative suitability of each year's temperature regime for supporting humpback chub aggregations in the mainstem Colorado River downstream of Glen Canyon Dam.

F.4.2.1 Historic Temperature Suitability for Humpback Chub

Historic temperature suitability of mainstem water temperatures for humpback chub aggregations was examined using modeled water historic temperatures at the aggregation locations for a 23-year period from October 1, 1989, through September 30, 2012 (water years 1990–2012), as the temperature inputs (Figure F-21). The annual values of the modeled historic temperature suitability for the various aggregation locations are summarized in Figure F-22.

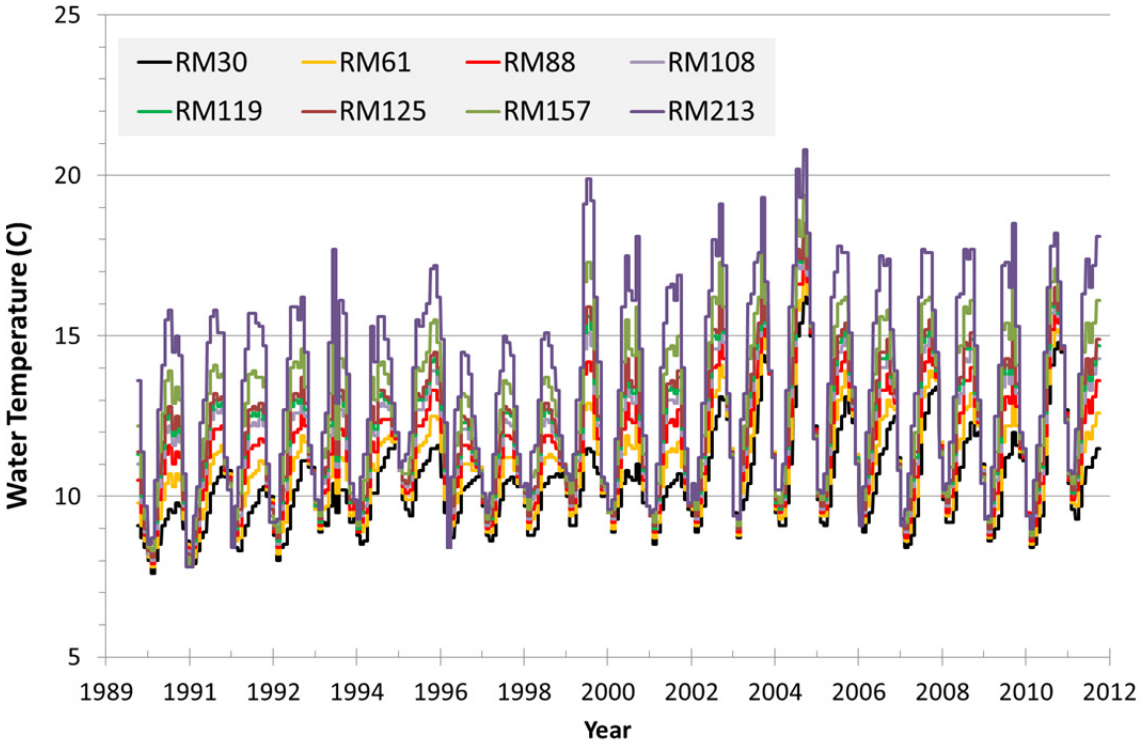

FIGURE F-21 Modeled Historic Water Temperatures in the Colorado River at Humpback Chub Aggregation Locations, Water Years 1990–2012 (Source: Williams 2013)

F.4.2.2 Results for LTEMP Alternatives

Figure F-23 summarizes the temperature suitability for humpback chub at aggregation locations under the LTEMP alternatives and long-term strategies. Modeled main channel water temperature suitability for humpback chub was relatively low and similar to Alternative A under all the long-term strategies for most aggregation locations. Modeled mean annual main channel temperature suitability for humpback chub at RM 61 (the Little Colorado River confluence) was slightly higher under Alternative F than under the other long-term strategies (Figure F-23), because the lower summer and fall flows of this alternative resulted in warmer water that would benefit growth during those seasons; note that the overall suitability score for RM 61 reflects temperature suitability for growth in the main channel, and optimal spawning and egg incubation temperatures in the Little Colorado River where the species spawns. Because the water warms as it travels downstream from the dam (for spring through fall months), temperature suitability improves with increasing distance. At RM 213, mean annual temperature suitability for humpback chub was similar to Alternative A under all long-term strategies except for C1, C2, C3, and C4, and Alternative F. Compared to Alternative A, long-term strategies C1, C2, C3, and C4 were slightly lower, although differences were small (Figure-F-23). Modeled temperature suitability at RM 213 was lowest under Alternative F (Figure F-23), reflecting the higher, colder flows expected to occur under this alternative during spawning and egg incubation periods (April through June). Based on these results, the combined suitability of mainstem temperatures for spawning, egg incubation, and growth by humpback

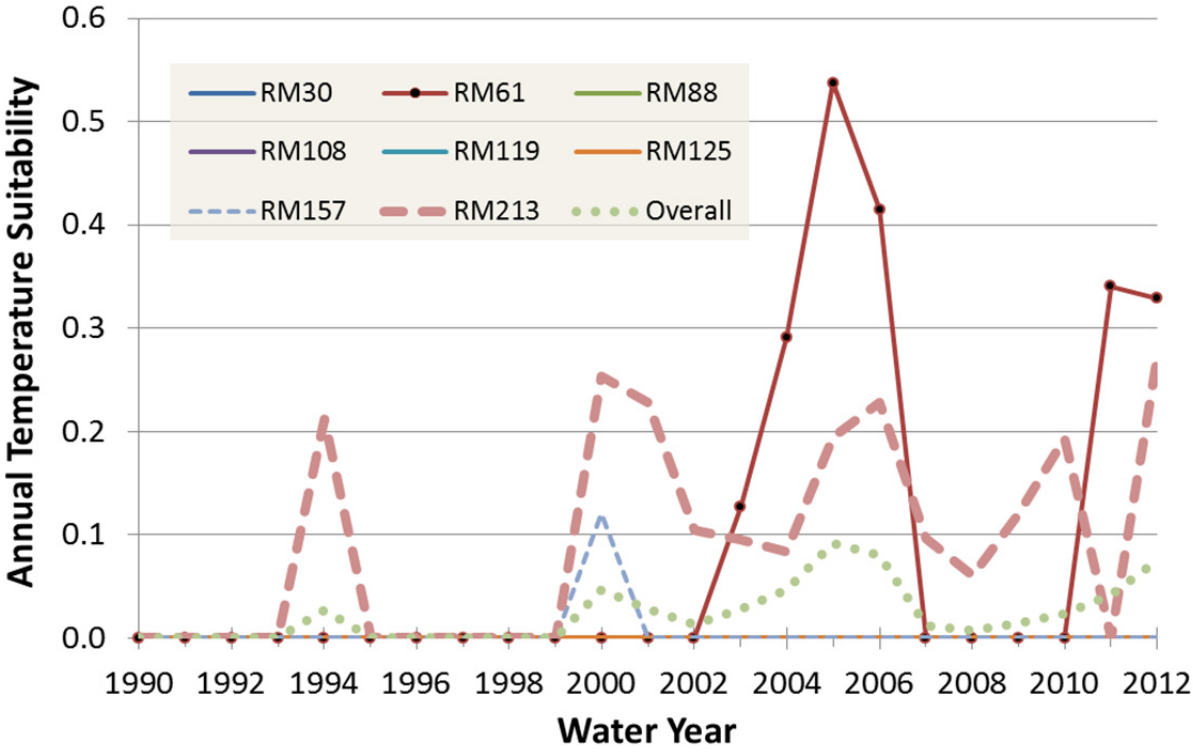

FIGURE F-22 Output from the Temperature Suitability Model for Humpback Chub Aggregation Locations Based on Modeled Water Temperatures for Water Years 1990–2012

chub in the downstream-most aggregation sites is anticipated to be negatively affected compared to current conditions under Alternative F; however, for the other long-term strategies, suitability would remain similar to the low historic levels, as represented by the suitability under Alternative A (the no-action alternative). It should be noted that, historically, there have been years where the magnitude and timing of mainstem water temperatures have likely coincided to allow spawning and egg incubation to occur in some of the downstream aggregation areas; however, the overall average suitability has likely been low (Figure F-22).

F.4.3 Other Native Fish

The temperature suitability model for native fish evaluates how well alternatives provide mainstem water temperatures suitable for spawning, egg incubation, and growth of four species of warmwater native fish other than humpback chub (speckled dace [*Rhinichthys osculus*], razorback sucker [*Xyrauchen texanus*], flannelmouth sucker [*Catostomus latipinnis*], and bluehead sucker [*C. discobolus*]). In order to account for changes in water temperatures as water released from Glen Canyon Dam travels downstream, evaluations of temperature suitability were conducted for five mainstem Colorado River locations (Table F-11). As described in Section F.4.1, the time series of water temperatures used as inputs for these locations are generated using a water temperature model developed by Wright et al. (2009).

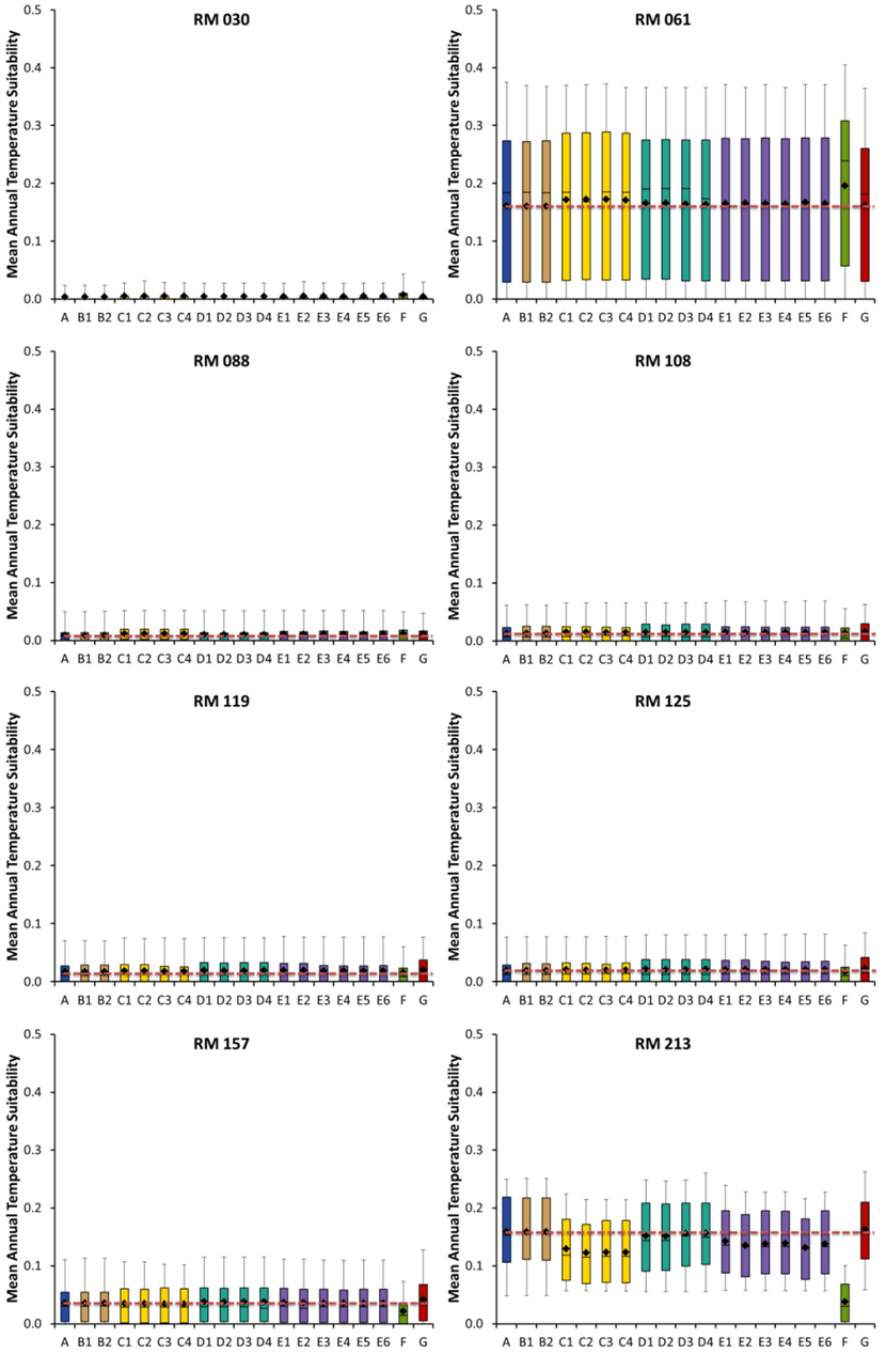

FIGURE F-23 Mainstem Temperature Suitability for Humpback Chub Aggregation Locations under LTEMP Alternatives and Long-Term Strategies (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

TABLE F-11 Locations Used for Temperature Suitability Modeling of Native Fish, Nonnative Fish, and Parasites

Aggregation Location	River Mile (RM)[a]
Glen Canyon Dam	RM –15
Paria River/Lee Ferry	RM 0
Little Colorado River confluence	RM 61
Havasu Creek	RM 157
Diamond Creek	RM 225

[a] River mile distances are calculated as the distance downstream from the Lee Ferry Gage. Glen Canyon Dam is indicated as being at RM –15, since it is located upstream of Lee Ferry.

The calculated suitability of various water temperatures for successful spawning, egg incubation, and growth of the four native species is depicted in Figure F-24. The months encompassing the spawning, egg incubation, and growth periods for each of the four native fish species are indicated in Figure F-25.These time periods were identified by reviewing the scientific literature pertaining to each of the species.

F.4.3.1 Historic Temperature Suitability for Native Fish

Historic temperature suitability of mainstem water temperatures for the four native fish species was examined using modeled water historic temperatures at five evaluation locations for a 23-year period from October 1, 1989, through September 30, 2012 (water years 1990–2012) as the temperature inputs (Figure F-26). Figure F-27 presents the annual temperature suitability scores for spawning, incubation, and growth of the four native fish species based upon the modeled historic temperatures for water years 1990–2012 at RM 225 (Diamond Creek). Figure F-28 presents the annual temperature suitability scores for the five river locations and a combined overall score for all locations based on the modeled historic temperature suitability for the various assessment locations. The overall means of annual suitability scores at each river location for native fish over the 1990–2012 water years are presented in Figure F-29.

F.4.3.2 Results for LTEMP Alternatives

The temperature suitability for the four native fish at multiple downstream locations under the LTEMP alternatives and long-term strategies is summarized in Figure F-30. Modeled main channel water temperature suitability for native fish species was relatively low and similar to Alternative A under all long-term strategies at RM 61, reflecting the prevalence of coldwater releases from Glen Canyon Dam throughout the year and the limited effect that the long-term strategies would have on mainstem water temperature regimes at RM 61. Because the water

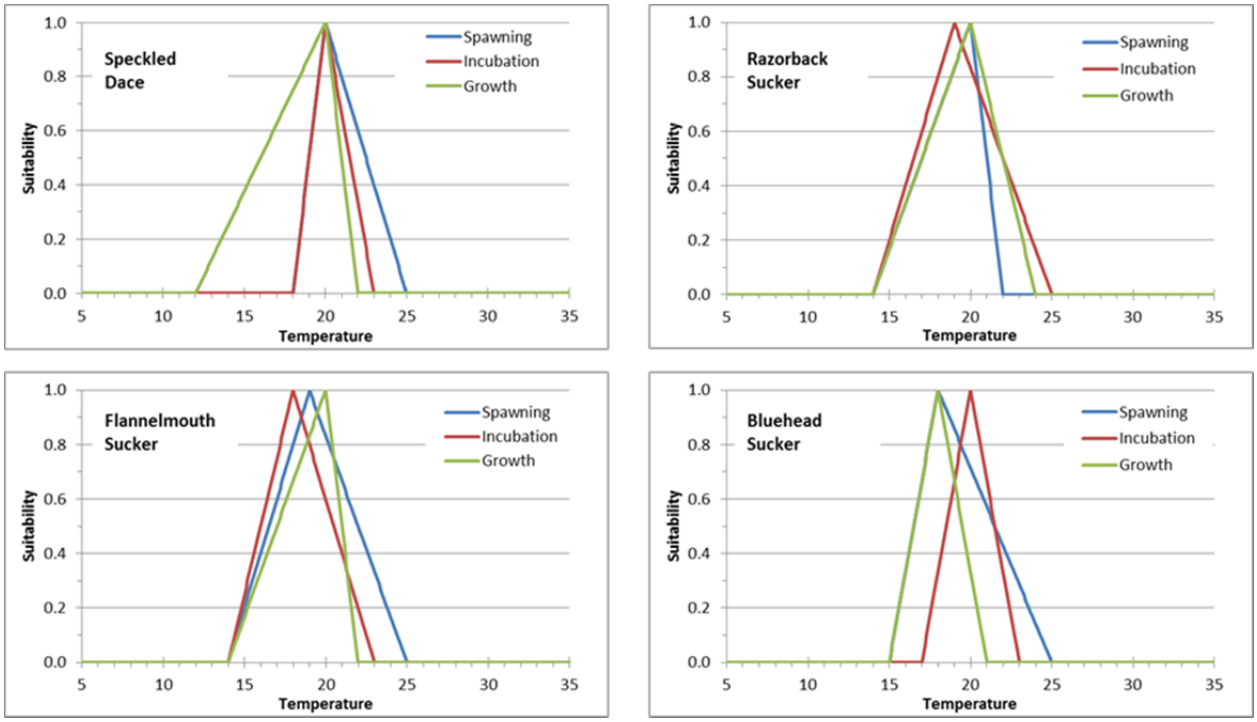

FIGURE F-24 Suitability of Water Temperatures (°C) for Spawning, Egg Incubation, and Growth of Native Fish Species (Source: Valdez and Speas 2007)

Species	Life History Aspect	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speckled Dace	Spawning												
	Incubation												
	Growth												
Razorback Sucker	Spawning												
	Incubation												
	Growth												
Flannelmouth Sucker	Spawning												
	Incubation												
	Growth												
Bluehead Sucker	Spawning												
	Incubation												
	Growth												

FIGURE F-25 Months for Which Temperature Suitability for Specific Life History Aspects Were Considered for Native Fish Species

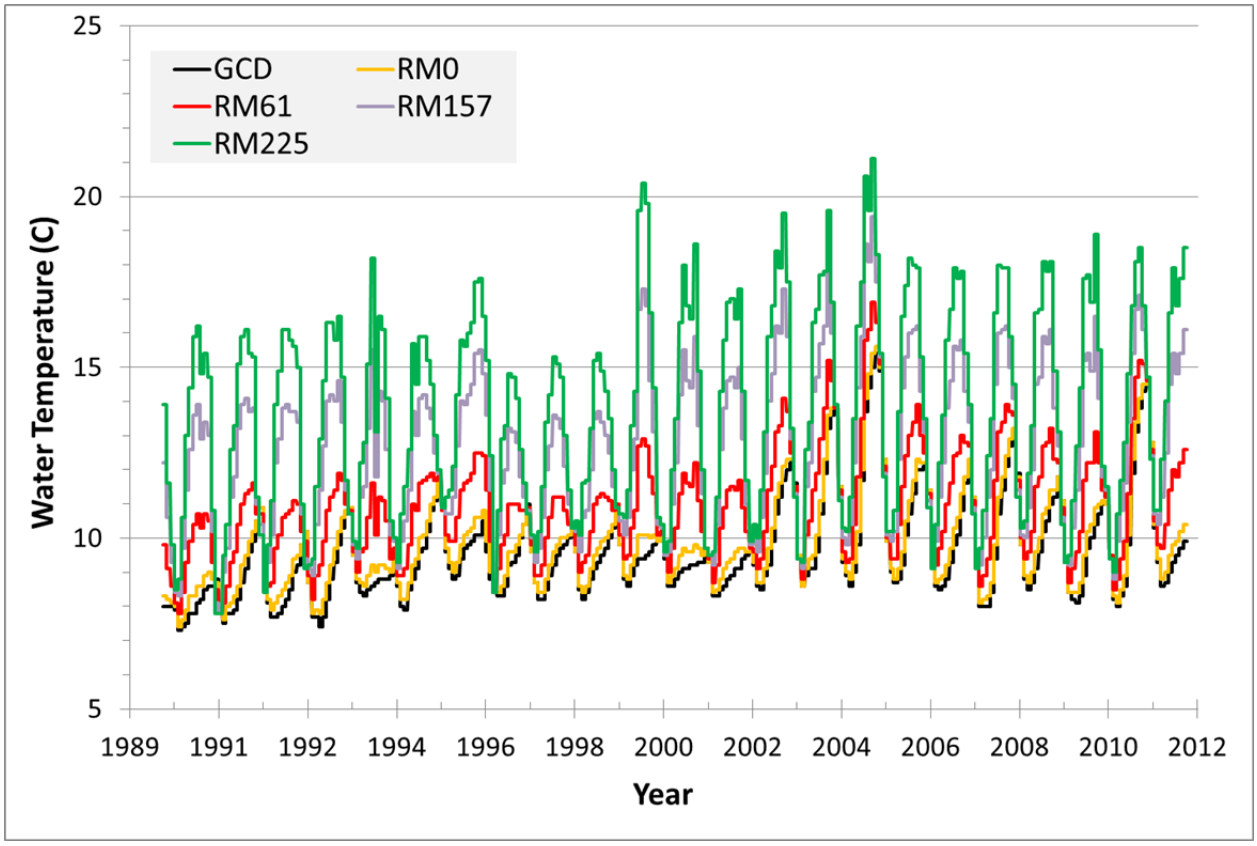

FIGURE F-26 Modeled Historic Water Temperatures in the Colorado River Downstream of Glen Canyon Dam, Water Years 1990–2012 (Source: Williams 2013)

warms as it travels downstream from the dam (for spring through fall months), temperature suitability improves with increasing downstream distance, and differences in suitability among the long-term strategies begin to appear. Whereas suitability for most long-term strategies remain similar to, or lower than, the modeled suitability under Alternative A at these downstream locations, temperature suitability for native fish improves somewhat under long-term strategies D1, D2, D3, and D4 (Figure F-30). It should be noted that there is little difference in temperature suitability among the long-term strategies specific to Alternatives B, C, D, and E, suggesting that experimental elements identified in Table 4.1-1 such as HFEs, low summer flows, TMFs, and hydropower improvement flows would have little effect on mainstem water temperature regimes during periods of the year considered most important for spawning and egg incubation by native species. Rather, differences in temperature suitability for native fish under the various long-term strategies appear to be more related to differences in the seasonal patterns of releases and the effects of those patterns on seasonal temperatures. Thus, the reduction in modeled temperature suitability under Alternative F at RM 225 reflects the higher flows expected to occur under this alternative during spring and early summer months when native fish are expected to spawn; those higher flows would result in temperatures less suitable for spawning and egg incubation.

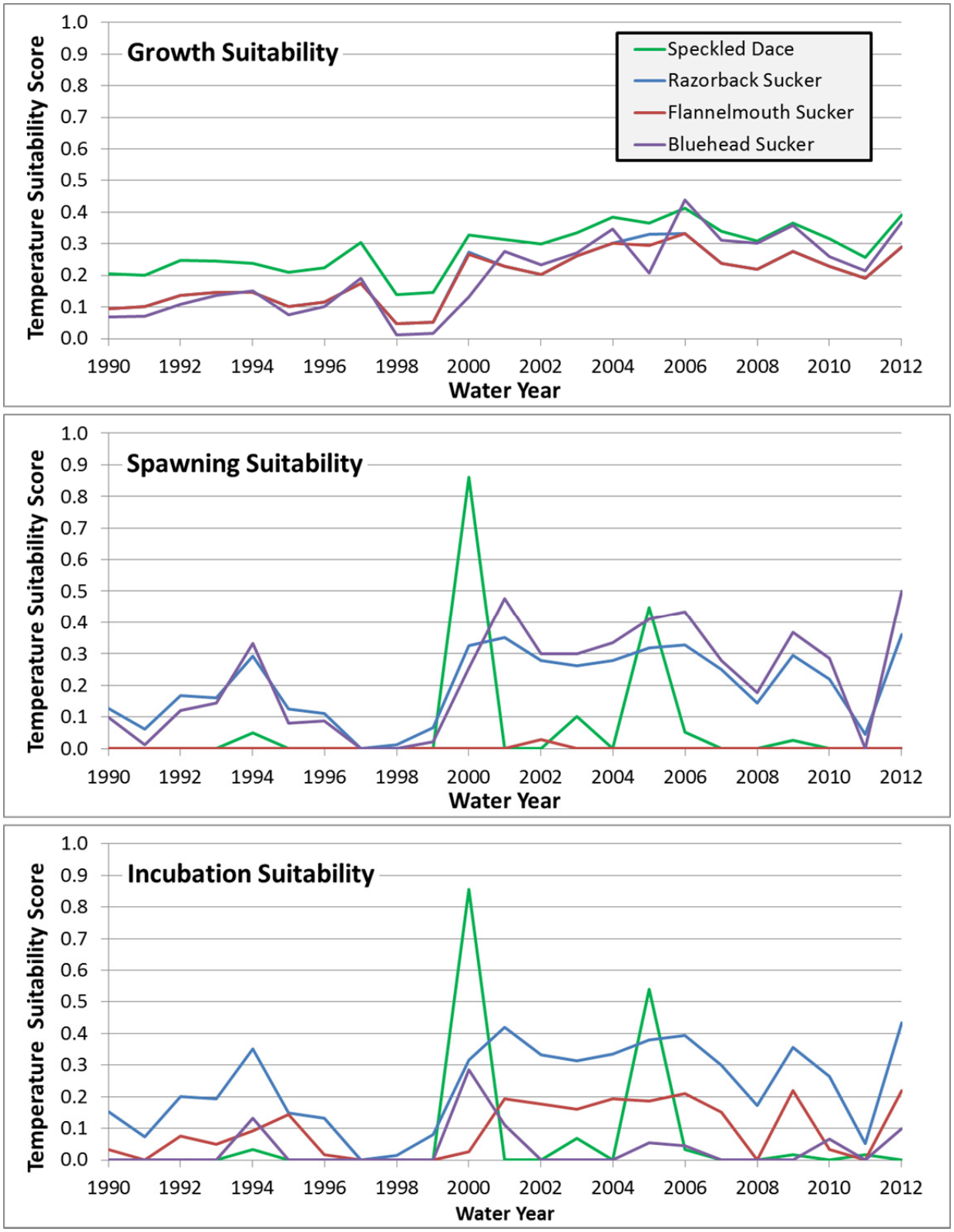

FIGURE F-27 Annual Temperature Suitability Scores for Growth, Spawning, and Egg Incubation of Native Fish Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012

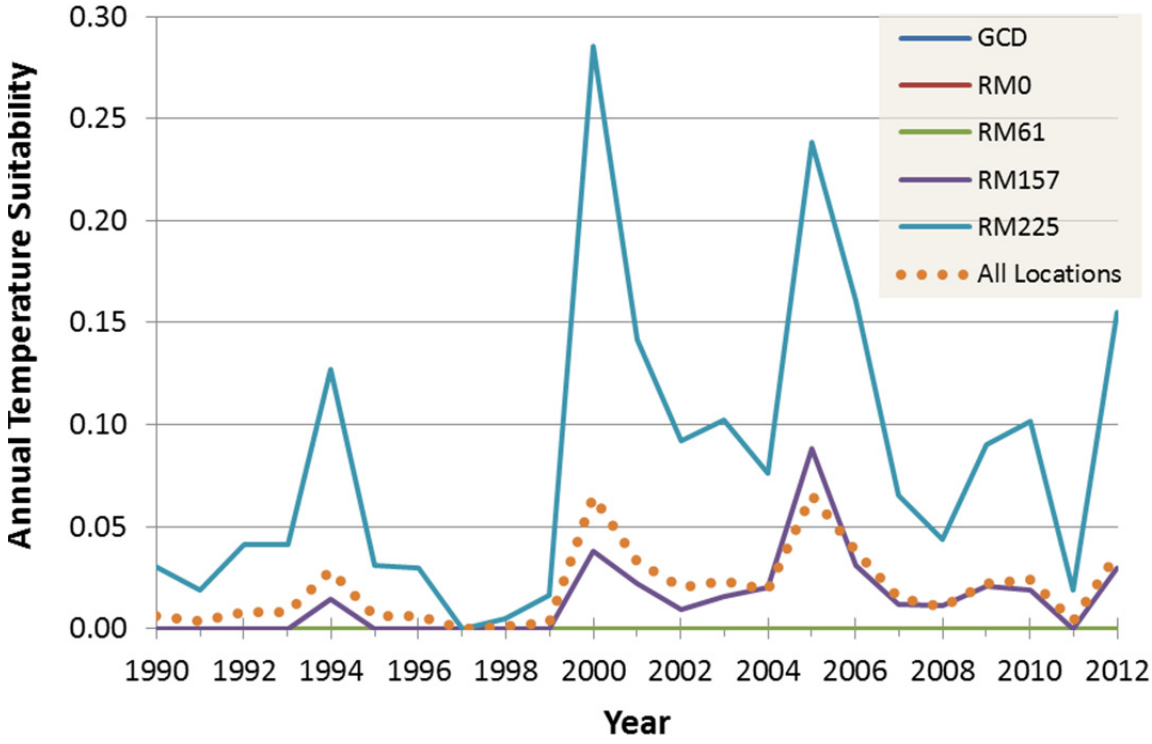

FIGURE F-28 Annual Temperature Suitability Scores for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012

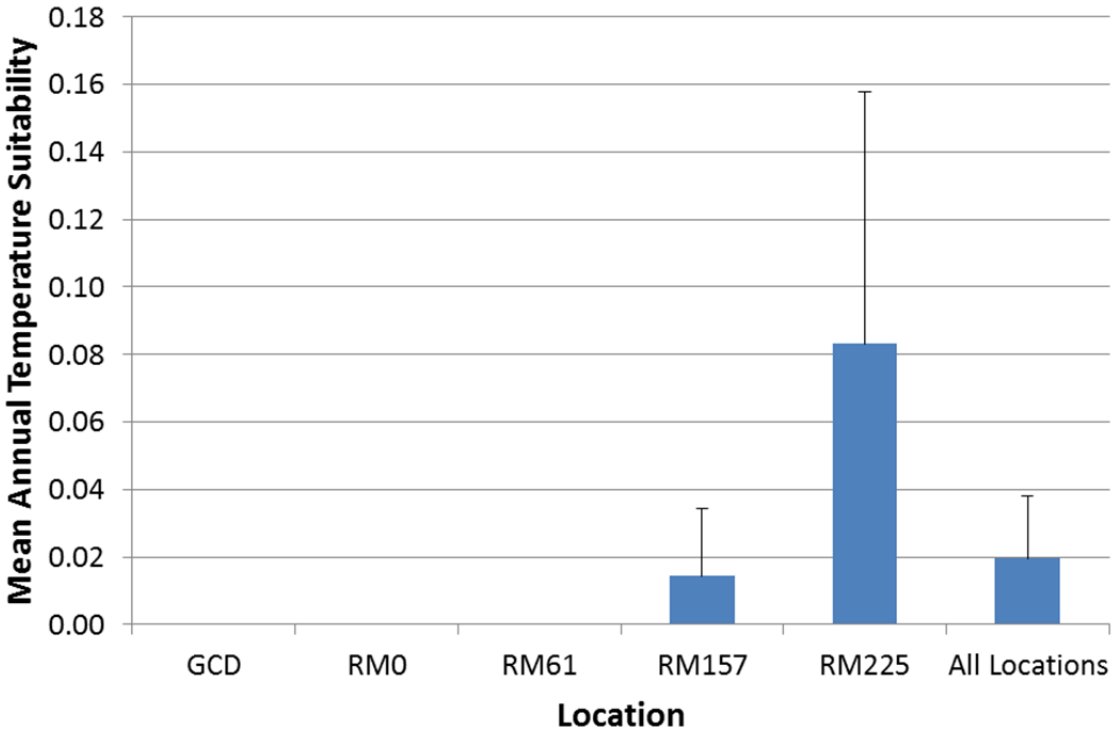

FIGURE F-29 Mean (±SD) Annual Overall Temperature Suitability for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012

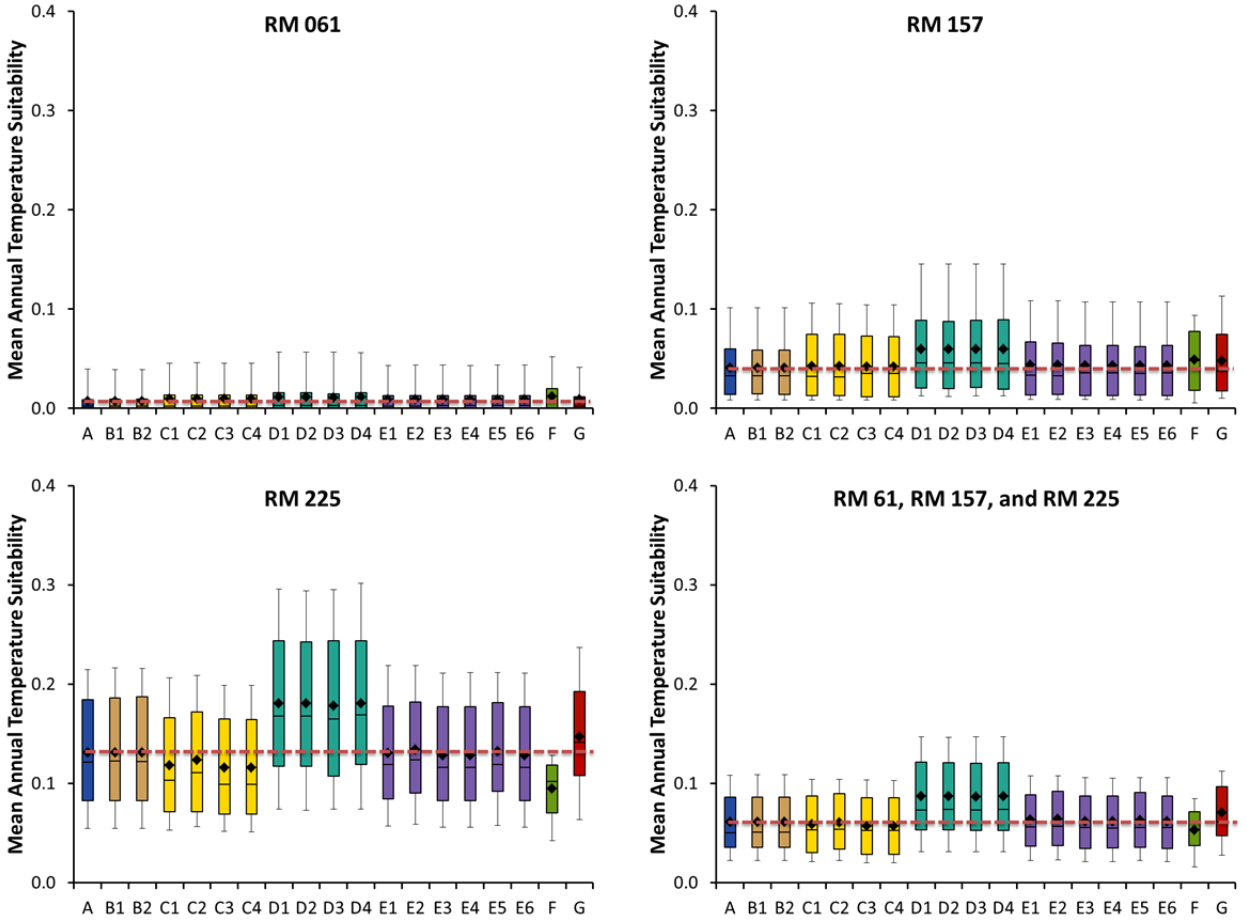

FIGURE F-30 Mean Annual Mainstem Temperature Suitability for Native Fish under LTEMP Alternatives and Long-Term Strategies at RM 61, RM 157, and RM 225, and Overall Mean for RM 61–225 (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

F.4.4 Nonnative Fish

The temperature suitability model for nonnative fish evaluates how well alternatives provide mainstem water temperatures suitable for spawning, egg incubation, and growth of six species of coldwater (brown trout [*Salmo trutta*], rainbow trout) and warmwater (channel catfish [*Ictalurus punctatus*], green sunfish [*Lepomis cyanellus*], smallmouth bass [*Micropterus dolomieu*], and striped bass [*Morone saxatilis*]) nonnative fish. In order to account for changes in water temperatures as water released from Glen Canyon Dam travels downstream, evaluations of temperature suitability were conducted for the five mainstem Colorado River locations identified in Table F-11. As described in Section F.4.1, the time series of water temperatures used as inputs for these locations were generated using a water temperature model developed by Wright et al.

(2009). The calculated suitability values for various water temperatures for successful spawning, egg incubation, and growth of the six nonnative fish species are depicted in Figure F-31. The months encompassing the spawning and egg incubation periods for each of the six nonnative fish species are indicated in Figure F-32. The annual suitability of daily temperatures for growth is calculated as the mean of daily suitability values for the entire water year (October through September). The overall means of temperature suitability values for the coldwater and warmwater nonnative species groups were examined separately.

F.4.4.1 Historic Temperature Suitability for Nonnative Fish

Historic suitability of mainstem water temperatures for the six nonnative fish species was examined using modeled water historic temperatures at the five evaluation locations for a 23-year period from October 1, 1989, through September 30, 2012 (water years 1990–2012), as the temperature inputs (Figure F-26). Figure F-33 presents the annual temperature suitability scores for spawning, incubation, and growth of the six nonnative fish species based upon the modeled historic temperatures for water years 1990–2012 at RM 225 (Diamond Creek). The mean annual temperature suitability scores for each species and temperature group for the five river locations are presented in Figure F-34. The overall means of annual suitability scores for the coldwater and warmwater nonnative fish species across all river locations during the 1990–2012 water years are presented in Figure F-35.

F.4.4.2 Results for LTEMP Alternatives

In general, temperature suitability for coldwater nonnative species (i.e., brown and rainbow trout) would be similar among most of the long-term strategies at most locations downstream of Glen Canyon Dam and would be remain similar to current conditions based on comparisons to Alternative A (Figure F-36). Because of the effects of the timing and magnitude of peak and base flow releases on water temperatures, temperature suitability would be slightly greater under Alternative F than under the other long-term strategies at the confluence with the Little Colorado River (RM 61), and lower under Alternative F than under the other long-term strategies for locations farther downstream; however, those differences are very small and may not be biologically significant. Although main channel temperature regimes at and downstream of RM 61 appear to become more suitable for trout species than at locations closer to the dam (Figure F-36), the abundance of trout is known to be lower at those locations (based on sampling), suggesting that other habitat characteristics (e.g., substrate composition and water clarity) may be less suitable at these downstream locations. Because inclusion of flow actions—such as HFEs, TMFs, and low summer flows—had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by trout, these flow actions have little effect on modeled mainstem temperature suitability and would not alter relative suitability for coldwater nonnative species among the long-term strategies (Figure F-36).

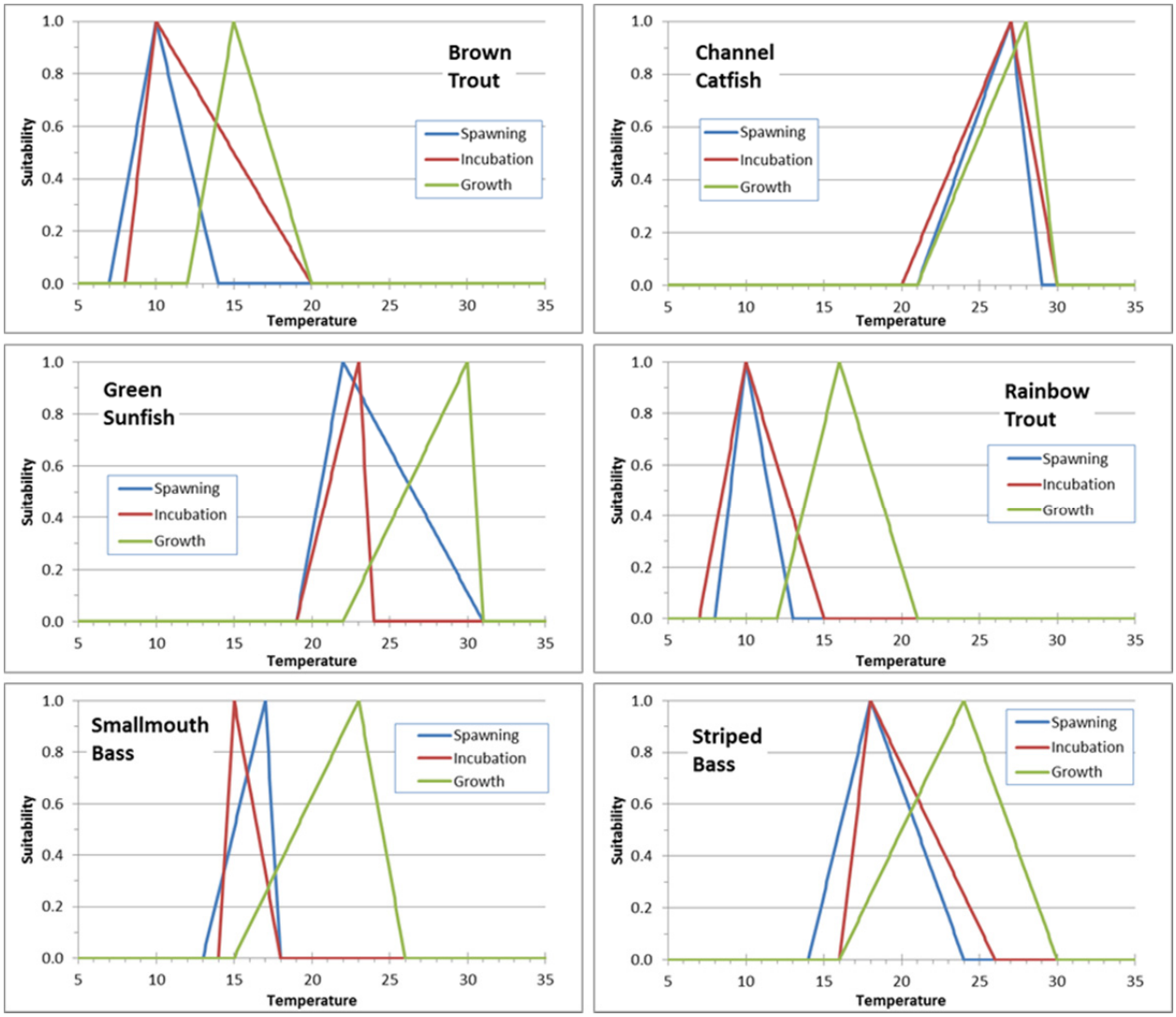

FIGURE F-31 Suitability of Water Temperatures (°C) for Spawning, Egg Incubation, and Growth of Nonnative Fish Species (Source: Valdez and Speas 2007)

Temperature suitability at the various main channel locations was modeled for the four nonnative warmwater species considered to be representative of the warmwater nonnative fish community (smallmouth bass, green sunfish, channel catfish, and striped bass). In general, the estimated average main-channel temperature suitability for these nonnative fish did not differ greatly among the long-term strategies, and was low under all long-term strategies (Figure F-37). The modeled temperature suitability indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61); this agrees with past surveys that have found more warmwater nonnative fish species in those areas. Relative to current conditions (as exemplified by Alternative A), the temperature suitability model indicated that the long-term strategies for Alternative C (i.e., long-term strategies C1, C2, C3, and C4) and Alternative F have the greatest potential to improve conditions for warmwater nonnative fish at locations downstream of RM 157, which could result in increased numbers

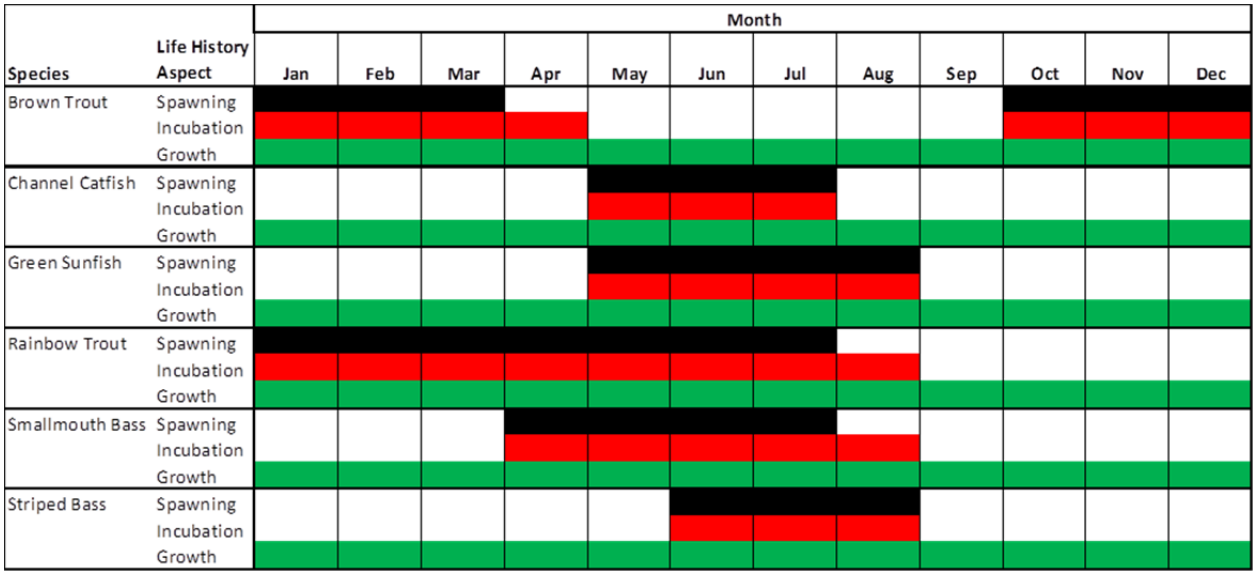

FIGURE F-32 Months during Which Temperature Suitability for Specific Life History Aspects Were Calculated for Nonnative Fish Species

and a greater potential for upstream spread of warmwater nonnative fish species. As described above for coldwater fish species, inclusion of flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by nonnative warmwater species. As a consequence, the various experimental elements associated with the long-term strategies (Table 4.1-1) would be expected to have little effect on mainstem temperature suitability for warmwater nonnative species (Figure F-37). Rather, as identified for native fish in Section F.4.3.2, differences among alternatives appear to be more related to differences in the seasonal patterns of releases and the effects of those patterns on seasonal temperatures.

F.4.5 Aquatic Parasites

The temperature suitability model for aquatic parasite species evaluates how well alternatives provide mainstem water temperatures suitable for host activity for and infestation by four species (Asian tapeworm [*Bothriocephalus acheilognathi*], anchor worm [*Lernaea cyprinacea*], trout nematode [*Truttaedacnitis truttae*], and whirling disease [*Myxobolus cerebralis*]) that could parasitize fish in the Colorado River downstream of Glen Canyon Dam. In order to account for changes in water temperatures as water released from Glen Canyon Dam travels downstream, evaluations of temperature suitability were conducted for the mainstem Colorado River locations identified in Table F-11. As described in Section F.4.1, the time series of water temperatures used as inputs for these locations were generated using a water temperature model developed by Wright et al. (2009).

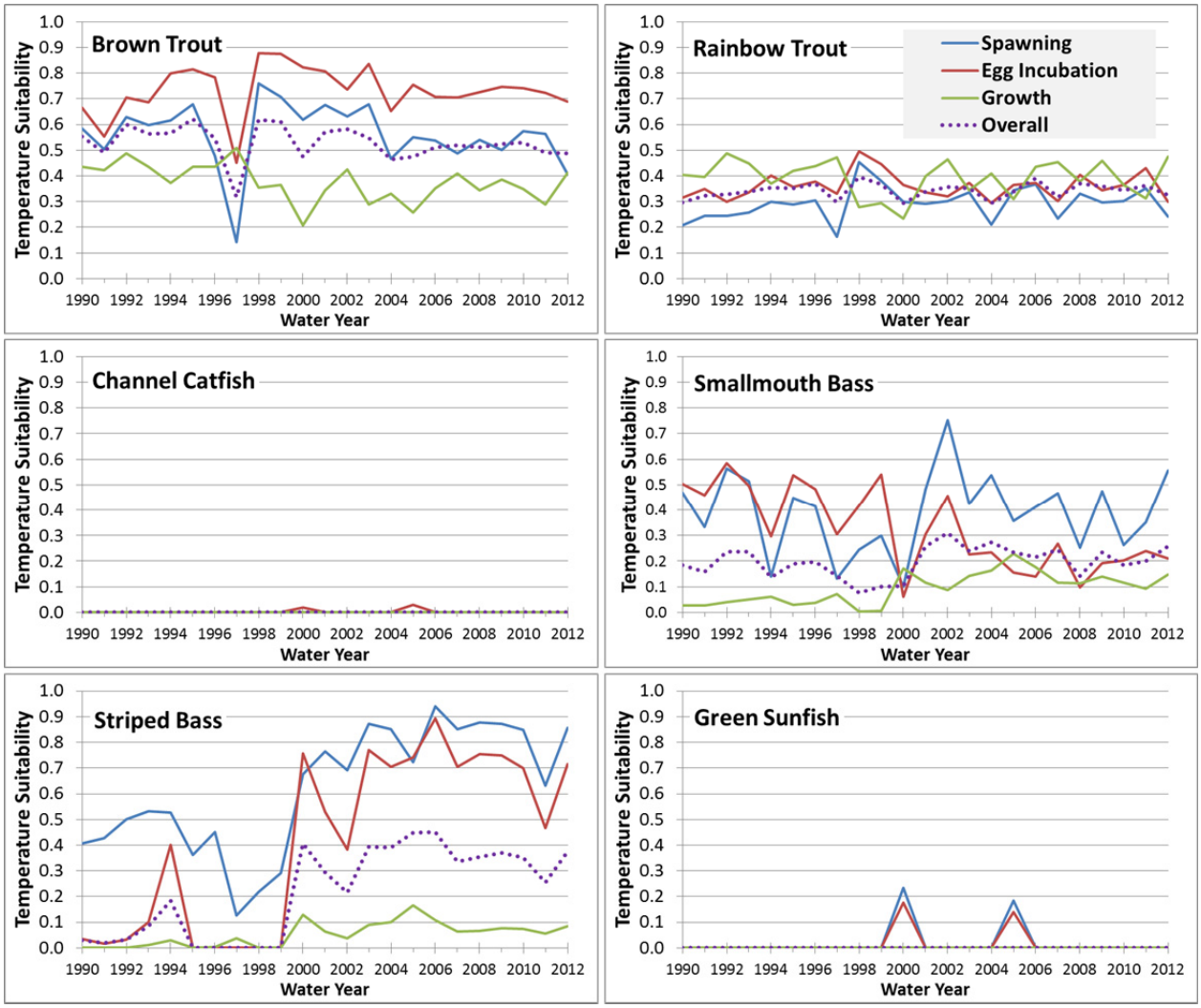

FIGURE F-33 Annual Temperature Suitability Scores for Spawning, Incubation, and Growth of Nonnative Fish Species at RM 225 (Diamond Creek) Based on Modeled Temperatures for Water Years 1990 to 2012

The calculated suitability values at various water temperatures for host activity and infestation rates of the four parasite species is depicted in Figure F-38. It was assumed that evaluation of temperature suitability across the entire water year (rather than just a portion of the year) was relevant for both of the parasite life history components. The geometric mean of the annual temperature suitability values for host activity and infestation was used as an indicator of the annual overall suitability for each parasite species and served as the indicator of the potential for each of the parasite species to become problematic at a particular downstream location. The combined mean of the annual suitability scores for all four parasite species was used as an indication of the overall suitability of each year's temperature regime for the group of parasite species at each downstream location. The mean of the group means for all of the downstream locations was calculated as an indication of overall relative suitability of the temperature regime

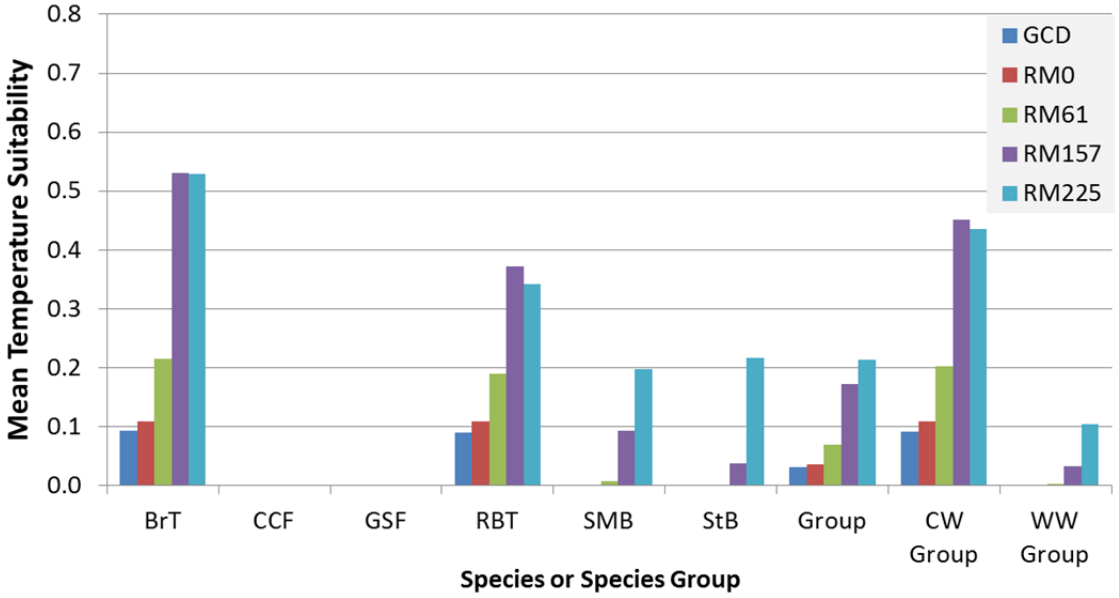

FIGURE F-34 Mean Annual Temperature Suitability Scores for Nonnative Fish Species and for Temperature Groups by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 (BrT = brown trout; CCF = channel catfish; GSF = green sunfish; RBT = rainbow trout; SMB = smallmouth bass; StB = striped bass; Group = combined coldwater and warmwater; CW = coldwater; WW = warmwater)

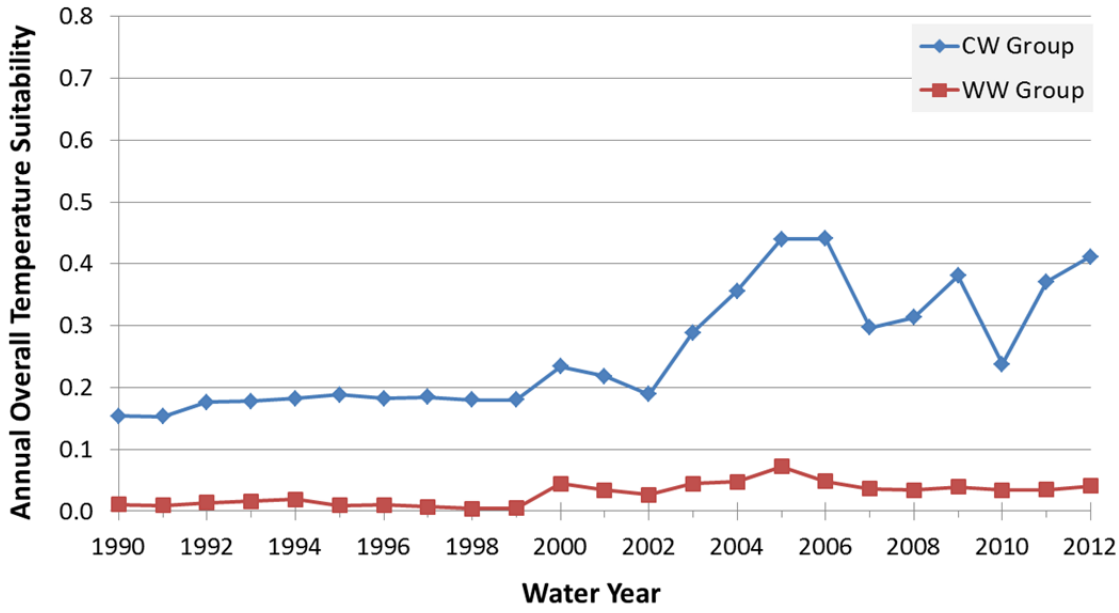

FIGURE F-35 Mean Annual Overall Temperature Suitability Scores for Coldwater (CW) and Warmwater (WW) Nonnative Fish Species Groups Based on Modeled Historic Temperatures for Water Years 1990–2012

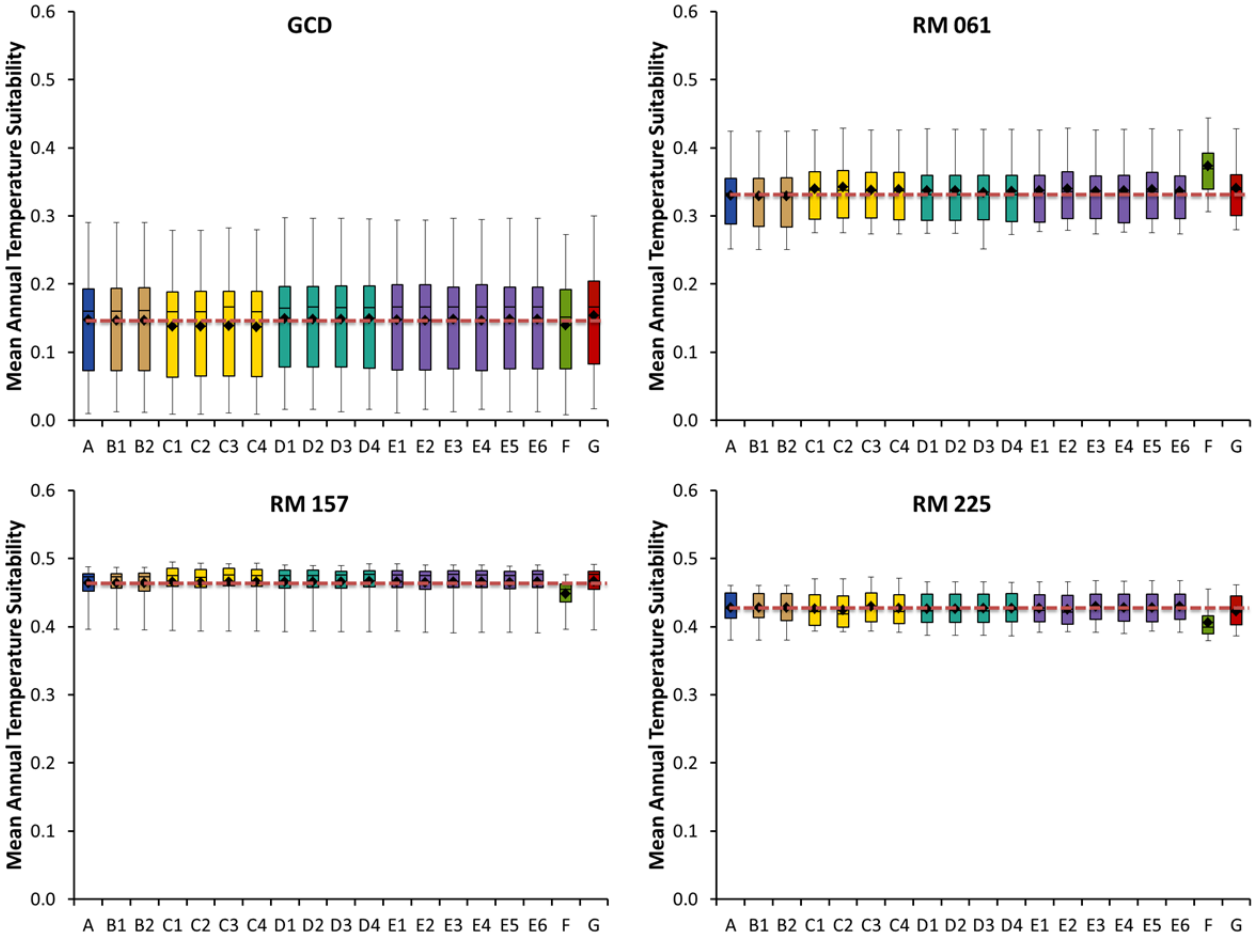

FIGURE F-36 Mean Annual Mainstem Temperature Suitability for Coldwater Nonnative Fish (brown trout and rainbow trout) under LTEMP Alternatives and Long-Term Strategies at RM 15 (Glen Canyon Dam, GCD), RM 61, RM 157, and RM 225 (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

within a particular year for parasite species in the mainstem Colorado River downstream of Glen Canyon Dam.

F.4.5.1 Historic Temperature Suitability for Aquatic Parasites

Historic suitability of mainstem water temperatures for the four aquatic parasite species was examined using modeled water historic temperatures at the five evaluation locations for a 23-year period from October 1, 1989, through September 30, 2012 (water years 1990–2012), as the temperature inputs (Figure F-26). Figure F-39 presents the annual temperature suitability

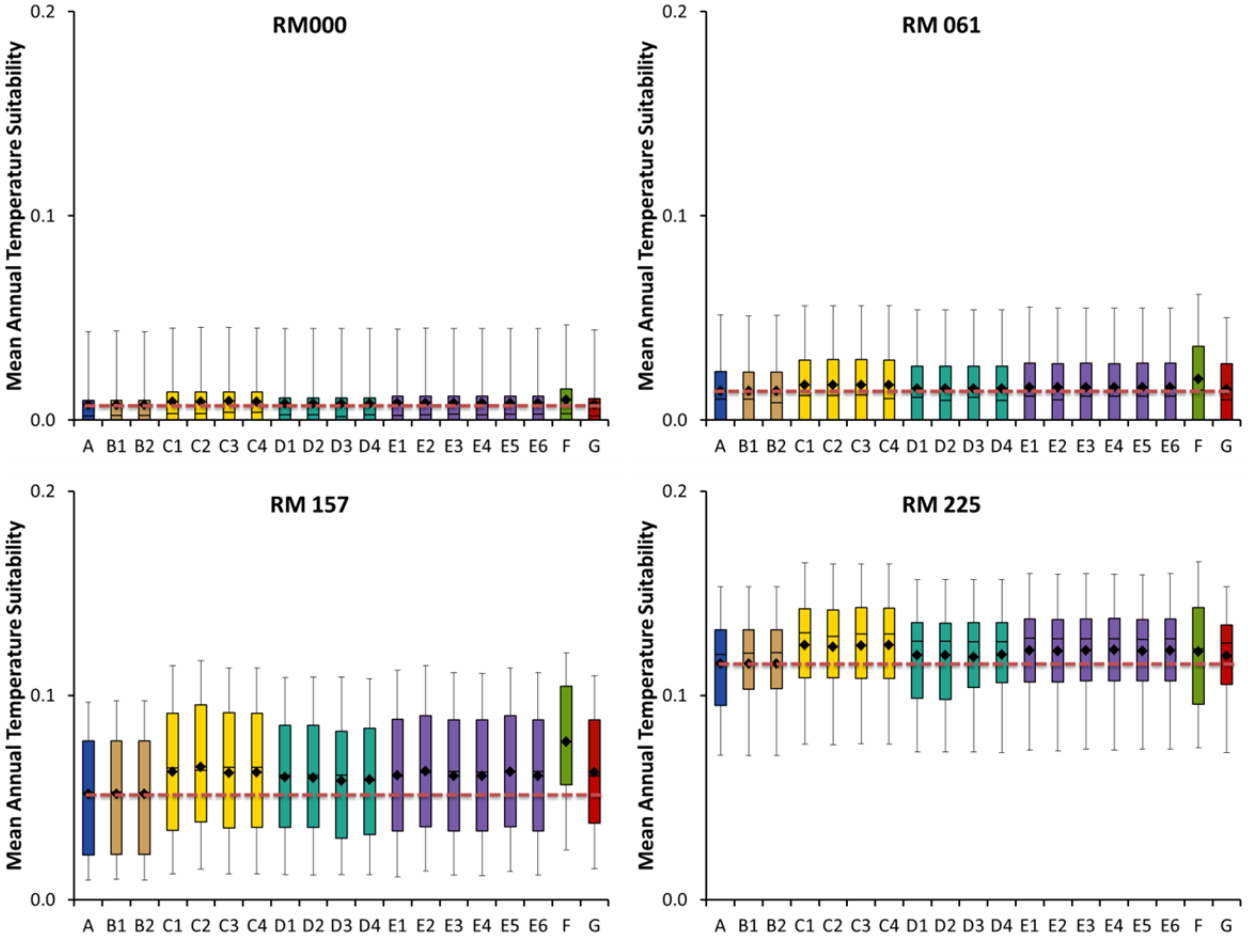

FIGURE F-37 Mean Annual Mainstem Temperature Suitability for Warmwater Nonnative Fish (channel catfish, green sunfish, smallmouth bass, and striped bass) under LTEMP Alternatives and Long-Term Strategies at RM 0, RM 61, RM 157, and RM 225 (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

scores for host activity and infestation rates of the parasite species based upon the modeled historic temperatures for water years 1990–2012 at RM 225 (Diamond Creek). The mean annual temperature suitability scores for each species and temperature group for the five river locations are presented in Figure F-40. The overall means of modeled annual suitability scores for the coldwater and warmwater nonnative fish species groups across all river locations during the 1990–2012 water years are presented in Figure F-41.

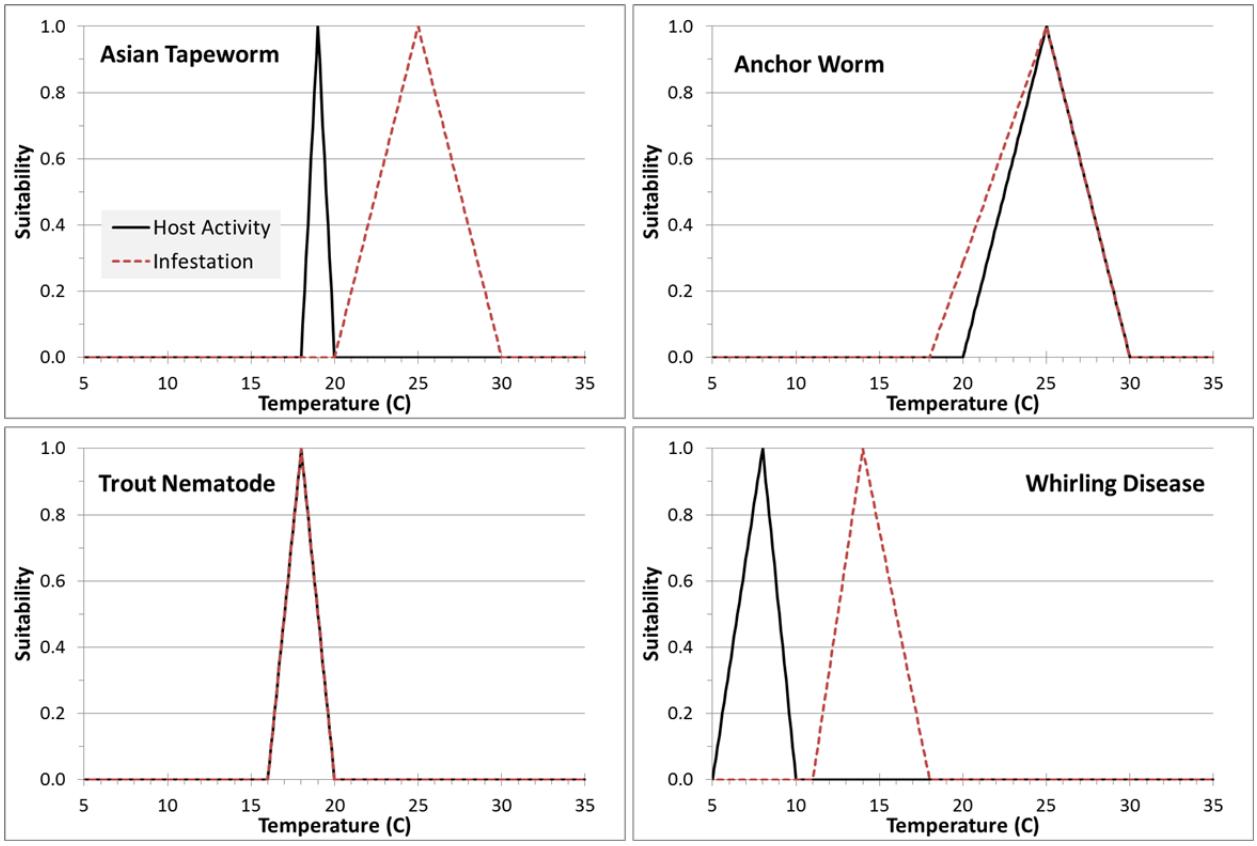

FIGURE F-38 Suitability of Various Water Temperatures for Host Activity and Infestation Rates of Parasite Species (Source: Valdez and Speas 2007)

F.4.5.2 Results for LTEMP Alternatives

Temperature suitability for the four aquatic parasite species (Asian tapeworm, anchor worm, trout nematode, and whirling disease) under the LTEMP alternatives and long-term strategies was modeled for various locations downstream from Glen Canyon Dam. Modeling indicated that temperature suitability for the aquatic parasite species would generally be very low under all long-term strategies and would be comparable to the suitability under current operations as represented by Alternative A (no-action alternative; Figure F-42). As a consequence, the relative distributions of aquatic parasites or the effects of aquatic parasites on survival and growth of native fish or trout species would not be expected to change relative to current conditions under any of the long-term strategies. Under current conditions, population-level effects of parasites on survival and growth of native fish or trout have not been observed. Inclusion of flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by native fish. As a consequence, these flow actions are expected to have minor effects on temperature suitability for the parasite species group and would not alter the relative suitability among the long-term strategies.

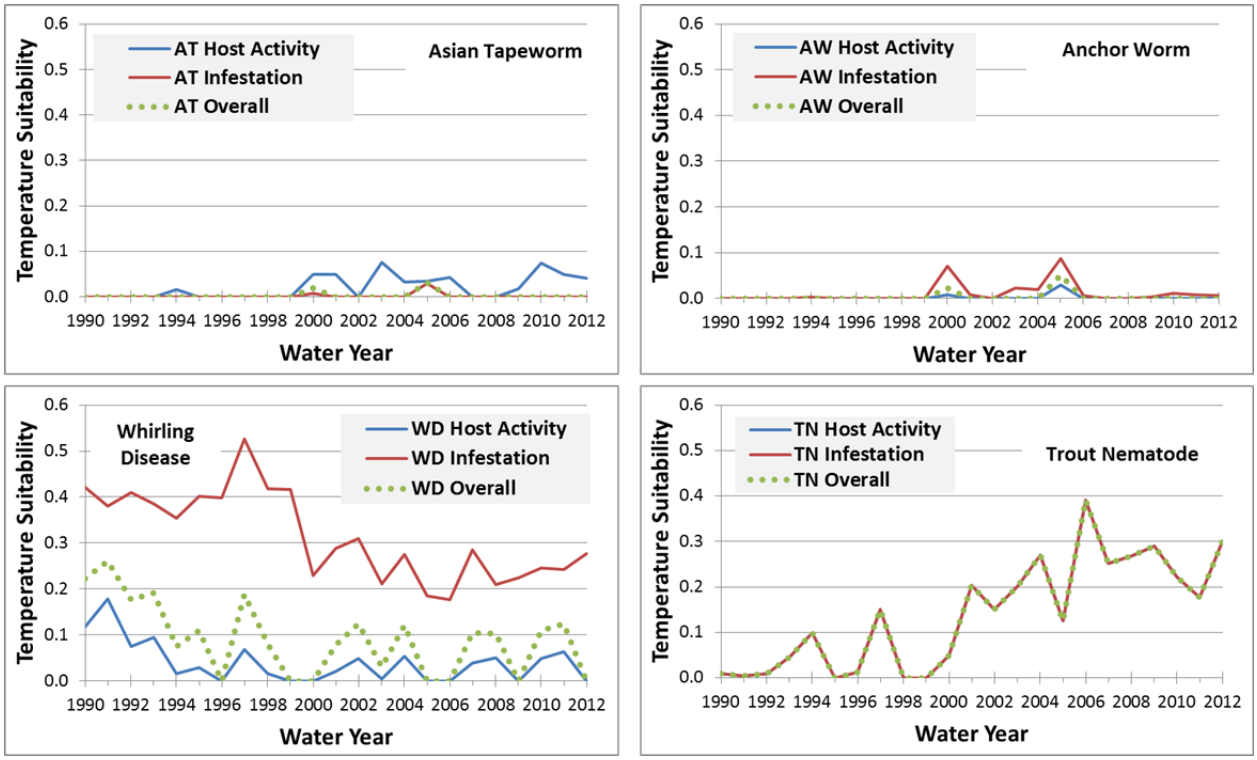

FIGURE F-39 Annual Temperature Suitability Scores for Parasite Species at RM 225 (Diamond Creek) Based on Modeled Water Temperatures for Water Years 1990–2012 (AT = Asian tapeworm; AW = anchor worm; TN = trout nematode; and WD = whirling disease)

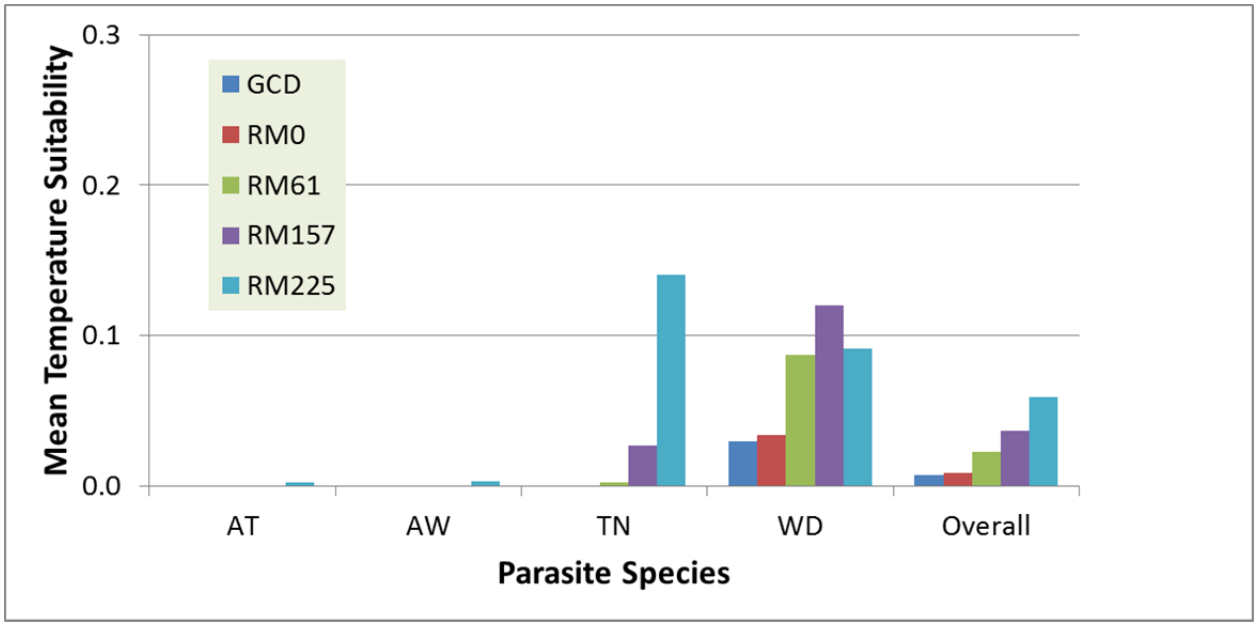

FIGURE F-40 Mean Annual Temperature Suitability Scores for Parasite Species by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 (AT = Asian tapeworm; AW = anchor worm; TN = trout nematode; and WD = whirling disease)

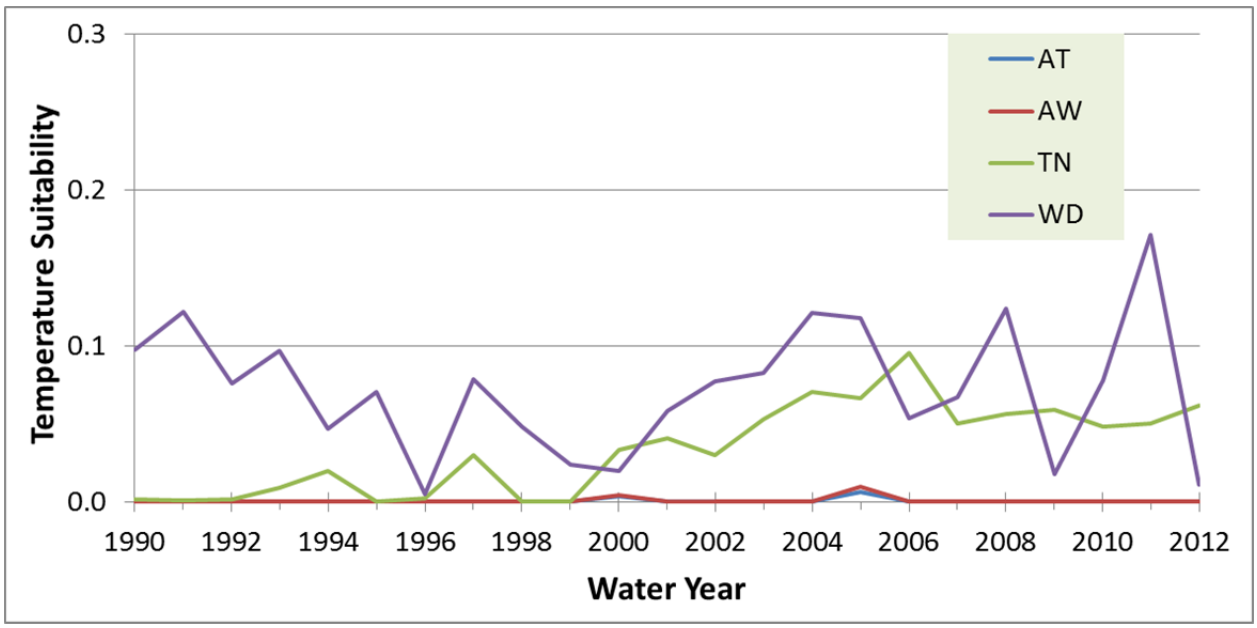

FIGURE F-41 Overall Means of Annual Suitability Scores for Parasite Species across All River Locations during the 1990–2012 Water Years (AT = Asian tapeworm; AW = anchor worm; TN = trout nematode; and WD = whirling disease)

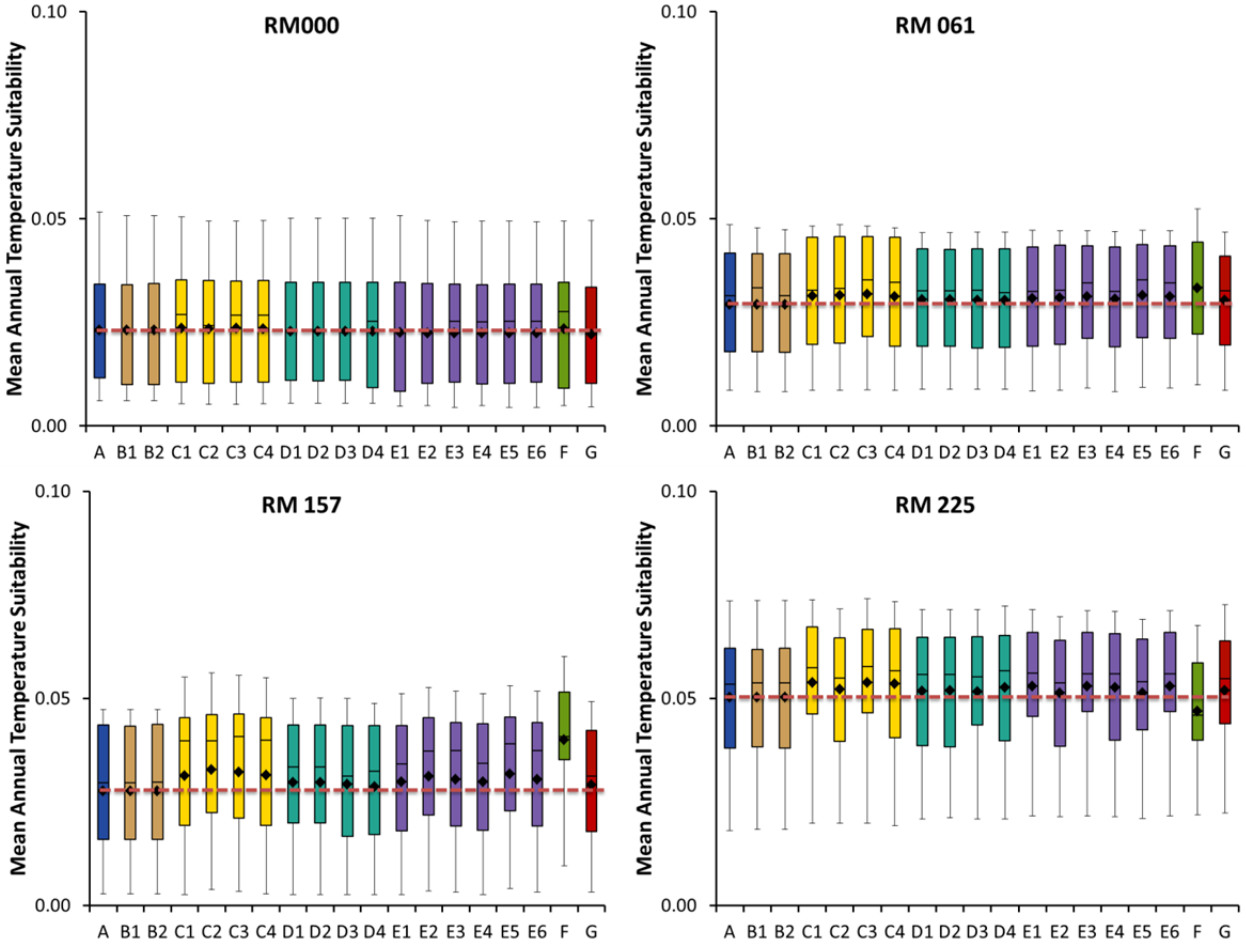

FIGURE F-42 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives and Long-Term Strategies for Aquatic Fish Parasites (Asian tapeworm, anchor worm, trout nematode, and whirling disease) at Four Locations Downstream of Glen Canyon Dam (The graph shows the mean, median, 75th percentile, 25th percentile, minimum, and maximum values for 21 hydrology scenarios and three sediment scenarios. Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum; horizontal dashed line identifies mean value for Alternative A.)

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APPENDIX G:

VEGETATION TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX G:

VEGETATION TECHNICAL INFORMATION AND ANALYSIS

G.1 ANALYSIS METHODS

The analysis of impacts on plant communities is primarily based on the evaluation of four performance metrics that were developed for the Long-Term Experimental and Management Plan (LTEMP) assessment process. The metrics are calculated using the results of an existing state and transition model for Colorado River riparian vegetation downstream from Glen Canyon Dam. Model details are described in Ralston et al. (2014). The four metrics are as follows:

- *Native Cover metric*. Relative change in cover of native vegetation community types (other than arrowweed[1]) on sandbars and channel margins using the total percentage increase in native states (change in native cover = $cover_{final}/cover_{initial}$).

- *Native Diversity metric*. Relative change in diversity of native vegetation community types (other than arrowweed) on sandbars and channel margins using the Shannon-Weiner Index for richness/evenness (change in diversity = $diversity_{final}/diversity_{initial}$).

- *Native/Nonnative Ratio metric*. Relative change in the ratio of native- (other than arrowweed) to nonnative-dominated vegetation community types on sandbars and channel margins (change in native/nonnative ratio = $ratio_{final}/ratio_{initial}$).

- *Arrowweed metric.* Relative change in the arrowweed state on sandbars and channel margins using the total percentage decrease in arrowweed states (change in arrowweed = $arrowweed_{initial}/arrowweed_{final}$).

These performance metrics were developed from the resource goal for riparian vegetation downstream from Glen Canyon Dam: *Maintain native vegetation and wildlife habitat, in various stages of maturity, that is diverse, healthy, productive, self-sustaining, and ecologically appropriate*.

The state and transition model was developed to compare the effects of various flow regimes on Colorado River riparian vegetation. Seven vegetation states are used in the model to represent plant community types found along the river on sandbars and channel margins in the new high-water zone and fluctuation zone. Species associated with a state respond similarly to Colorado River hydrologic factors, such as depth, timing, and duration of inundation. These

[1] This species was selected to be excluded from the native species metrics and to be a fourth metric. It is managed differently from other native species because of its tendency to rapidly establish on sandbars to the exclusion of other species.

states and the plant species associated with each are given in Table G-1. The model and data used to calculate performance metrics are based on vegetation studies conducted within Grand Canyon National Park and may have limited application to riparian vegetation communities within Glen Canyon. The model consists of six submodels based on landforms: lower separation bar, upper separation bar, lower reattachment bar, upper reattachment bar, lower channel margin, and upper channel margin. Upper and lower bars are divided at the 25,000-cfs flow stage.

The model uses the daily maximum flow from the GTMax-Lite 2 hydrograph (GTMax-Lite 2 includes hourly flows for the entire 20-yr flow period); it does not include daily fluctuations (the range in flows within a day). A total of 63 hydrology-sentiment trace combinations were included in the analysis of each alternative and long-term strategy. Within each run of each alternative, the model identifies the occurrence of hydrologic events, such as spill flows, spring and fall high-flow experiments (HFEs), extended low flows, extended high flows, and growing or nongrowing seasons without extended high or low flows, occurring during the growing season (May–September) or nongrowing season (October–March) (see Table G-2). The model then records transitions between vegetation states, based on a set of rules developed for each submodel, driven by these hydrologic events. The model includes a subset of states and transition rules for each bar type and channel margin type. The transition rules for the upper portions of the bars and channel margins are the same because of the similarity of plant community types and responses to flow characteristics. The transition rules are based on the effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species. The interrelationships among vegetation states were developed primarily from published vegetation studies based on data collected in Grand Canyon National Park (see Ralston et al. 2014 and citations therein). A subject matter expert team refined the transitions based on extensive field experience in the Colorado River riparian system. Transition rules for the submodels are given in Table G-3. Although the model is a simplification of the complexities of the riparian ecosystem, it is a valuable tool for estimating the changes in riparian vegetation under a variety of flow regimes.

Model results include the total number of years each state occurs for the 20-yr period of the model run, according to each potential starting state in each submodel (i.e., the number of years each feature is in each state, based on the transition rules). Each model run starts with each potential state of each submodel, shown in Table G-1. For example, the lower reattachment bar submodel uses five different starting states for each hydrologic trace: bare sand, *Phragmites australis* Temperate Herbaceous Vegetation, *Equisetum hyemale* Herbaceous Vegetation, Tamarisk Temporarily Flooded Shrubland, and *Pluchea sericea* Seasonally Flooded Shrubland. Therefore, five model runs, each with a different starting state, are made with the reattachment bar submodel for each trace.

G.1.1 Old High-Water Zone Analysis

Plant communities of the old high-water zone are not included in the riparian state and transition model. Therefore, a qualitative assessment was conducted to evaluate impacts of alternatives. The old high-water zone vegetation is located at high-flow stage elevations (above 60,000 cfs, but primarily from about 100,000 to approximately 200,000 cfs), well above the level

of current dam operations. Dam operations, other than HFEs, are limited to 31,500-cfs flows (generally will not exceed 25,000 cfs), and HFEs do not exceed 45,000 cfs.

None of the alternatives considered would include flows sufficient to maintain these pre-dam plant communities. HFEs could potentially provide occasional soil moisture to some older deep-rooted plants located in the old high-water zone that are at the lower edge, close to the new high-water zone. Dam releases can affect water availability for plants at elevations up to approximately 15,000 cfs above discharge levels (Melis et al. 2006; Ralston 2005). Alternatives with more frequent spring HFEs—such as Alternative F, with annual spring HFEs, or Alternative G; Alternative C, long-term strategies C1 and C2; and Alternative D, long-term strategies D1–D4, all with considerably more spring HFEs than Alternative A—may result in higher survival rates of plants at lower elevations of the old high-water zone than under Alternative A because of increased moisture within the root zone. The differences between alternatives in effects on the lower margin of the old high-water zone are expected to be minor. Spill flows (between 45,000 and 85,000 cfs) would provide soil moisture to old high-water zone plants; however, these have not occurred since the mid-1980s. Periodic spill flows could occur within the 20-yr period of this evaluation, but would likely be infrequent and would occur equally under all alternatives. Because of a lack of sufficiently high flows and nutrient-rich sediment, mortality of pre-dam plants within this zone has been occurring for decades, along with a lack of seedling establishment for some species, such as mesquite and hackberry (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011). Because of generally continued low soil moisture and lack of recruitment opportunities under all alternatives, the upper margins of this zone would be expected to continue moving downslope, with a continued narrowing of this zone. Desert species occurring on the pre-dam flood terraces and aeolian deposits above the old high-water zone would increasingly establish within this zone. Therefore, the narrowing of the old high-water zone is outside the scope of the LTEMP impact analysis.

G.1.2 New High-Water Zone

The four metrics—(1) relative change in cover of native vegetation community types, (2) relative change in diversity of native vegetation community types, (3) relative change in the ratio of native- to nonnative-dominated vegetation community types, and (4) relative change in the arrowweed state—were calculated from the model results for each alternative and long-term strategy. The four native-dominated states are *Phragmites australis* Temperate Herbaceous Vegetation, *Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation, *Populus fremontii*/*Salix exigua* Forest, and *Prosopis glandulosa* var. *torreyana* Shrubland. Two of these states, both of which represent wetland community types, are further discussed below. Although arrowweed is a native species, because of its invasive characteristics and tendency to form monocultures, the *Pluchea sericea* Seasonally Flooded Shrubland state is excluded from the native states in the performance metrics.

Model results were used to calculate the performance metrics for each alternative/long-term strategy using the sum of years of each of the states for all six models. This value was then compared to the number of years each state would have accumulated if the current condition was maintained (i.e., if no transitions occurred and each of the seven states remained the same for the

full 20 yr of the model run). This proportion was then multiplied by the acreage of mapped cover types from the National Park Service Vegetation Map of Grand Canyon National Park (Table G-4) corresponding to the seven model states (Table G-5). This final acreage and the initial mapped acreage were then used to calculate the performance metrics.

The results for the four metrics were then summed to derive a final score for each alternative long-term strategy. Alternatives with higher scores were considered to have come closer to achieving the resource goal.

The 63 hydrology-sediment trace combinations used in the model runs were developed from the historical record (see Section 4.2 of the EIS for a detailed description). Twenty-one potential Lake Powell inflow scenarios for the 20-yr LTEMP period were sampled from the 105-yr historic record (water years 1906–2010), producing 21 hydrology traces for analysis. In addition, three 20-yr sequences of sediment input from the Paria River sediment record (water years 1964–2013) were analyzed. In combination, the analysis considered 63 possible hydrology-sediment scenarios. An assumption underlying the model results is that future river flows will be similar to past flows. To examine the effect of potential climate change, each of the traces used in the model runs was then differentially weighted (see Section 4.17.1.2). Weights were developed based on climate change projections of the 2012 Colorado River Basin Water Supply and Demand Study (Reclamation 2012). These assigned weights thus reflect the likelihood of occurrence of each hydrology trace under potential future climate change, emphasizing the drier scenarios. The model result for each trace was then multiplied by the assigned weight.

G.1.2.1 Native Cover Metric

The first metric is the relative change in cover of native vegetation community types (other than arrowweed) on sandbars and channel margins, calculated by using the total percentage increase in native states (change in native cover = $cover_{final}/cover_{initial}$).

The results for the Native Cover metric based on historical flows are shown in Figure G-1. The two highest scoring long-term strategies, E6 and E3, are significantly different from the others (differences between means of the 63 traces based on a three-factor ANOVA followed by Tukey's Studentized Range [HSD] Test) but not from each other. Results under projected climate change are similar to those for historical flows (all alternatives score slightly higher) and are shown in Figure G-2. Thus the relative performance of each alternative under climate change would be similar to that modeled under historical conditions.

To illustrate the relative change in native cover, the modeled acreage changes for several alternatives/long-term strategies are shown in Table G-6.

Native states tend to increase with growing and nongrowing seasons without extended high or low flows. Bare Sand, Tamarisk Temporarily Flooded Shrubland, and *Pluchea sericea* Seasonally Flooded Shrubland tend to increase with extended high and extended low flows. The

effect of differences between hydrologic traces is greater than the effect of differences between alternatives.

G.1.2.2 Native Diversity Metric

The second metric is the relative change in diversity of native vegetation community types (other than arrowweed) on sandbars and channel margins, calculated by using the Shannon-Weiner Index for richness/evenness (change in diversity = $\text{diversity}_{final}/\text{diversity}_{initial}$).

The Native Diversity metric is calculated using the Shannon-Weiner Index for richness/evenness: $-\Sigma(p_i)(\log_2 p_i)$, where p_i is the proportion of the i-th state of the total native cover. The calculations use the initial mapped cover and final (modeled) cover of each of the four native-dominated states. The results for the Native Diversity metric based on historical flows are shown in Figure G-3. the two highest scoring alternatives—Alternative E, long-term strategy E4, and Alternative B, long-term strategy B1—are not significantly different from each other (differences between means based on a three-factor ANOVA followed by Tukey's Studentized Range [HSD] Test); long-term strategy B1 is not significantly different from long-term strategies D3 and D2. Results under projected climate change are similar to those for historical flows, with 11 alternatives showing a slight increase and 8 a slight decrease, and are shown in Figure G-4. thus the performance of each alternative under climate change would be similar to that modeled under historical conditions. The results for all alternatives include all states. Therefore, there is no difference in the number of states between alternatives; diversity is increased by the evenness of states. For example, long-term strategy B2 and Alternative F, which are somewhat lower scoring, have a low representation of the *Phragmites australis* Temperate Herbaceous Vegetation state, while long-term strategies B1 and E4, somewhat higher scoring, have a relatively high representation of that state. The transition to the *Phragmites australis* Temperate Herbaceous Vegetation state from the bare sand state in the lower reattachment bar is slowed by growing-season extended high flows, and growing-season extended low or high flows contribute to transitions of the *Phragmites australis* Temperate Herbaceous Vegetation state to other states. The effect of differences between alternatives is greater than the effect of differences between hydrologic traces.

G.1.2.3 Native/Nonnative Ratio Metric

The third metric is the relative change in the ratio of native- (other than arrowweed) to nonnative-dominated vegetation community types on sandbars and channel margins (change in native/nonnative ratio = $\text{ratio}_{final}/\text{ratio}_{initial}$).

The Native/Nonnative Ratio metric is calculated using the ratio of the cover of each of the four native-dominated states to the cover of the tamarisk state. The ratio of the final (modeled) cover is then divided by the ratio of the initial mapped cover. The results for the Native/Nonnative Ratio metric based on historical flows are shown in Figure G-5. the three highest-scoring long-term strategies, E6, E3, and E5, are not significantly different from each other (between means based on a three-factor ANOVA followed by Tukey's Studentized

Range [HSD] Test); long-term strategy E5 is not significantly different from long-term strategy B1. Results under projected climate change are similar to those for historical flows (all alternatives score slightly higher) and are shown in Figure G-6. Thus the performance of each alternative under climate change would be similar to that modeled under historical conditions.

Native states tend to increase with growing and nongrowing seasons without extended high or low flows. The tamarisk state tends to increase with extended high flows followed by extended low flows, as well as spring HFEs with an extended low or high flow. Under Alternative C, long-term strategy C1, and Alternative F, high flows shift all states to sand, which then shifts to tamarisk (e.g., lower reattachment bar, growing-season extended low).

G.1.2.4 Arrowweed Metric

The fourth metric is the relative change in the arrowweed state on sandbars and channel margins, calculated by using the total percentage decrease in arrowweed states (change in arrowweed = $\text{arrowweed}_{initial}/\text{arrowweed}_{final}$).

The results for the Arrowweed metric based on historical flows are shown in Figure G-7. The two highest scoring long-term strategies, C1 and C2, are not significantly different from each other (between means based on a three-factor ANOVA followed by Tukey's Studentized Range [HSD] Test); long-term strategy C2 is not significantly different from Alternatives F and G. Results under projected climate change are similar to those for historical flows (all alternatives score slightly lower) and are shown in Figure G-8. Thus the performance of each alternative under climate change would be similar to that modeled under historical conditions (Alternative F would be the highest scoring, however).

To illustrate the relative change in arrowweed, acreage changes for several alternatives/long-term strategies are shown in Table G-7.

The arrowweed state tends to increase with extended high and extended low flows, but this increase can be slowed by fall HFEs. The effect of differences between hydrologic traces is greater than the effect of differences between alternatives.

G.1.2.5 Overall Score

The results for the overall score based on historical flows are shown in Figure G-9. The six highest scoring long-term strategies, D4, E4, E6, E3, E5, and B1, are not significantly different from each other (between means based on a three-factor ANOVA followed by Tukey's Studentized Range [HSD] Test); long-term strategies E5 and B1 are not significantly different from long-term strategy E2. These alternatives included the five highest scores in the Native Cover metric and Native/Nonnative Ratio metric. The lowest scoring is long-term strategy C3, which is the lowest in the Arrowweed metric and consistently low scoring in the other metrics. Results under projected climate change are similar to those for historical flows, with four alternatives showing a slight decrease and all others a slight increase, and are shown in

Figure G-10. thus the performance of each alternative under climate change would be similar to that modeled under historical conditions.

For the overall score, the effects of the differences between alternatives are greater than the effects of differences between hydrologic traces; sediment traces 1 and 2 are significantly different.

The following is a review of the components of the overall score:

- *Native Cover metric*. Long-term strategies E6 and E3 are the highest scoring; native states tend to increase with growing and nongrowing seasons without extended high or low flows.

- *Native Diversity metric*. Long-term strategies E4 and B1 are the highest scoring. The transition to the *Phragmites australis* Temperate Herbaceous Vegetation state from the bare sand state in the lower reattachment bar is slowed by growing-season extended high flows, reducing diversity, and growing-season extended low or high flows contribute to transitions of the *Phragmites australis* Temperate Herbaceous Vegetation state to other states.

- *Native/Nonnative Ratio metric*. Long-term strategies E6, E3, and E5 are the highest scoring; the tamarisk state tends to increase with extended high flows followed by extended low flows, as well as spring HFEs with an extended low or high flow.

- *Arrowweed metric*. Long-term strategies C1and C2 are the highest scoring; the arrowweed state tends to increase with extended high and extended low flows.

G.1.3 Wetlands

Two of the model states discussed above represent wetland community types: *Phragmites australis* Temperate Herbaceous Vegetation, a marsh community, and *Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation, a shrub wetland community. These occur on the lower reattachment bar and lower channel margin (as well as lower reattachment bar) (Table G-1) and occupy 4.4 and 0.2 ac, respectively (Table G-5). The relative change in cover of these wetland community types was calculated from the model results using the method described for the Native Cover metric. The results for the 19 alternatives/long-term strategies are presented in Table G-27 and Figure G-11 (a score of 1.0 means no change from initial conditions). Only Alternative E long-term strategies E3, E5, and E6 show an increase in wetland community cover (based on mean scores); all others show a decrease. Decreases of greater than 50% occur under Alternative B, long-term strategy B2; Alternative C; Alternative F; and Alternative G. Results under projected climate change are similar to those for historical flows (all alternatives score slightly higher; however, Alternative F shows only a minimal

increase) and are shown in Figure G-12. Thus the performance of each alternative under climate change would be similar to that modeled under historical conditions.

G.2 ALTERNATIVE-SPECIFIC IMPACTS

This section provides additional information on the impacts of alternatives, specifically the impacts associated with the long-term strategies that were analyzed for condition-dependent alternatives (Alternatives B, C, D, and E). This analysis supplements the information presented in Section 4.6 of the EIS.

G.2.1 Alternative A (No Action Alternative)

Alternative A includes sediment-triggered spring and fall HFEs through 2020 (no spring HFEs until 2015). Alternative A has higher monthly volumes in the high-electricity-demand months of December, January, July, and August. This alternative has fewer spring and fall HFEs than other alternatives, occasional extended low flows, and more frequent extended high flows than most other alternatives, the last being particularly frequent in the growing season. The model results for each of the metrics as well as the overall score for Alternative A are presented in Table G-8.

G.2.2 Alternative B

Alternative B includes spring and fall HFEs (the number of HFEs not to exceed one every other year). This alternative lacks low summer flows and has higher monthly volumes December–January and July–August. Alternative B has few spring HFEs, similar to Alternative A, but more fall HFEs than Alternative A. The expected number of HFEs would be lower under this alternative than under any other. Alternative B has the same monthly pattern in release volume as Alternative A; however, Alterative B has no extended low flows; long-term strategy B1 has a slightly greater frequency of extended high flows compared to Alternative A; and long-term strategy B2 has considerably more extended high flows than long-term strategy B1—far more than any other alternative long-term strategy. The results for Alternative B are presented in Table G-9 for long-term strategy B1 and in Table G-10 for long-term strategy B2.

G.2.3 Alternative C

Alternative C includes spring and fall HFEs in long-term strategies C1 and C2, fall HFEs only in long-term strategy C4, and no HFEs in long-term strategy C3; proactive spring HFEs are tested in April, May, or June in high-volume years. This alternative features low summer flows in some years in long-term strategy C2 and has highest monthly release volumes December–January and July, and lower volumes August–November. Long-term strategies C1–C4 have more extended low flows and fewer growing-season extended high flows than

Alternative A (although long-term strategies C2–C4 have more growing-season extended high flows than long-term strategy C1); long-term strategy C3 has slightly more nongrowing-season extended high flows than the other Alternative C long-term strategies. Long-term strategies C1 and C2 have considerably more spring and fall HFEs than Alternative A; the number of long-term strategy C4 fall HFEs is similar to those of long-term strategies C1 and C2. The model results for each of the metrics, as well as the overall score for Alternative C, are presented in Table G-11 for long-term strategy C1; in Table G-11 in Table G-12 for C2, in Table G-13 for C3, and in Table G-14 for C4.

G.2.4 Alternative D (Preferred Alternative)

Alternative D includes spring (March–April) and fall (October–November) HFEs; proactive spring HFEs (24 hr, 45,000 cfs) would be tested (April, May, or June) in high-volume years; no spring HFEs the first 2 yr; and extended-duration fall HFEs (up to 250-hr duration, up to 45,000 cfs), up to four in a 20-yr period. As a result, Alternative D has a greater frequency of fall and spring HFEs compared to Alternative A. Monthly water volumes would be similar to Alternative E, but August and September would have higher volumes and January–July would have slightly lower volumes than Alternative E. A 2- or 3-yr test for invertebrate production would reduce flows to the minimum for the month on Saturdays and Sundays in May–August starting the third year of the LTEMP period. If successful, these flows would be implemented for the remainder of the LTEMP period (up to 18 yr total), resulting in few, if any, growing-season extended high flows during those years. Low summer flows (July–September) would be tested in two or three of the second 10 yr. This alternative has very few growing-season extended low flows, as well as slightly fewer nongrowing-season extended low or high flows, because of the monthly pattern of flows as well as the amount of daily fluctuations. Alternative D has frequent growing-season extended high flows but not as many as Alternative A. Seasons, especially nongrowing seasons, without extended low or high flows are frequent. The model results for each of the metrics as well as the overall score for Alternative D are presented in Table G-15 for long-term strategy D1, in Table G-16 for D2, in Table G-17 for D3, and in Table G-18 for D4.

G.2.5 Alternative E

Alternative E includes spring and fall HFEs; no spring HFEs in the first 10 yr; rapid response tested every fourth HFE matching Paria flood; spring and fall HFEs in long-term strategies E1 and E2; fall HFEs only in long-term strategy E4; and no HFEs in long-term strategies E3, E5, and E6. This alternative has lower monthly water volumes in August, September, and October. Low summer flows occur in some years (triggered) of the second 10 yr in long-term strategies E2 and E5. Long-term strategies E1–E6 have fewer growing-season extended high flows than Alternative A (long-term strategies E2 and E5 have slightly more than the other Alternative E long-term strategies) and more HFEs than Alternative A. Long-term strategies E1 and E2 have similar numbers of HFEs; the number of fall HFEs for long-term strategy E4 is similar to those for long-term strategies E1 and E2. The model results for each of the metrics as well as the overall score for Alternative E are presented in Table G-19 for long-

term strategy E1, in Table G-20 for E2, in Table G-21 for E3, in Table G-22 for E4, in Table G-23 for E5, and in Table G-24 for E6.

G.2.6 Alternative F

Alternative F includes spring and fall HFEs; peak flows in May and June; base flows July–January; and a 168-hr (7-day) 25,000-cfs flow at the end of June. This alternative also features higher volumes than Alternative A April–June and lower volumes than Alternative A in the other months. This alternative has more extended low flows, slightly fewer extended high flows, and considerably more HFEs than Alternative A (more than any other alternative). The model results for each of the metrics as well as the overall score for Alternative F are presented in Table G-25.

G.2.7 Alternative G

Alternative G includes spring and fall HFEs; HFEs for up to 336 hr (2 weeks); proactive spring HFEs tested in high-volume years; and monthly volumes varying only in response to runoff forecast and other requirements. This alternative has more extended low flows and fewer extended high flows than Alternative A. The model results for each of the metrics, as well as the overall score for Alternative G, are presented in Table G-26.

G.3 SUMMARY

Transitions between plant community types, or to bare sand, are driven by specific flow events that vary among the alternatives. Spring HFEs, fall HFEs, spill flows, extended low flows, extended high flows, and seasons without extended high or low flows occurring during the growing or nongrowing season result in changes in the distribution and cover of new high-water zone plant communities.

HFEs result in sediment deposition, but scouring is minor and limited to low-elevation wetland species. HFEs transport seeds of nonnative as well as native species. Repeated extended high flows result in removal of vegetation by drowning and scouring, primarily on lower elevation surfaces. Increased soil moisture at upper elevations from extended high flows can increase vegetation growth and seedling establishment. The germination of seeds transported by HFEs or extended high flows is promoted by extended low flows (e.g., elevated base flows) that reduce disturbance, expose lower elevation surfaces, and maintain soil moisture at lower elevations, all of which are conducive to seedling growth. Extended low flows also can result in the lowering of groundwater levels, thus increasing the depth to groundwater and reducing soil moisture, creating conditions that favor the growth of more drought-tolerant species.

Repeated seasons of extended high flows, extended high flows above 50,000 cfs, or spill flows transition native communities to bare sand through the processes of drowning, scouring, and burial. All the alternatives would result in a decrease in native plant community cover.

Wetland communities generally transition only from bare sand or other wetlands; they can transition back to bare sand or to arrowweed, tamarisk, or cottonwood-willow communities. Alternatives that include frequent extended low flows, such as annually for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases for Alternative F.

The overall cover of tamarisk-dominated communities would be expected to increase under Alternatives C, F, and G, each of which is expected to produce frequent transitions to tamarisk communities, in large part because they frequently have extended high flows, extended low flows, and spring HFEs. This combination of flows encourages transitions to tamarisk because tamarisk increases when high flows coincide with seed release during spring and early summer, followed by lower flows, all of which results in establishment of seedlings above the elevation of subsequent floods. Also, under these alternatives, various community types frequently shift to bare sand, which then shifts to tamarisk. Each of these alternatives has more extended low flows and more spring HFEs than the other alternatives. The overall cover of the tamarisk is expected to decrease under Alternatives A, B, D, and E. Each of these alternatives has frequent extended high flows, which result in consecutive seasons and consecutive years of extended high flows. Two or more years of extended high flows are required for tamarisk to be removed by drowning, leaving a bare sand lower reattachment bar, or two consecutive seasons on a lower separation bar.

The overall cover of the arrowweed community would be expected to increase under Alternatives A, B, and E; under these alternatives, bare sand would transition to arrowweed rather than tamarisk because there are few spring HFEs and/or few growing-season extended high flows, both of which promote the establishment of tamarisk on bare sand, and, except in Alternative B, arrowweed would transition from marsh because of growing-season extended low flows. Once established, arrowweed would tend to remain for many years under these alternatives. HFEs alone are not effective at reducing arrowweed as burial typically results in resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth occurs. Arrowweed would decrease under Alternatives C, D, F, and G, usually by transitioning to bare sand with repeated extended high flows, but often by transitioning to tamarisk.

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TABLE G-1 Vegetation States, Plant Associations, and Corresponding Submodels

Vegetation State	Primary Plant Species	Additional Species	Submodel/Landform
Bare Sand	<1% vegetation		All submodels
Phragmites australis Temperate Herbaceous Vegetation[a]	Common reed (*Phragmites australis*), cattail (*Typha domingensis*, *T. latifolia*)	Common tule (*Schoenoplectus acutus*), creeping bent grass (*Agrostis stolonifera*)	Lower reattachment bar
Salix exigua–Baccharis emoryi Shrubland/ *Equisetum laevigatum* Herbaceous Vegetation[a]	Horsetail (*Equisetum laevigatum*), coyote willow (*Salix exigua*), *Baccharis emoryi*, *Schoenoplectus pungens*	*Eleocharis palustris, Muhlenbergia asperifolia*	Lower channel margin, lower reattachment bar
Tamarix spp. Temporarily Flooded Shrubland[b]	Tamarisk (*Tamarix* spp.)		All submodels
Populus fremontii/Salix exigua Forest[a]	Coyote willow, cottonwood (*Populus fremontii*)	*Salix gooddingii, Baccharis salicifolia, Distichlis spicata, Muhlenbergia asperifolia, Phragmites australis*, *Equisetum* spp., *Juncus spp.*, *Carex* spp., *Elaeagnus angustifolia, Tamarix* spp., *Poa pratensis, Melilotus* spp.	Lower channel margin, lower separation bar
Pluchea sericea Seasonally Flooded Shrubland	Arrowweed (*Pluchea sericea*)	*Baccharis* spp., *Mesquite* (*Prosopis glandulosa*), coyote willow	Lower reattachment bar, upper separation bar, upper reattachment bar, upper channel margin
Prosopis glandulosa var. *torreyana* Shrubland[a]	Mesquite (*Prosopis glandulosa* var. *torreyana*)	*Baccharis* spp., *Pluchea sericea*	Lower channel margin, upper separation bar, upper reattachment bar, upper channel margin

[a] Native-dominated states used in the metric calculations.

[b] Nonnative-dominated state used in the metric calculations.

Source: Ralston et al. (2014).

TABLE G-2 Hydrologic Events Considered in the Riparian Vegetation Model

Event	Flow Range	Timing
Spill flow[a]	>45,000 cfs one day or more	Any month
Spring HFE	>31,500 cfs to ≤45,000 cfs, less than 30 days[b]	March–June
Fall HFE	>31,500 cfs to ≤45,000 cfs, less than 30 days[b]	October–December
Extended low flow	≤10,000 cfs for at least 30 consecutive days	Growing season; nongrowing season
Extended high flow	≥20,000 cfs to ≤45,000 cfs for at least 30 consecutive days	Growing season; nongrowing season
Growing or nongrowing seasons without extended high or low flows	Flows that can fluctuate up to 25,000 cfs (i.e., the absence of spill flows or extended high or extended low flows)	Growing season; nongrowing season

[a] Spill flows (i.e., flows that include releases through the spillway and total >45,000 cfs) are not a function of the alternatives, but rather a function of annual hydrology. These do not differ among the alternatives.

[b] A peak or spike in flow between 31,500 and 45,000 cfs that begins or ends below 31,500 cfs is considered an HFE.

TABLE G-3 Riparian Vegetation Model Transition Rules

Transition	From	To	Trigger	Notes
Upper Separation Bar				
T1	Bare Sand	*Pluchea sericea* Seasonally Flooded Shrubland	*Pluchea* cover[a] = 30%	*Pluchea* growth variable (before T1 transition): cover starts at 1% in bare sand frame; nongrowing-season extended low flow or season without extended high or low flow + growing-season extended low flow or season without extended high or low flow same year = 5%; nongrowing-season extended low flow or season without extended high or low flow + growing-season extended high flow same year = 7.5%; nongrowing-season extended high flow + growing-season extended low flow or season without extended high or low flow same year = 7.5%; nongrowing-season extended high flow + growing-season extended high flow same year = 10%; fall HFE same year = increase × 0.5.
T2	Bare Sand	Tamarisk Temporarily Flooded Shrubland	Spring HFE + growing-season extended high flow same year	*Pluchea* cover must be ≤10%.
T3	Tamarisk Temporarily Flooded Shrubland	*Prosopis glandulosa* var. torreyana Shrubland	*Prosopis* cover = 25%	*Prosopis* growth variable (before T3 transition): cover starts at 0% in tamarisk frame; spring HFE + growing season without extended high or low flow same year = +2%; spring HFE + growing-season extended high flow same year = +2%; growing-season extended low flow = −0.5%.
T4	Tamarisk Temporarily Flooded Shrubland, *Pluchea sericea* Seasonally Flooded Shrubland, or *Prosopis glandulosa* var. *torreyana* Shrubland	Bare Sand	Spill flow; *or* any season extended high flow >50K cfs	Extended high flow must be >50K cfs.

TABLE G-3 (Cont.)

Transition	From	To	Trigger	Notes
Lower Separation Bar				
T1	Bare Sand	*Populus fremontii/Salix exigua* forest	*Populus/Salix* cover = 20%	*Populus/Salix* growth variable (before T1 transition): cover starts at 1% in S1 frame; nongrowing season without extended high or low flow + growing season without extended high or low flow same year = +3%; nongrowing-season extended high flow + growing season without extended high or low flow same year = cover × 0.5.
T2	Bare Sand	Tamarisk Temporarily Flooded Shrubland	Nongrowing-season extended high flow + growing-season extended low flow same year; *or* spring HFE + growing-season extended low flow same year	
T3	Tamarisk Temporarily Flooded Shrubland or *Populus fremontii*/*Salix exigua* Forest	Bare Sand	Nongrowing-season or growing-season spill flow; *or* nongrowing-season extended high flow + growing-season extended high flow same year; *or* growing-season extended high flow + nongrowing-season extended high flow next year	
Lower Reattachment Bar				
T1	Bare Sand	*Phragmites australis* Temperate Herbaceous Vegetation	*Phragmites* cover = 20%	*Phragmites* growth variable (before T1 transition): growing season without extended high or low flow = +10%; growing-season extended high flow set to 0.

TABLE G-3 (Cont.)

Transition	From	To	Trigger	Notes
Lower Reattachment Bar (Cont.)				
T2	*Phragmites australis* Temperate Herbaceous Vegetation	*Salix exigua-Baccharis emoryi* shrubland/*Equisetum laevigatum* Herbaceous Vegetation	Growth variable = 4 (see "Notes" column of this table for growth variable calculation)	*Salix-Baccharis/Equisetum* growth variable (before T2 transition): nongrowing season without extended high or low flow + growing season without extended high or low flow same year = +1; fall HFE or spring HFE = −1; any season extended high flow sets to 0. Values are not additive within a year; e.g., fall HFE + spring HFE in same year is still −1. Nongrowing-season extended low flow = season without extended high or low flow.
T3	*Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation	Tamarisk Temporarily Flooded Shrubland	Nongrowing-season extended high flow + growing-season extended low flow same year; *or* growing-season extended high flow + next year growing-season extended low flow	
T4	*Phragmites australis* Temperate Herbaceous Vegetation, or *Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation, or *Pluchea sericea* Seasonally Flooded Shrubland	Bare Sand	Nongrowing-season extended high flow + growing-season extended high flow same year; *or* growing-season extended high flow + nongrowing-season extended high flow next year; *or* growing-season extended high flow + growing-season extended high flow next year; *or* any spill flow	
T5	*Phragmites australis* Temperate Herbaceous Vegetation	Tamarisk Temporarily Flooded Shrubland	Nongrowing-season extended high flow + growing-season extended low flow same year *or* growing-season extended high flow + growing-season extended low flow next year	

TABLE G-3 (Cont.)

Transition	From	To	Trigger	Notes
Lower Reattachment Bar (Cont.)				
T6	Tamarisk Temporarily Flooded Shrubland	Bare Sand	Growing-season extended high flow + nongrowing-season extended high flow in sequence of 4; *or* growing-season extended high flow in sequence of 4; *or* any season spill flow	Does not have to be same year.
T7	Bare Sand	Tamarisk Temporarily Flooded Shrubland	Growing-season extended low flow	
T8	*Pluchea sericea* Seasonally Flooded Shrubland	Tamarisk Temporarily Flooded Shrubland	Growing-season extended high flow + growing-season extended low flow the next year *or* nongrowing-season extended high flow + growing-season extended low flow same year	
T9	*Phragmites australis* Temperate Herbaceous Vegetation	*Pluchea sericea* Seasonally Flooded Shrubland	Growing-season extended low flow	*Not* if nongrowing-season extended high flow same year (then *Phragmites* transitions to tamarisk).
Lower Channel Margin				
T1	Bare Sand	*Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation	Growth variable = 4 (see *Notes* for growth variable calculation)	*Salix-Baccharis/Equisetum* growth variable (before T1 transition): nongrowing season without extended high or low flow + growing season without extended high or low flow same year = +1; growing-season extended low flow = −1; fall HFE or spring HFE = −1; any season extended high flow sets to 0. Values are not additive within a year; e.g., fall HFE + growing-season extended low flow in same year is still −1.

TABLE G-3 (Cont.)

Transition	From	To	Trigger	Notes
Lower Channel Margin (Cont.)				
T2	*Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation	*Populus fremontii/Salix exigua* Forest	Nongrowing-season extended high flow + growing-season extended low flow same year; *or* growing-season extended high flow + next year growing-season extended low flow	
T3	Bare Sand	Tamarisk Temporarily Flooded Shrubland	Nongrowing-season extended high flow + growing-season extended low flow	*Salix-Baccharis/Equisetum* must be ≤2.
T4	Tamarisk Temporarily Flooded Shrubland	*Prosopis glandulosa* var. *torreyana Shrubland*	*Prosopis* cover = 25%	*Prosopis* growth variable (before T4 transition): cover starts at 0% in woody riparian tamarisk frame; spring HFE + growing season without extended high or low flow same year = 2%; spring HFE + growing-season extended high flow = 2%; growing-season extended low flow = −0.5%.
T5	Tamarisk Temporarily Flooded Shrubland, *Populus fremontii*/*Salix exigua* Forest, *Prosopis glandulosa* var. *torreyana* Shrubland	Bare Sand	Any season spill flow; *or* any season extended high flow >50K cfs	Extended high flow must be >50K cfs.
T6	*Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation	Bare Sand	Any season extended high flow >25K cfs	Extended high flow must be >25K cfs.

[a] Percentage cover refers to the overall percentage of a hypothetical geomorphic feature (e.g., lower reattachment bar) beneath a vertical projection of the vegetation canopy.

TABLE G-4 New High-Water Zone and Old High-Water Zone Vegetation Classes Mapped from Lees Ferry to Diamond Creek[a]

Vegetation Class	Dominant Species	Area (ac)
New High-Water Zone		
Phragmites australis Western North America Temperate Semi-natural Herbaceous Vegetation	Cattail, common reed	4.4
Tamarix spp. Temporarily Flooded Semi-natural Shrubland	Tamarisk	273.7
Baccharis spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	*Baccharis* spp., coyote willow, arrowweed	354.7
Prosopis glandulosa var. *torreyana* Shrubland	Western honey mesquite	137.1
Abronia elliptica Herbaceous Dune Vegetation	Fragrant white sand verbena	4.0
Acacia greggii Shrubland	Catclaw acacia	30.4
Arctostaphylos–Quercus turbinella Shrubland Alliance	Bearberry, live oak	2.2
Artemisia bigelovii Shrubland Alliance	Bigelow sagebrush	1.1
Artemisia tridentata Shrubland Alliance	Big sagebrush	2.4
Brickellia longifolia–Fallugia paradoxa–Isocoma acradenia Shrubland	Longleaf brickellbush, Apache plume, goldenbush	65.5
Encelia (*farinosa, resinifera*) Shrubland Alliance	Brittlebush, sticky brittlebush	401.0
Ephedra (*torreyana, viridis*) Mixed Semi-desert Grasses Shrubland	Mormon tea, green ephedra	29.0
Ephedra fasciculate Mojave Desert Shrubland Alliance	Arizona joint-fir	103.6
Ephedra torreyana–Opuntia basilaris Shrubland	Mormon tea, beavertail cactus	64.0
Gutierrezia (*sarothrae, microcephala*)–*Ephedra* (*torreyana, viridis*) Mojave Desert Shrubland Alliance	Snakeweed, broom snakeweed, Mormon tea, green ephedra	14.5
Larrea tridentata–Encelia spp. Shrubland Alliance	Creosote, brittlebush	15.3
Sparsely Vegetated Slickrock	–[b]	5.4
Other[c]	–	5.0

TABLE G-4 (Cont.)

Vegetation Class	Dominant Species	Area (ac)
Old High-Water Zone		
Abronia elliptica Herbaceous Dune Vegetation	Fragrant white sand verbena	5.7
Acacia greggii Shrubland	Catclaw acacia	56.1
Artemisia tridentata Shrubland Alliance	Big sagebrush	1.1
Baccharis spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	*Baccharis* spp., coyote willow, arrowweed	200.2
Brickellia longifolia–Fallugia paradoxa–Isocoma acradenia Shrubland	Longleaf brickellbush, Apache plume, goldenbush	78.5
Encelia (*farinosa, resinifera*) Shrubland Alliance	Brittlebush, sticky brittlebush	438.1
Ephedra (*torreyana, viridis*) Mixed Semi-desert Grasses Shrubland	Mormon tea, green ephedra	41.4
Ephedra fasciculata Mojave Desert Shrubland Alliance	Arizona joint-fir	120.1
Ephedra torreyana–(*Atriplex canescens, Atriplex confertifolia*) Sparse Vegetation	Mormon tea, four-wing saltbush, shadscale	2.1
Ephedra torreyana–Opuntia basilaris Shrubland	Mormon tea, beavertail cactus	109.7
Great Basin and Intermountain Ruderal Dry Shrubland and Grassland Group	–	1.1
Gutierrezia (*sarothrae, microcephala*)–*Ephedra* (*torreyana, viridis*) Mojave Desert Shrubland Alliance	Snakeweed, broom snakeweed, Mormon tea, green ephedra	24.0
Larrea tridentata–Encelia spp. Shrubland Alliance	Creosote, brittlebush	41.4
Pleuraphis rigida Herbaceous Vegetation	Big galleta	1.3
Prosopis glandulosa var. *torreyana* Shrubland	Western honey mesquite	315.9
Sparsely Vegetated Slickrock	–	1.4
Tamarix spp. Temporarily Flooded Semi-natural Shrubland	Tamarisk	224.6
Unvegetated Surfaces and Built-up Areas	–	32.1
Other[c]	–	6.4

Footnotes on next page.

TABLE G-4 (Cont.)

[a] The new high-water Zone and old high-water zone were separated at the 45,000-cfs stage elevation.

[b] – = No dominant species identified.

[c] Includes all vegetation classes with less than 1 ac mapped within the zone.

Source: Kearsley et al. (2015).

TABLE G-5 Vegetation States and Corresponding Mapped Vegetation Types

Vegetation State	Mapped Vegetation Class[a]	Area (ac)
Bare Sand	Unvegetated surfaces and built-up Areas	112
Phragmites australis Temperate Herbaceous Vegetation	*Phragmites australis* Western North America Temperate Semi-natural Herbaceous Vegetation	4.4
Salix exigua Baccharis emoryi shrubland/*Equisetum laevigatum* Herbaceous Vegetation	Arid West Emergent Marsh	0.2
Tamarisk Temporarily Flooded Shrubland	*Tamarix* spp. Temporarily Flooded Semi-natural Shrubland	273.7
Populus fremontii/Salix exigua Forest	*Baccharis* spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	177.3[b]
Pluchea sericea Seasonally Flooded Shrubland	*Baccharis* spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance	177.3[b]
Prosopis glandulosa var. *torreyana* Shrubland	*Prosopis glandulosa* var. *torreyana Shrubland*	137.1

[a] Kearsley et al. (2015), which mapped river miles 0–278; vegetation classes and area are based on 2007 and 2010 aerial photography and do not necessarily reflect current conditions.

[b] The *Baccharis* spp.–*Salix exigua–Pluchea sericea* Shrubland Alliance (354.7 ac) was divided equally between the *Populus fremontii/Salix exigua* Forest state and *Pluchea sericea* Seasonally Flooded Shrubland state.

TABLE G-6 Example Results for the Native Cover Metric[a]

Alternative/ Long-Term Strategy	Final Ara (ac)	Change
E6	307	−12
D4	280	−39
A	264	−55
B2	169	−150

[a] Initial area: 319 ac (based on Kearsley et al. 2015).

TABLE G-7 Example Results for the Arrowweed Metric[a]

Alternative/ Long-Term Strategy	Final Area (ac)	Change
C1, C2	152	−25
D4	160	−17
A	222	45
C3	235	58

[a] Initial area: 177 a\c (based on Kearsley et al. 2015).

TABLE G-8 Results for Alternative A

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.827	0.983	1.051	0.799	3.661
Modeled values	263.8 ac, all four native states (initial cover 319.0 ac)	Modeled diversity 1.065, all four native states (initial diversity 1.083)	Modeled ratio 1.226 (initial ratio 1.166)	221.8 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 55.2 ac	NA	Tamarisk state decrease of 58.4 ac[b]	Arrowweed state increase of 44.5 ac	NA
Percentage change in cover	17.3% reduction in cover of native states	1.7% reduction in diversity of native states[a]	5.1% increase in the native/ nonnative ratio	25.1% increase in the arrowweed state cover	Overall movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-9 Results for Alternative B, Long-Term Strategy B1

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.849	1.027	1.148	0.842	3.865
Modeled values	270.7 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.113, all four native states (initial diversity 1.083)	Modeled ratio 1.338 (initial ratio 1.166)	210.6 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 48.3 ac	NA	Tamarisk state decrease of 71.4 ac[b]	Arrowweed state increase of 33.3 ac	NA
Percentage change in cover	15.1% reduction in cover of native states	2.7% increase in diversity of native states[a]	14.8% increase in the native/ nonnative ratio	18.8% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-10 Results for Alternative B, Long-Term Strategy B2

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0. 529	0.913	0. 869	0. 809	3.120
Modeled values	168.9 ac, all four native states (initial cover 319 ac)	Modeled diversity 0.988, all four native states (initial diversity 1.083)	Modeled ratio 1.013 (initial ratio 1.166)	219.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 150.1 ac	NA	Tamarisk state decrease of 107.0 ac[b]	Arrowweed state increase of 41.9 ac	NA
Percentage change in cover	47.1% reduction in cover of native states	8.7% decrease in diversity of native states[a]	13.1% decrease in the native/ nonnative ratio	23.6% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-11 Results for Alternative C, Long-Term Strategy C1

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.631	0.924	0.457	1.165	3.177
Modeled values	201.3 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.001, all four native states (initial diversity 1.083)	Modeled ratio 0.533 (initial ratio 1.166)	152.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 117.7 ac	NA	Tamarisk state increase of 104.0 ac[b]	Arrowweed state decrease of 25.1 ac	NA
Percentage change in cover	36.9% reduction in cover of native states	7.6% decrease in diversity of native states[a]	54.3% decrease in the native/ nonnative ratio	14.2% decrease in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-12 Results for Alternative C, Long-Term Strategy C2

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.632	0.925	0.463	1.163	3.183
Modeled values	201.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.001, all four native states (initial diversity 1.083)	Modeled ratio 0.540 (initial ratio 1.166)	152.4 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 117.5 ac	NA	Tamarisk state increase of 99.3 ac[b]	Arrowweed state decrease of 24.9 ac	NA
Percentage change in cover	36.8% reduction in cover of native states	7.5% decrease in diversity of native states[a]	53.7% decrease in the native/ nonnative ratio	14.0% decrease in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-13 Results for Alternative C, Long-Term Strategy C3

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.626	0.923	0.529	0.755	2.834
Modeled values	199.8 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.000, all four native states (initial diversity 1.083)	Modeled ratio 0.617 (initial ratio 1.166)	234.9 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 119.2 ac	NA	Tamarisk state increase of 50.1 ac[b]	Arrowweed state increase of 57.6 ac	NA
Percentage change in cover	37.4% reduction in cover of native states; 74.8% reduction in wetland cover	7.7% decrease in diversity of native states[a]	47.1% decrease in the native/ nonnative ratio	32.5% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-14 Results for Alternative C, Long-Term Strategy C4

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.632	0.925	0.533	0.892	2.981
Modeled values	201.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.001, all four native states (initial diversity 1.083)	Modeled ratio 0.621 (initial ratio 1.166)	198.8 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 117.5 ac	NA	Tamarisk state increase of 50.9 ac[b]	Arrowweed state increase of 21.5 ac	NA
Percentage change in cover	36.8% reduction in cover of native states	7.5% decrease in diversity of native states[a]	46.7% decrease in the native/ nonnative ratio	12.1% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-15 Results for Alternative D, Long-Term Strategy D1

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.840	1.017	0.910	0.905	3.671
Modeled values	267.8 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.101, all four native states (initial diversity 1.083)	Modeled ratio 1.061 (initial ratio 1.166)	196.0 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 51.2 ac	NA	Tamarisk state decrease of 21.2 ac[b]	Arrowweed state increase of 18.7 ac	NA
Percentage change in cover	16.0% reduction in cover of native states	1.7% increase in diversity of native states[a]	9.0% decrease in the native/ nonnative ratio	10.5% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-16 Results for Alternative D, Long-Term Strategy D2

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.845	1.019	0.919	0.903	3.686
Modeled values	269.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.103, all four native states (initial diversity 1.083)	Modeled ratio 1.072 (initial ratio 1.166)	196.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 49.5 ac	NA	Tamarisk state decrease of 22.2 ac[b]	Arrowweed state increase of 18.9 ac	NA
Percentage change in cover	15.5% reduction in cover of native states	1.9% increase in diversity of native states[a]	8.1% decrease in the native/ nonnative ratio	10.7% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-17 Results for Alternative D, Long-Term Strategy D3

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.859	1.019	0.930	0.889	3.697
Modeled values	274.0 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.104, all four native states (initial diversity 1.083)	Modeled ratio 1.084 (initial ratio 1.166)	199.5 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 45.0 ac	NA	Tamarisk state decrease of 21.0 ac[b]	Arrowweed state increase of 22.2 ac	NA
Percentage change in cover	14.1% reduction in cover of native states	1.9% increase in diversity of native states[a]	7.0% decrease in the native/ nonnative ratio	12.5% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-18 Results for Alternative D, Long-Term Strategy D4

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.876	1.017	0.954	1.107	3.954
Modeled values	279.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.101, all four native states (initial diversity 1.083)	Modeled ratio 1.112 (initial ratio 1.166)	160.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 39.5 ac	NA	Tamarisk state decrease of 22.4 ac[b]	Arrowweed state decrease of 17.1 ac	NA
Percentage change in cover	12.4% reduction in cover of native states	1.7% increase in diversity of native states[a]	4.6% decrease in the native/ nonnative ratio	9.6% decrease in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-19 Results for Alternative E, Long-Term Strategy E1

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.801	0.979	0.961	0.801	3.541
Modeled values	255.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.060, all four native states (initial diversity 1.083)	Modeled ratio 1.120 (initial ratio 1.166)	221.3 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 63.5 ac	NA	Tamarisk state decrease of 45.7 ac[b]	Arrowweed state increase of 44.0 ac	NA
Percentage change in cover	19.9% reduction in cover of native states	2.1% decrease in diversity of native states[a]	3.9% decrease in the native/ nonnative ratio	24.8% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-20 Results for Alternative E, Long-Term Strategy E2

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.875	1.019	1.067	0.881	3.842
Modeled values	279.3 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.103, all four native states (initial diversity 1.083)	Modeled ratio 1.244 (initial ratio 1.166)	201.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 39.7 ac	NA	Tamarisk state decrease of 49.2 ac[b]	Arrowweed state increase of 23.9 ac	NA
Percentage change in cover	12.5% reduction in cover of native states	1.9% increase in diversity of native states[a]	6.7% increase in the native/ nonnative ratio	13.5% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-21 Results for Alternative E, Long-Term Strategy E3

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.961	0.977	1.227	0.768	3.932
Modeled values	306.5 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.058, all four native states (initial diversity 1.083)	Modeled ratio 1.430 (initial ratio 1.166)	231.0 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 12.5 ac	NA	Tamarisk state decrease of 59.4 ac[b]	Arrowweed state increase of 53.7 ac	NA
Percentage change in cover	3.9% reduction in cover of native states	2.3% decrease in diversity of native states[a]	22.7% increase in the native/ nonnative ratio	30.3% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-22 Results for Alternative E, Long-Term Strategy E4

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.899	1.027	1.124	0.884	3.934
Modeled values	286.8 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.113, all four native states (initial diversity 1.083)	Modeled ratio 1.311 (initial ratio 1.166)	200.6 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 32.2 ac	NA	Tamarisk state decrease of 54.9 ac[b]	Arrowweed state increase of 23.3 ac	NA
Percentage change in cover	10.1% reduction in cover of native states; 9.0% reduction in wetland cover	2.7% increase in diversity of native states[a]	12.4% increase in the native/ nonnative ratio	13.2% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-23 Results for Alternative E, Long-Term Strategy E5

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed Initial Arrowweed/ Final Arrowweed	Overall Score
Mean score (weighted mean for all sediment traces)	0.941	0.977	1.187	0.769	3.875
Modeled final values	300.2 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.058, all four native states (initial diversity 1.083)	Modeled ratio 1.384 (initial ratio 1.166)	230.5 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 18.8 ac	NA	Tamarisk state decrease of 56.9 ac[b]	Arrowweed state increase of 53.2 ac	NA
Percentage change in cover	5.9% reduction in cover of native states	2.3% decrease in diversity of native states[a]	18.7% increase in the native/ nonnative ratio	30.0% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-24 Results for Alternative E, Long-Term Strategy E6

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.961	0.977	1.227	0.768	3.933
Modeled final values	306.7 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.058, all four native states (initial diversity 1.083)	Modeled ratio 1.431 (initial ratio 1.166)	231.0 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 12.3 ac	NA	Tamarisk state decrease of 59.4 ac[b]	Arrowweed state increase of 53.7 ac	NA
Percentage change in cover	3.9% reduction in cover of native states	2.3% decrease in diversity of native states[a]	22.7% increase in the native/ nonnative ratio	30.3% increase in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-25 Results for Alternative F

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.702	0.909	0.381	1.143	3.136
Modeled final values	224.0 ac, all four native states (initial cover 319 ac)	Modeled diversity 0.985, all four native states (initial diversity 1.083)	modeled ratio 0.444 (initial ratio 1.166)	155.1 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 95.0 ac	NA	Tamarisk state increase of 230.7 ac[b]	Arrowweed state decrease of 22.2 ac	NA
Percentage change in cover	29.8% reduction in cover of native states	9.1% decrease in diversity of native states[a]	61.9% decrease in the native/ nonnative ratio	12.5% decrease in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-26 Results for Alternative G

Parameter	Metric 1: Native Cover (Final Cover/ Initial Cover)	Metric 2: Native Diversity (Final Diversity/ Initial Diversity)	Metric 3: Native/ Nonnative Ratio (Final Ratio/ Initial Ratio)	Metric 4: Arrowweed (Initial Arrowweed/ Final Arrowweed)	Overall Score
Mean score (weighted mean for all sediment traces)	0.706	0.967	0.604	1.128	3.405
Modeled final values	225.3 ac, all four native states (initial cover 319 ac)	Modeled diversity 1.047, all four native states (initial diversity 1.083)	Modeled ratio 0.704 (initial ratio 1.166)	157.2 ac arrowweed state (initial cover 177.3 ac)	NA
Change in cover (ac)	Native states decrease of 93.7 ac	NA	Tamarisk state increase of 46.4 ac[b]	Arrowweed state decrease of 20.1 ac	NA
Percentage change in cover	29.4% reduction in cover of native states	3.3% decrease in diversity of native states[a]	39.6% decrease in the native/ nonnative ratio	11.3% decrease in the arrowweed state cover	Movement away from the resource goal

[a] Because the results for each modeled run include the same number of states (each state is a different starting condition for model runs), a reduction in diversity indicates a reduction in evenness among the vegetation states.

[b] A relative increase in native cover or decrease in nonnative cover can increase the ratio.

TABLE G-27 The Effects of LTEMP Long-Term Strategies on Wetlands[a]

Alternative/ Long-Term Strategy	Final Wetland Area (ac)[b]	Relative Change in Wetland Cover	Change in Cover from Initial (ac)	Percentage Change from Initial
A	3.3	0.724	−1.3	−27.6%
B1	3.7	0.800	−0.9	−20.0%
B2	0.8	0.168	−3.8	−83.2%
C1	1.2	0.251	−3.4	−74.9%
C2	1.2	0.254	−3.4	−74.6%
C3	1.2	0.252	−3.4	−74.8%
C4	1.2	0.254	−3.4	−74.6%
D1	3.5	0.751	−1.1	−24.9%
D2	3.5	0.762	−1.1	−23.8%
D3	3.6	0.777	−1.0	−22.3%
D4	3.8	0.836	−0.8	−16.4%
E1	2.9	0.620	−1.7	−38.0%
E2	3.9	0.852	−0.7	−14.8%
E3	5.1	1.099	+0.5	+9.9%
E4	4.2	0.910	−0.4	−9.0%
E5	4.8	1.053	+0.2	+5.3%
E6	5.1	1.101	+0.5	+10.1%
F	0.6	0.139	−4.0	−86.1%
G	2.0	0.425	−2.6	−57.5%

[a] Weighted mean for all sediment traces. Relative change in wetland cover was calculated as *final wetland area*/*initial wetland area* using the initial and final total areas of the two wetland community types: *Phragmites australis* Temperate Herbaceous Vegetation (marsh community) and *Salix exigua-Baccharis emoryi* Shrubland/*Equisetum laevigatum* Herbaceous Vegetation, (shrub wetland community).

[b] Initial wetland area = 4.6 ac.

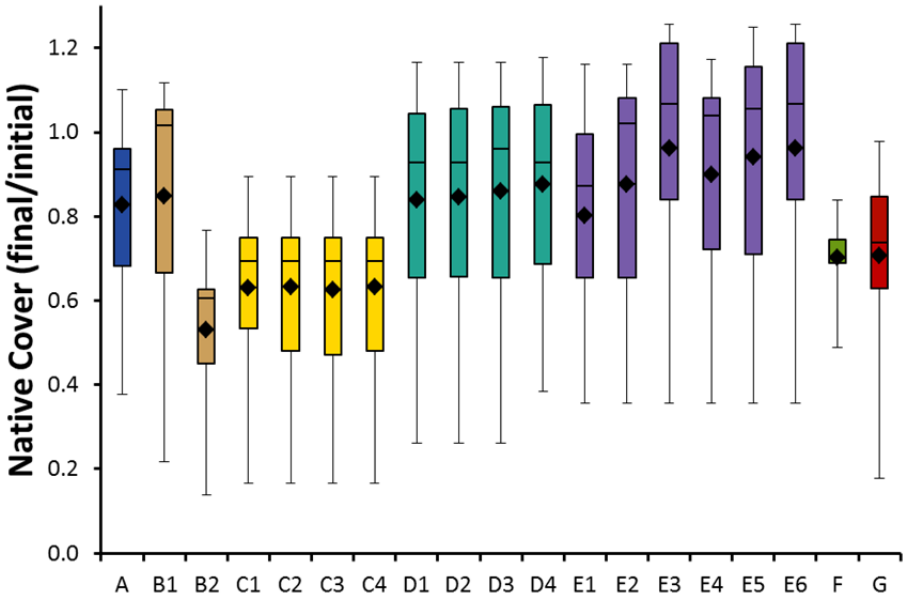

FIGURE G-1 Native Cover Metric for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

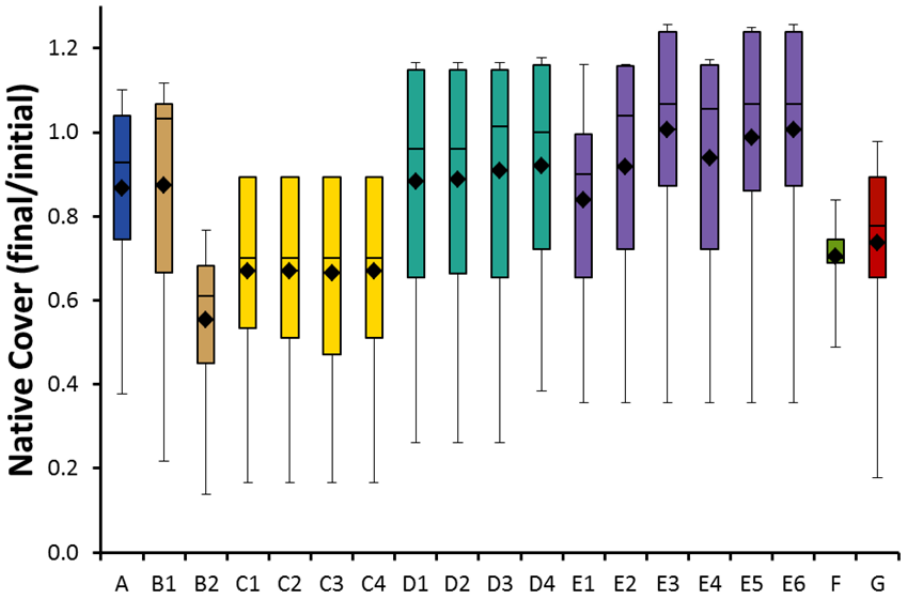

FIGURE G-2 Native Cover Metric under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

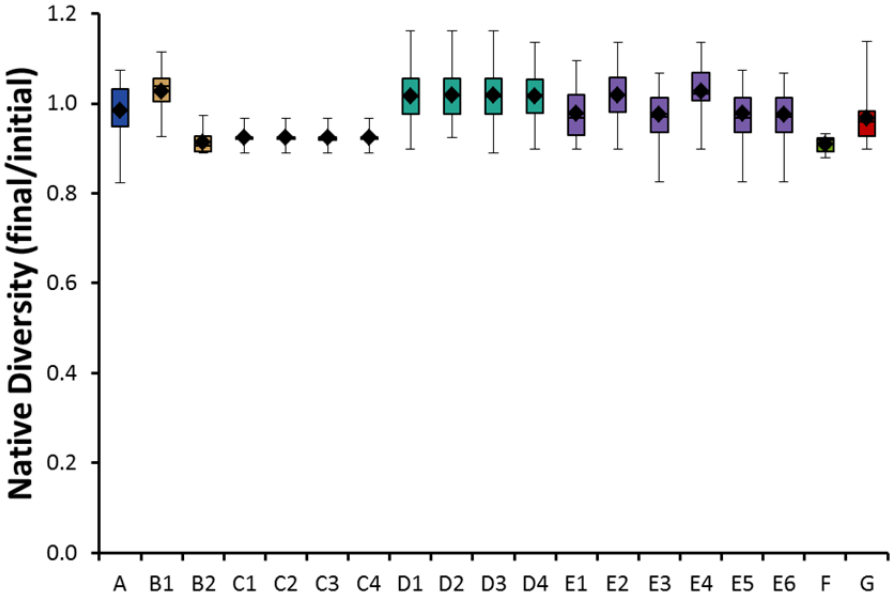

FIGURE G-3 Native Diversity Metric for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

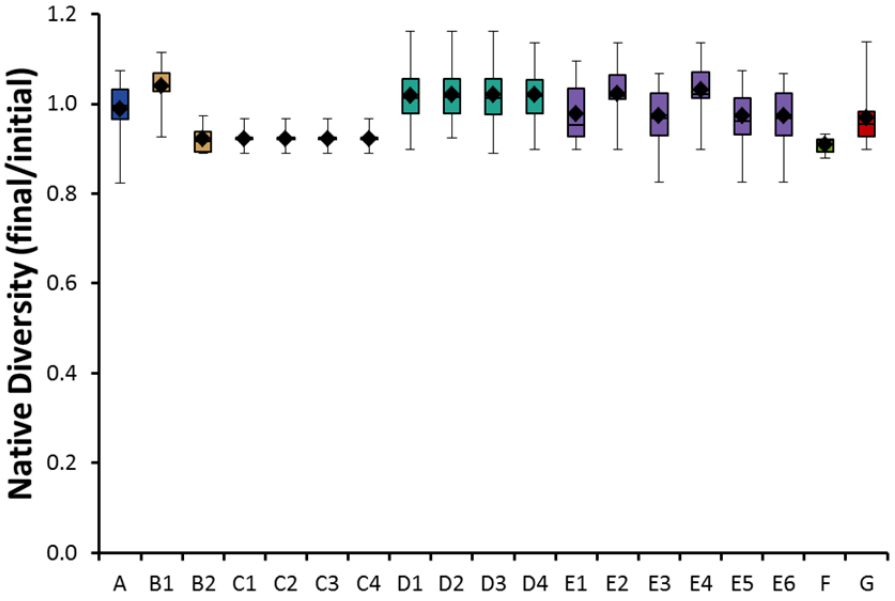

FIGURE G-4 Native Diversity Metric under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

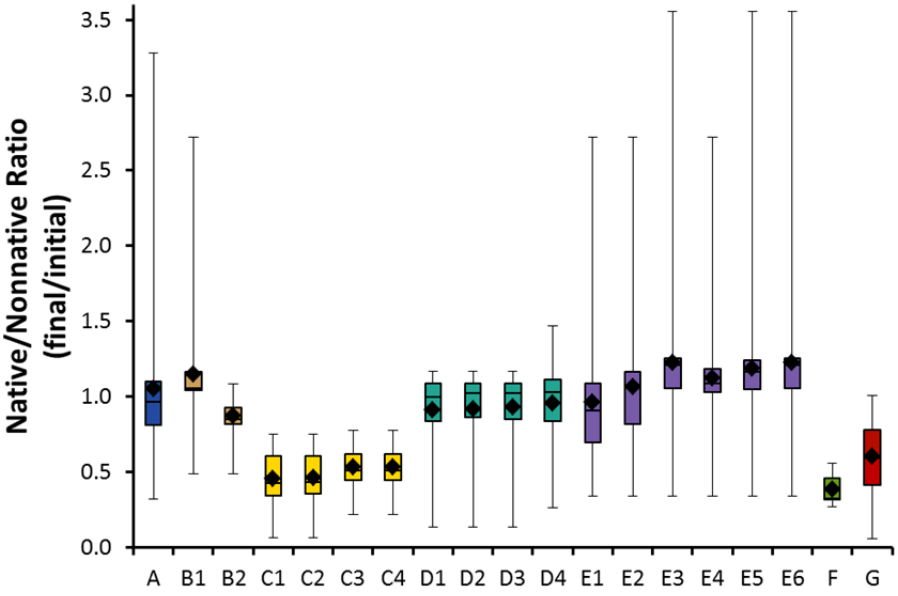

FIGURE G-5 Native/Nonnative Ratio Metric for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

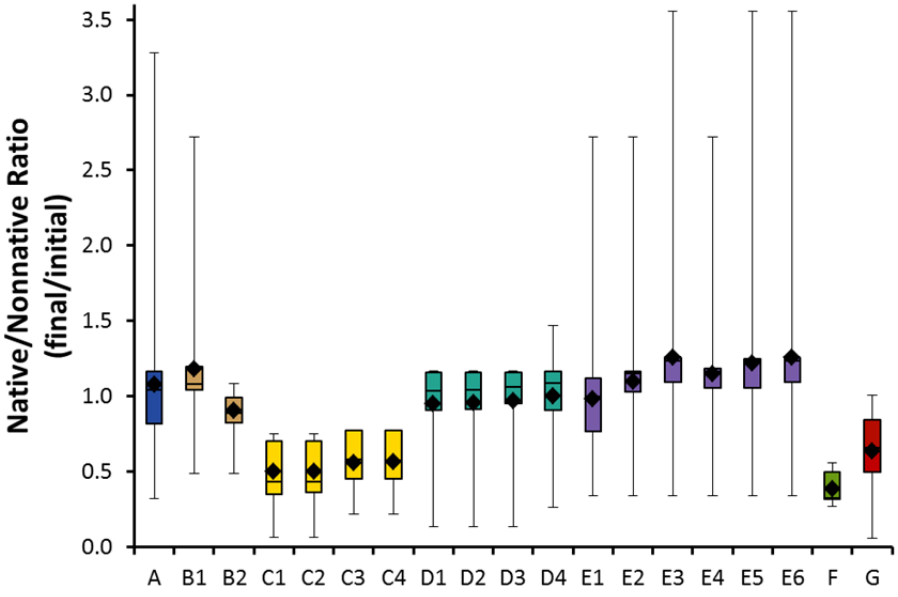

FIGURE G-6 Native/Nonnative Ratio Metric under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

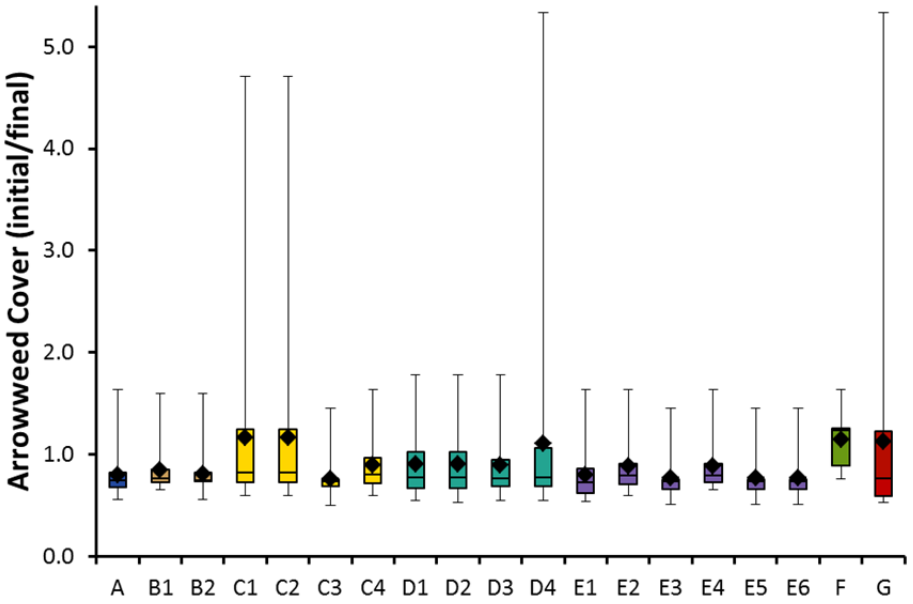

FIGURE G-7 Arrowweed Metric for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers); Higher Values Indicate Less Arrowweed (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

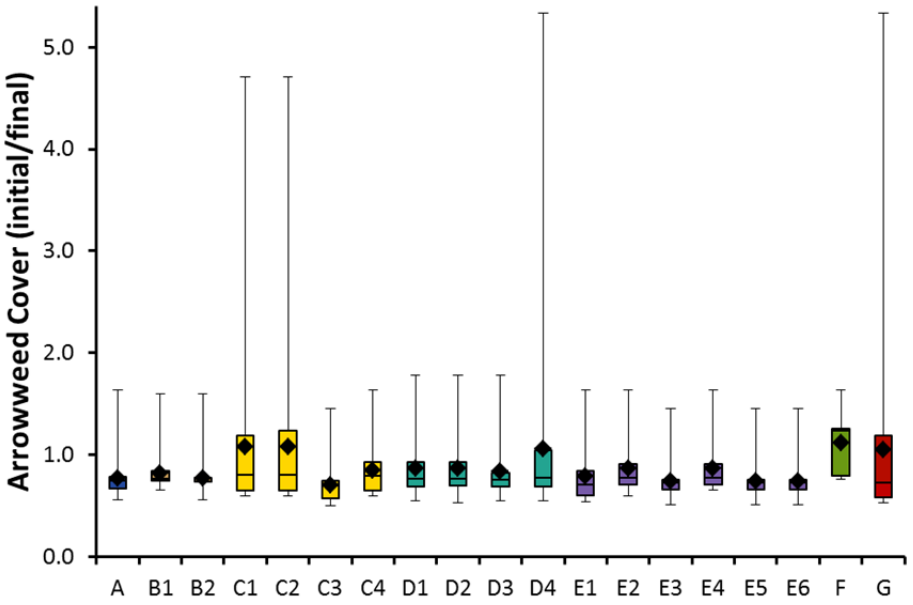

FIGURE G-8 Arrowweed Metric under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers); Higher Values Indicate Less Arrowweed (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

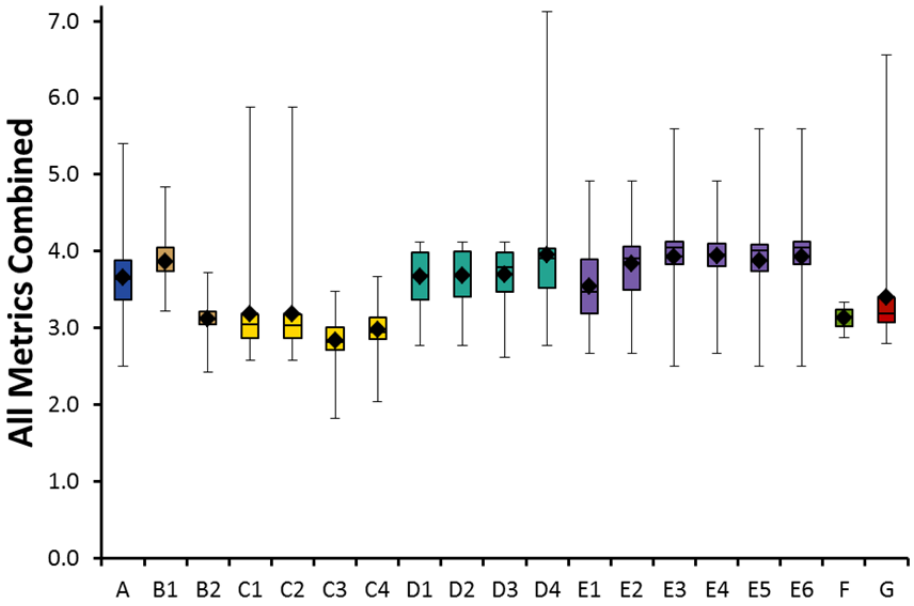

FIGURE G-9 Overall Combined Score for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

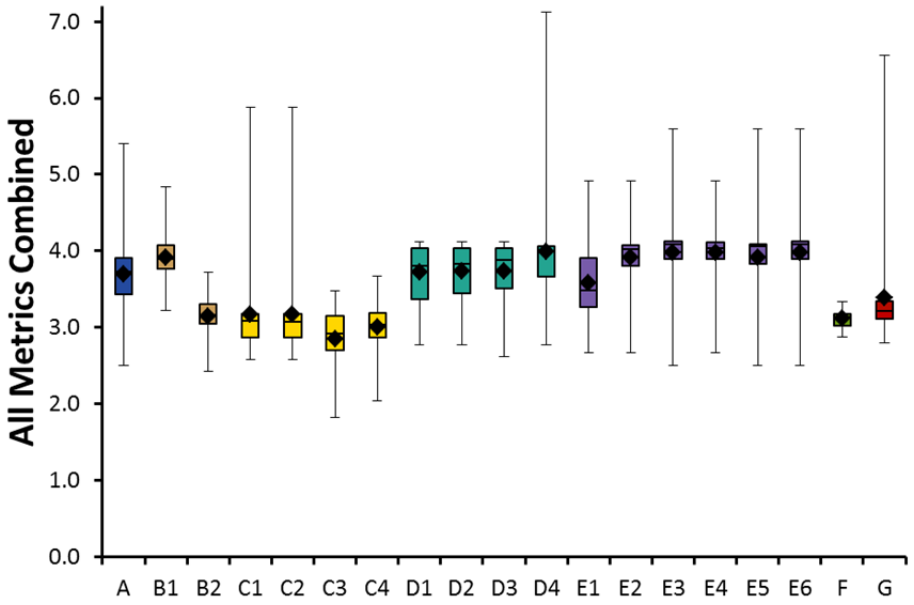

FIGURE G-10 Overall Combined Score under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

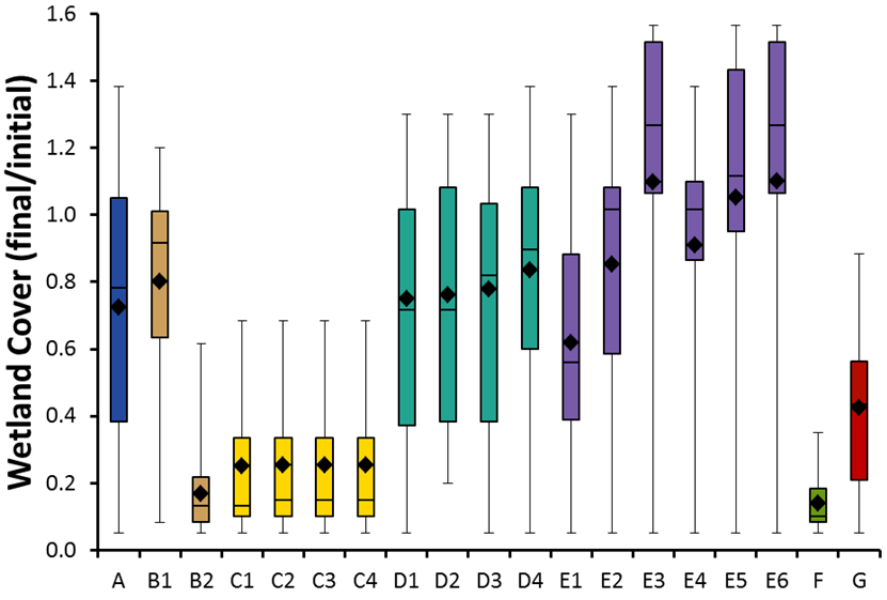

FIGURE G-11 Relative Change in Wetland Cover for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

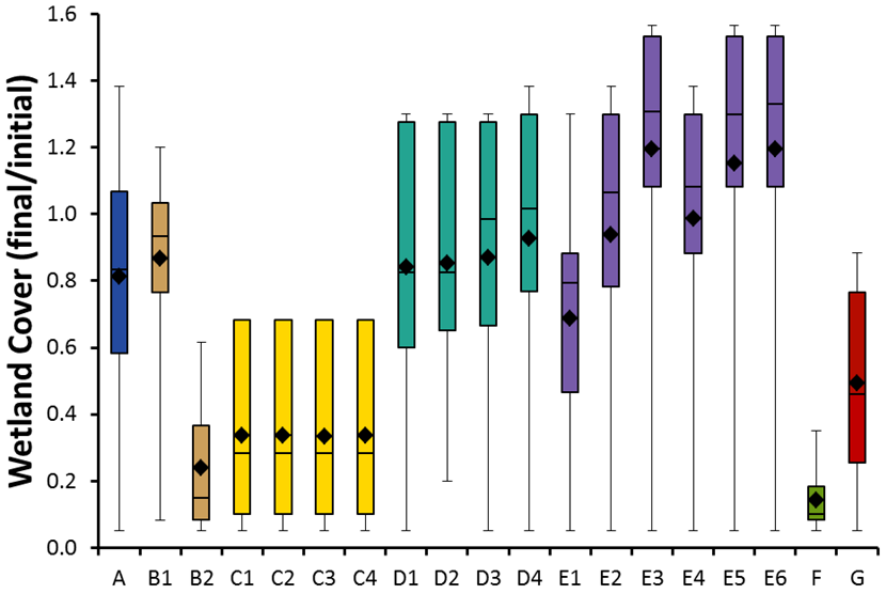

FIGURE G-12 Relative Change in Wetland Cover under Climate Change for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum of the values for the 63 traces analyzed.)

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APPENDIX H:

CULTURAL RESOURCES TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX H:

CULTURAL RESOURCES TECHNICAL INFORMATION AND ANALYSIS

The assessment of potential impacts on cultural resources relied on three factors identified during the Long-Term Experimental and Management Plan (LTEMP) assessment process as the primary factors affecting the stability of historic resources in the canyons: (1) erosion (Thompson and Potochnik 2000; Damp et al. 2007; Spurr and Collette 2007), (2) inundation (Baker 2013), and (3) visitor effects (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013). Metrics were formulated for these factors to quantitatively analyze the effects on cultural resources of the LTEMP alternatives based on modeling of discharge and sediment loads. The metrics are:

- Wind Transport of Sediment Index
- Flow Effects on Cultural Resources in Glen Canyon Index
- Time Off River Index

This appendix discusses the modeling of each metric and presents a detailed discussion of the modeling results. The metrics were developed through consultation with subject matter experts, findings in published papers and reports, and consideration of comments from cooperating agencies. See Section 3.8 for a more detailed description of Grand Canyon cultural resources and Chapter 2 for a detailed description of the LTEMP alternatives.

H.1 WIND TRANSPORT OF SEDIMENT

Prior to the construction of Glen Canyon Dam, periodic large-magnitude storm events would flood the Colorado River and deposit fluvial sediment onto high-elevation terraces. Wind also transported sediment from the active river channel onto the high-elevation terraces and helped to maintain the sediment deposits (Draut 2012). The deposited sediment buried and protected evidence of past human activity within the floodplain of the river. However, the dam's closure in 1963 trapped most of the sand that would have been transported into the Glen Canyon and Grand Canyon reaches of the Colorado River, and operations reduced the magnitudes of annual peak flows and increased the magnitudes and durations of low flows (baseflows). The decrease in magnitude of sediment-rich peak flows has lowered the elevation of the area scoured by high flows and at which new sand can be deposited. The increase in elevation and duration of low flows has promoted the expansion of riparian vegetation onto bare sand (Sankey et al. 2015) and has limited the duration of time sand is dry and subaerially exposed, both of which reduce the wind's ability to transport sediment (East et al. 2016; Draut 2012; Draut and Rubin 2008). These changes decreased the renewal of sediment to high-elevation terraces downstream of the dam (East et al. 2016). With limited rejuvenation of sand, landscapes and archaeological sites are more prone to erosion, which can expose sites found along the riparian zone of the river (East et al. 2016; Collins et al. 2016; Sankey and Draut 2014).

Sediment deposited along the riverbank above the elevation of normal operational flows and below the elevation of peak operational flows can be transported by the wind and deposited onto high-elevation terraces, many of which contain archaeological sites (East et al. 2016). This windblown sediment can make the landscape less vulnerable to erosion from rainfall-runoff processes and can potentially increase the preservation potential of archaeological sites on these high-elevation terraces (East et al. 2016). It has been observed that the optimal annual timeframe for this transfer of sediment is in the spring months, when a reduced amount of rainfall and strong winds create conditions for windblown sediment transport (Draut and Rubin 2008). A wind transport metric was developed based on principles identified by Draut and Rubin (2008) to address the possibility of systemwide benefits to archaeological sites located on these higher terraces.

H.1.1 Wind Transport of Sediment—Methods

The Wind Transport of Sediment Index (WTSI) evaluates the availability of fine sediment for wind transport to cover cultural resources at higher elevations (i.e., those properties located at stages above 31,500 cfs). Optimal conditions for wind transport of sediment occur when (1) fine sediment is deposited by flows above the stage of normal operations and (2) low flows occur during the windy season, which exposes more sand for redistribution by the wind. These two conditions are accounted for by the Wind Transport of Sediment Index (WTSI) using the following equation (Eq. H.1), where SLI is the Sand Load Index and FF is the flow factor*:*

$$WTSI = SLI \times Average(FF)_{2014-2033} \quad \text{(H.1)}$$

Both of the inputs for the metric (SLI and FF) are indices ranging from 0 to 1. The resulting Wind Transport of Sediment Index is a value from 0 to 1, where a value of 1 corresponds to the most potential movement of sediment by the wind, and therefore has the highest likelihood to contribute to the preservation of cultural resources. Both elements of the equation (SLI and FF) are limiting factors in the sense that the highest value between the two is the highest possible output. This mirrors the occurring environmental limitations—no more sediment can be transported than available, while, regardless of availability, wet sand is not likely to be easily transported by the wind.

The WTSI is calculated for a total of 63 scenarios representing different hydrologic (20 traces) and sediment conditions (3 traces), and weighted by the historical exceedance percentage of the sediment traces included in the scenario. Because of modeling limitations, environmental factors—such as sandbar erosion due to fluctuations in water level, rainstorm events that may further saturate soil, and vegetation barriers that could prevent sediment transport by the wind—were not incorporated into the metric. Complex parameters like these would require more assumptions, which could result in less confidence in the model.

The SLI is an index of the potential sand deposited on sandbars along the river channel in Marble and Grand Canyons above normal stage elevations (31,500 cfs). The SLI is calculated as the ratio of the cumulative sand load at flows greater than 31,500 cfs relative to the total cumulative sand load at all flows. The sand load, or the mass of sand in transport by the river, is

calculated at RM 30 and is computed by a version of the Sand Budget Model (Wright et al. 2010) for the 20-year LTEMP modeling period. A larger SLI (on a scale of 0 to 1) indicates a greater potential for sediment deposition. The SLI is described in more detail in Appendix E. The SLI was calculated using Equation H.2:

$$SLI = \frac{\sum_{2014-2033} Sand\ Load\ at\ dam\ discharges > 31{,}500\ cfs}{\sum_{2014-2033} Sand\ Load\ at\ all\ dam\ discharges} \quad \text{(H.2)}$$

The FF represents the relative exposure of dry, fluvial sand along the banks of the river available for wind transport. An increase or decrease in dam discharge will increase or decrease the downstream river elevation, respectively. Therefore, a lower discharge will expose a greater amount of sediment. For this metric, maximum daily flows above normal river stage (8,000 cfs) are considered increasingly worse for sediment exposure. The maximum daily discharge (Q_{max}) modeled by GTMax-Lite represents the maximum discharge released from Glen Canyon Dam in cubic feet per second (cfs) and thus the extent of dry sand for each day. The yearly FF is the average of FF_{Daily} (Eq. H.3) for the spring months of March through June.

$$FF_{Daily} = \begin{cases} \text{if } Q_{max} \leq 8{,}000; & 1 \\ \text{if } 8{,}000 < Q_{max} < 31{,}500; & 1.34 - 0.0000425 \times Q_{max} \\ \text{if } Q_{max} \geq 31{,}500; & 0 \end{cases} \quad \text{(H.3)}$$

Note that although the FF only takes into account the months of March through June, the SLI incorporates the entire year. This is because the exposure of sand is most prominent during the windy season, but the sediment transported during those months is continuously built up throughout the year.

H.1.2 Wind Transport of Sediment—Results

WTSI values calculated for the LTEMP alternatives under historical flow and sediment inputs are shown in Figure H-1. The metric values represent the *potential* for sand to be transported to cultural sites rather than the actual transport that would occur or the level of protection that transport may provide to cultural sites. This results in some uncertainty with regard to actual differences in impact among the alternatives based on this metric. Our conclusions on relative impact are based on comparisons of the metric values calculated for Alternatives B, C, D, E, F, and G, and their long-term strategies against Alternative A (the no-action alternative), which has the same basic operational discharge pattern as current operations under Modified Low Fluctuation Flows (MLFF). Research done to date on the effects of windblown sand and archaeological sites has examined operations since the closure of Glen Canyon Dam including MLFF conditions. This research has shown that the number of archaeological sites ideally situated to receive aeolian sand supply from the river has decreased since the completion of the dam and most recently under MLFF conditions (East et al. 2016). When sites are no longer ideally situated to receive sand supply, they are at elevated risk from erosion (East et al. 2016). These changes in sand supply and erosion risk can be attributed to several specific characteristics and effects of MLFF, including the absence of sediment-rich

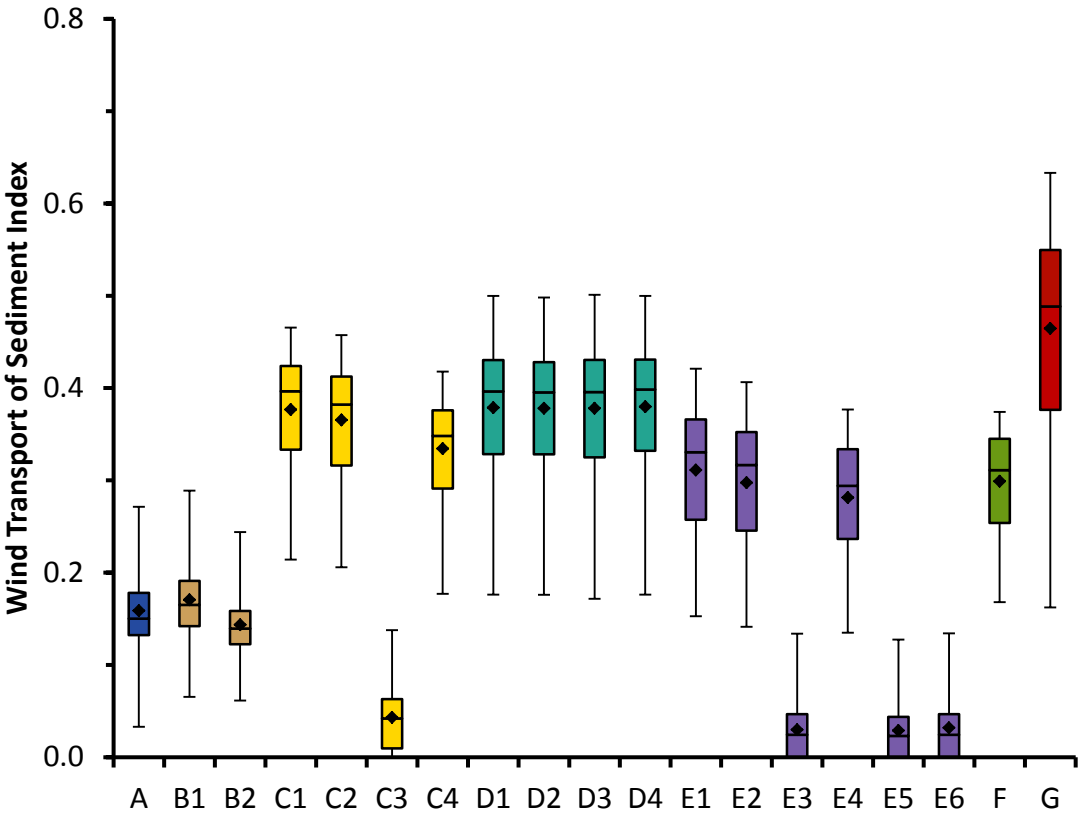

FIGURE H-1 Wind Transport of Sediment Index Values for the LTEMP Alternatives (letters) and Associated Long-Term Strategies (numbers) (Index values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

floods above 45,000 cfs, increases in riparian vegetation, and decreases in open, dry sand area that is available for aeolian transport within the active river channel (East et al. 2016).

Of the long-term strategies analyzed, one for each alternative was selected as most representative of the alternative as fully implemented. These representative long-term strategies were B1, C1, D4, and E1, and Alternatives A, F, and G. All of the representative long-term strategies B1, C1, D4, and E1, as well as Alternatives F and G, scored greater than Alternative A because they have more frequent high-flow experiments (HFEs). Long-term strategies B2, C3, E3, E5, and E6 rank below Alternative A. With the exception of long-term strategy B2, HFEs are not conducted for these strategies, and flows above 31,500 cfs would occur rarely, if at all. Recall that one of the primary assumptions for this metric is that flows above 31,500 cfs are the primary mechanism for sediment deposition at higher elevations. If there are no high flows to deposit sand at higher elevations along the banks of the river, there is no new sediment to be moved by the wind. Increased flow fluctuations in long-term strategy B2 cause it to rank below Alternative A.

Alternative G scores the highest of all the alternatives, with an average WTSI nearly three times greater than Alternative A. With the highest number of HFEs and the lowest maximum daily flows during the windy months (Figure H-2), this alternative has parameters ideal for wind-transport of fluvial sediment to high-elevation terraces that contain cultural resources. The second highest scoring long-term strategy, D4, is not significantly different from long-term strategies D1, D2, D3, and C1 (statistical differences between means based on a three-factor analysis of variance [ANOVA] followed by Tukey's Studentized Range Test).

On the whole, the WTSI is highly correlated with the number of HFEs and the corresponding SLI. The relationship between SLI and HFEs is discussed in Appendix E. The similarity between WTSI and HFEs can be seen by comparing Figure H-1 with the average number of HFEs in Figure H-2. The WTSI is highly correlated with the SLI because the average maximum discharge between March and June for each of the alternatives is within 5,000 cfs (standard deviation of 0.05). With minimal difference in flow, the amount of sediment for distribution becomes the determining factor for the index. The exception to this is Alternative F. Figure H-3 shows a sample trace of the typical 8.23 million acre-feet (maf) release year. In April, May, and June, the discharge of Alternative F is higher than that of all other alternatives. Although Alternative F was determined to have the second highest potential sand deposition (highest SLI), it ultimately has an average WTSI value lower than Alternatives C, D, E, and G, as larger discharges of water create less ideal conditions for wind transport.

Long-term strategies C2 and E2 feature low summer flows and trout management flows (TMFs) when conditions trigger them. Reallocation of water volume from low summer flows can cause increased discharge in other portions of the water year. This reallocation combined with

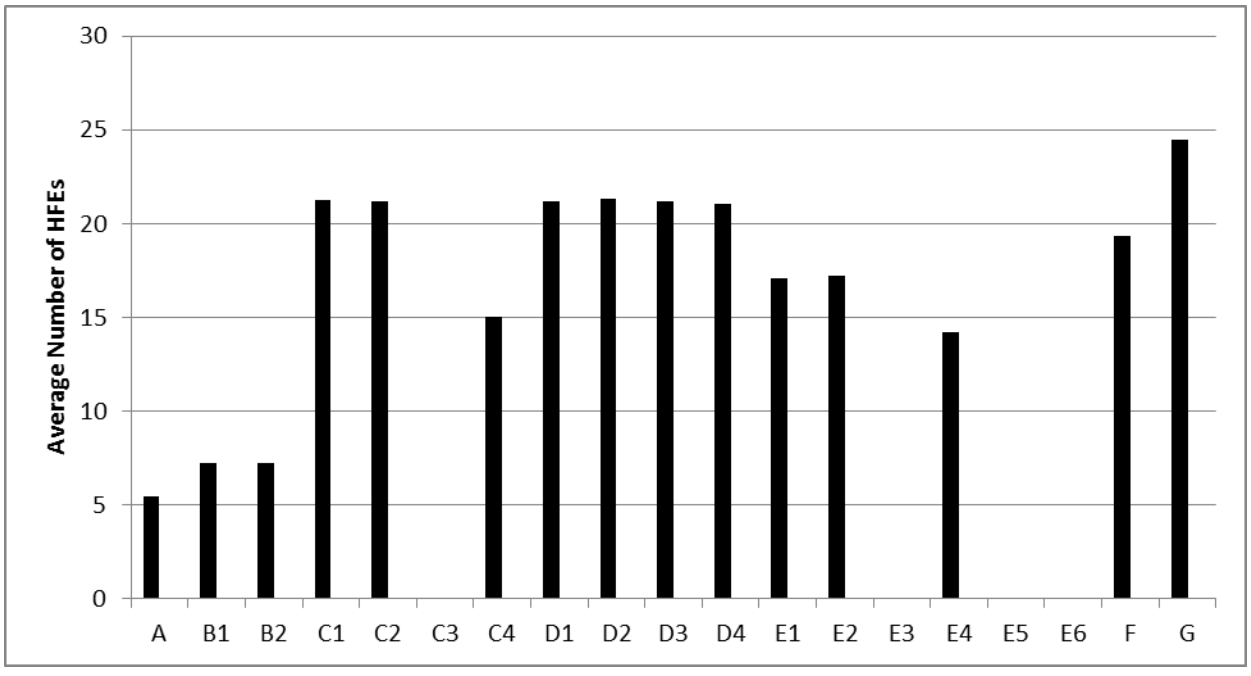

FIGURE H-2 Average Number of HFEs in the 20-Year LTEMP Period

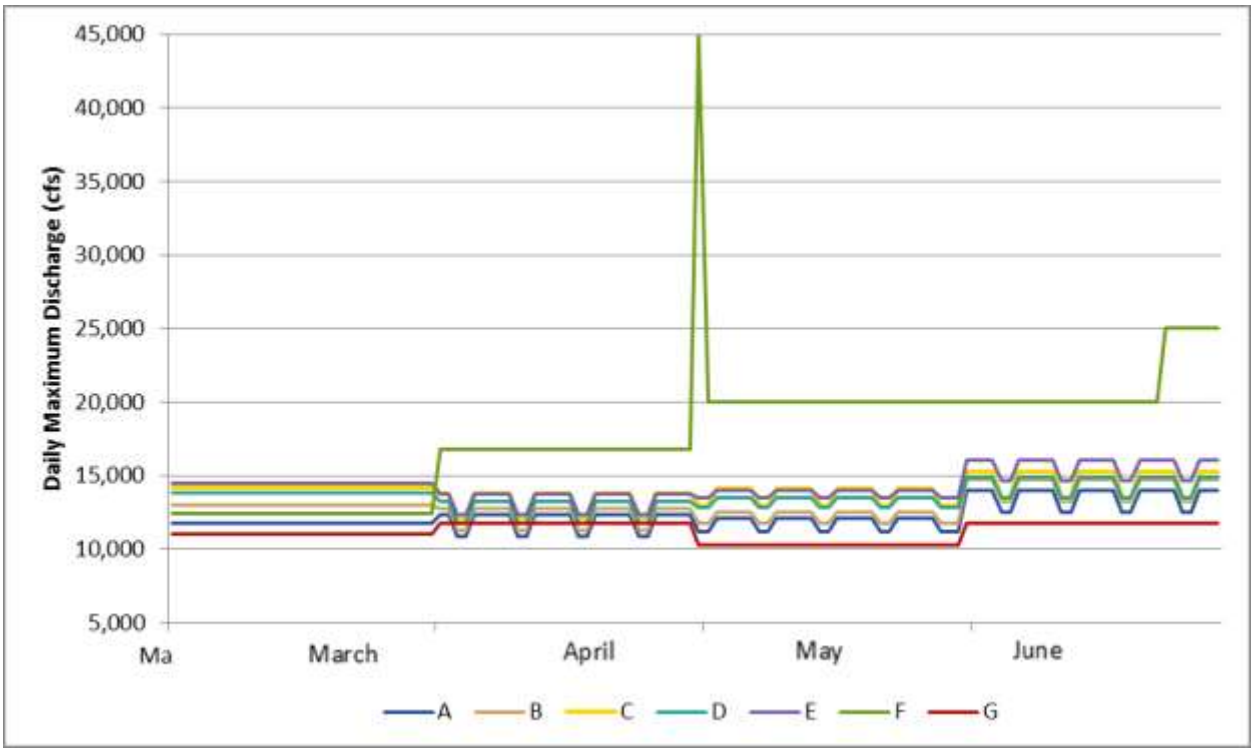

FIGURE H-3 Daily Maximum Discharge in a Typical 8.23-maf Water Volume Release Year from the Glen Canyon Dam during the Windy Season of March–June

the high-flow portion of TMFs causes long-term strategies C2 and E2 to rank lower than their base alternatives. Similarly, the exclusion of spring HFEs in long-term strategies C4 and E4 decrease their WTSI in comparison to long-term strategies C1 and E1.

The WTSI is useful for understanding the interplay between the components of the alternatives. Alternatives that incorporate strategies for enhancing sediment retention (i.e., Alternatives C, D, E, and G, which have reduced fluctuations or more even monthly volumes) have higher WTSI values. The metric also illustrates through Alternative F the effect that flow operations can have on wind transport. Index values are lower for Alternative F because the alternative features higher flows in the windier periods of the spring and summer, which negates some of the benefits of the higher sediment retention indicated in the SLI. Although the metric is beneficial for comparative and theoretical purposes, it reflects idealized conditions for wind transport of sediment that cannot be easily translated into actual site preservation. The extent to which wind transport of sediment can mitigate the erosion occurring in cultural sites on high-elevation terraces remains unknown.

H.2 FLOW EFFECTS ON CULTURAL RESOURCES IN GLEN CANYON

The construction of Glen Canyon Dam significantly scoured the immediate downstream Glen Canyon reach of the Colorado River and cut off nearly all of the sediment supply from

upstream. Unlike further downstream sections of the river, a lack of significant tributaries in Glen Canyon results in very little sediment deposition on river banks of the canyon. In fact, high flows meant to distribute sediment have been shown to degrade terraces in the Glen Canyon reach (Grams et al. 2007). Archaeological sites located in Glen Canyon are also not associated with significant wind deposition of sediment (Anderson 2006). Without the rejuvenation of sediment, higher flows can increase erosion within the Glen Canyon, which is a concern for significant archeological sites.

Anderson (2006) identified 14 archaeological sites within Glen Canyon that were being affected by river-based arroyos or gullies. However, only one of these sites, commonly referred to as Ninemile Terrace, was determined to have erosional features that are unequivocally related to direct impacts of river operations. Bank stability at Ninemile Terrace, and at other terraces with the potential to contain cultural resources, is partially dependent on the accumulation of material at the base of the slope. Removal of this protective material through erosion leaves the lower-bank material prone to a continuing cycle of undercutting, collapse, and removal. This, in turn, contributes to slumping of the upper-bank material, whether dry or saturated. The flow at which the base of the slope begins to erode serves as the "flow elevation threshold." Flows at or above this threshold have the potential to adversely affect cultural resources through bank erosion and destabilization (Baker 2013). Time-lapse photography from the November 2012 HFE shows that the inundation of the existing base of the slope at Ninemile Terrace occurs at a flow of 23,200 cfs.

Ninemile Terrace reflects many characteristics of other sites in Glen Canyon and was considered representative of other Glen Canyon terrace sites for determining the effects of water flow on high-elevation terraces. In the absence of direct field measurements to further clarify a flow elevation threshold, the flow rate of 23,200 cfs was identified by Glen Canyon National Recreation Area staff as an approximate measure to represent the flow elevation above which erosional processes could contribute to impacts that have the potential to adversely affect cultural resources.

H.2.1 Flow Effects on Cultural Resources in Glen Canyon—Methods

Impacts on cultural resources in the Glen Canyon reach were determined by calculating the number of days per year that the maximum daily flow would be >23,200 cfs. A higher number represents the increased potential for erosion of terraces that contain cultural resources. The maximum daily flow is used to capture all instances where flow is high enough to contribute to erosional processes. As with the WTSI, a total of 63 scenarios of different hydrologic and sediment conditions were analyzed.

This metric determines the relative difference among alternatives for the potential impacts of flow on cultural resources. Research would be needed to determine the number of days of high flow that would produce noticeable or extensive impacts on cultural sites.

H.2.2 Flow Effects on Cultural Resources in Glen Canyon—Results

Figure H-4 shows the number of days per year during which flows would be >23,200 cfs for each alternative. The average number of days flows would be >23,200 cfs ranges from 18 to 36 among the alternatives. High maximum values of 50–77 days would occur under all alternatives (as noted by the upper whisker) and would occur in years with high water volumes released from Glen Canyon Dam (e.g., annual average release volume for the trace was 11.5 maf or higher).

Alternative A has the highest number of days per year during which flows would be >23,200 cfs. Alternative A most closely represents the current conditions of MLFF. Long-term strategies C3, E3, E5, and E6 (long-term strategies with no HFEs) have average values that are lower than under Alternative A, but they differ from that number by no more than 3 days. Alternative F would have the highest number of days per year during which flows would be >23,200 cfs; it averages 14 days per year more than under Alternative A. Alternative F, therefore, has the highest potential for impacts on terraces that contain cultural resources in

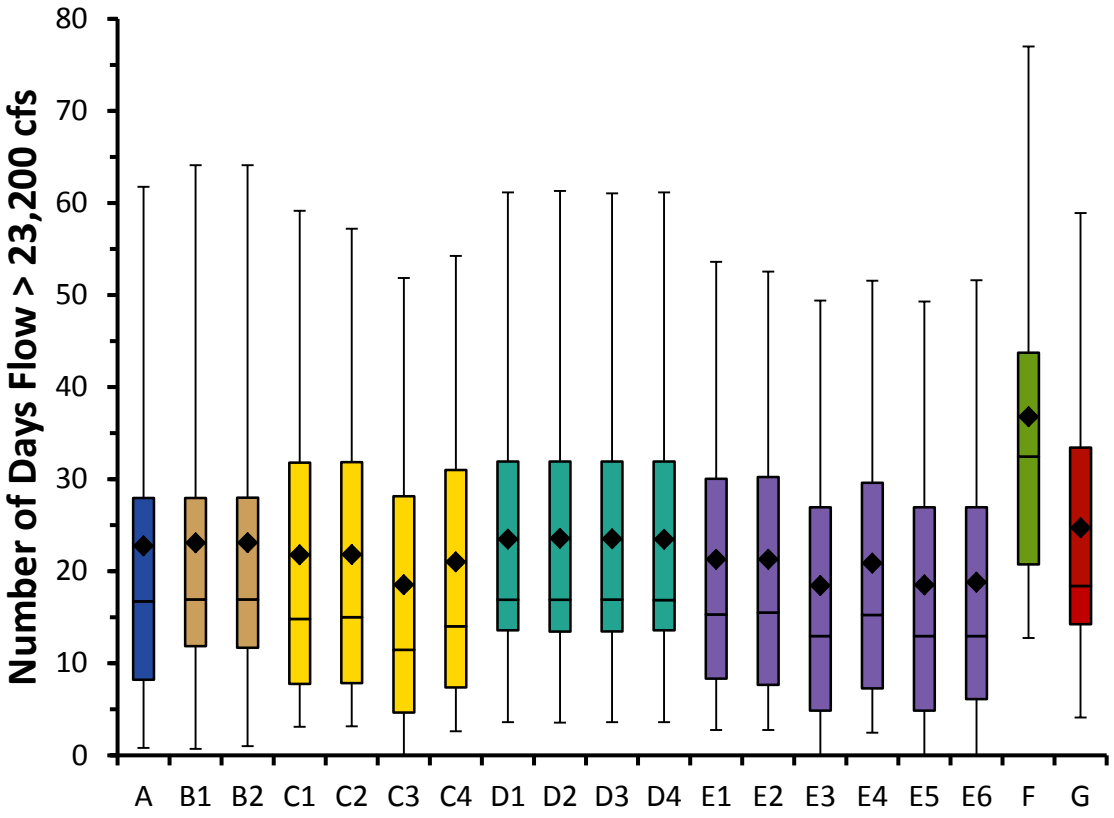

FIGURE H-4 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives (Letters) and Long-Term Strategies (Numbers) (Flows of this magnitude have the potential to affect cultural resources in Glen Canyon. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Glen Canyon. The higher number of high-flow days under Alternative F results from the relatively high spring flows between May and June (see Section 2.2.6). For the remaining alternatives, average number of days per year during which flows would be >23,200 cfs are within 4 days of those under Alternative A.

Besides the high spring flows of Alternative F and HFEs under all alternatives, operational changes within long-term strategies seem to have minimal effect on the number of days per year during which flows would be >23,200 cfs. Long-term strategy B2 includes tests of hydropower improvement flows (i.e., operations with wider water release fluctuations in high electrical demand months than the base operations of long-term strategy B1). Although hydropower improvement flows increase within-day flow fluctuations, in most cases, the altered maximum flow does not exceed 22,000 cfs. Therefore, long-term strategies B1 and B2 have nearly identical values and are not significantly different. Long-term strategies C2, D3, E2, and E5 all have low summer flows. Low summer flows result in higher flows at other times of year, but do not affect the number of days per year during which flows would be >23,200 cfs, and these long-term strategies will not have any effect on this metric. TMFs would also have minimal effect on this metric.

Although the number of HFEs (Figure H-2) in the alternatives differ, these differences have little effect on the number of days per year during which flows would be >23,200 cfs. This occurs because HFEs are relatively short (Figure H-5), and the large volume released under the HFE must be compensated for by releasing less water at other times of the year (Figure H-6). Because all alternatives must release the same annual volume of water, alternatives with HFEs may have lower releases at other times of years than those without. The effect on the metric

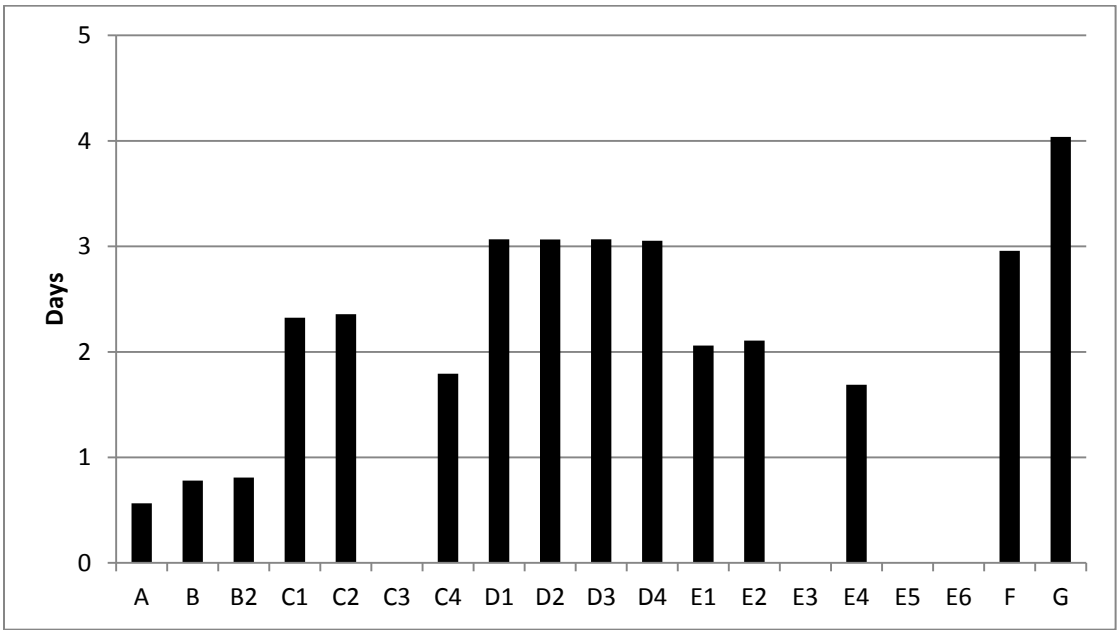

FIGURE H-5 Average Number of Days of an HFE Event per Year

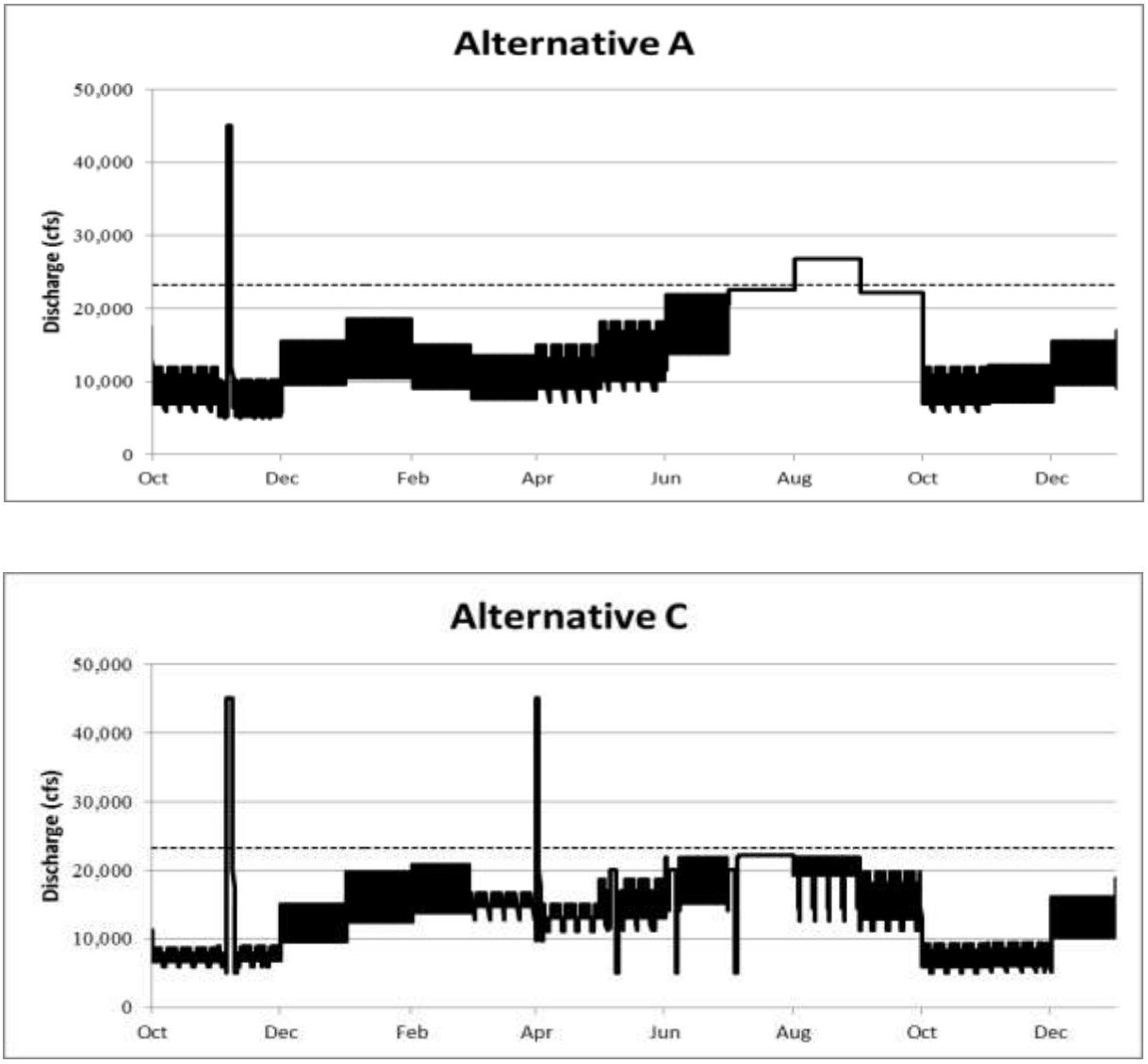

FIGURE H-6 Modeled Glen Canyon Dam Discharge for the Same Year (the line represents 23,200 cfs)

would be greater in years of high volume (≥10 maf) when equalization flows would be implemented according to the Interim Guidelines (Reclamation 2007).

This explains why Alternatives A and B, with minimal HFE events, have nearly the same metric value as alternatives like Alternative C with more than four times the number of HFEs (Figure H-2). Although Alternative C has two HFEs (Figure H-6) and Alternative A has only one, Alternative A must release more water in August to compensate. Historically, precipitation was higher than conditions in recent years; therefore, equalization flows may be triggered less frequently and days above 23,200 cfs might be less than for those based on historical flows. The 50th and 25th percentile values are more applicable to recent climate conditions seen in the Glen Canyon region. In addition, the variability (noted by the length of box) in the value is a result of

the variability in the release volume between water years, HFEs, and the interaction between the two for a particular alternative.

H.3 TIME OFF RIVER

Greater discretionary time for whitewater rafters to explore the canyons downstream of Glen Canyon Dam increases the likelihood that they could have an impact on archaeological sites by creating trails to sites or looting or vandalizing sites. When the river is moving at a faster pace and boat travelers arrive at their destination earlier, their discretionary time off river increases. It is therefore hypothesized that higher flows may increase the potential for adverse human contact with archeological sites.

H.3.1 Time Off River—Methods

The Time Off River Index (TORI) represents the degree to which flows could affect visitor potential to interact and disturb cultural sites. Grand Canyon visitor numbers vary depending on the time of the year. Recreational activity is more common in the warmer summer months, less so in the spring and fall months, and even less in the colder winter months. The yearly TORI (Eq. H.4) is the ratio of the sum of seasonal ratios that designate flows ideal for minimal visitor-site interaction. Summer has the highest weight (0.54), while winter has the lowest (0.15) and spring and fall are in between (0.31). The TORI is a 0–1 value, where 1 equals the least discretionary time for visitors to access archaeological sites, and, therefore, the lowest potential for impacts on cultural sites.

$$TORI = \left[0.15 \left(\frac{\sum_{winter} ORFF}{\sum Days_{winter}} \right) + 0.31 \left(\frac{\sum_{\frac{spring}{fall}} ORFF}{\sum Days_{\frac{spring}{fall}}} \right) + 0.54 \left(\frac{\sum_{summer} ORFF}{\sum Days_{summer}} \right) \right] \quad \text{(H.4)}$$

An overall annual mean TORI value for the 20-year modeling period was developed for each alternative and used as the performance metric (Eq. H.5).

$$TORI = Average\ (TOR_{annual})_{2014-2033} \quad \text{(H.5)}$$

The Off River Flow Factor (ORFF) represents the potential for discretionary time off river. The discharge level at which boats begin to exceed typical river travel times is 10,000 cfs. However, once flows reach more than 31,500 cfs, visitors are more likely to stay at campsite areas rather than travel in a turbulent river. Daily average flows (Q_{avg}) represent the average release from Glen Canyon dam in cubic feet per second. Average daily discharge from the dam was modeled in GTMax-Lite. The ORFF is a 0–1 value, where 1 indicates the lowest potential for discretionary time off river and therefore the lowest potential for increased visitation of archaeological sites. Specifically, the average daily ORFF is assigned as follows (Eq. H.6), where the value within the brackets in the right column is assigned to $ORFF_{Daily}$ if the equation in the left column is satisfied:

$$ORFF_{Daily} = \begin{cases} \text{if } Q_{avg} \leq 10{,}000; & 1 \\ \text{if } 10{,}000 < Q_{avg} < 31{,}500; & 1.465 - 0.0000465 \times Q_{avg} \\ \text{if } Q_{avg} \geq 31{,}500; & 0 \end{cases} \quad \text{(H.6)}$$

As with the WTSI, a total of 63 scenarios of different hydrologic and sediment conditions were analyzed.

H.3.2 Time Off River—Results

TORI does not specify how much additional discretionary time off river a visitor may experience. Instead, TORI is intended to determine the potential for visitors to spend more time off of the river exploring—which could result in more cultural resources being visited and possibly affected—by examining the flows under the various alternatives as compared to Alternative A.

A summary of TORI results is provided in Figure H-7. Except Alternative F, all of the alternatives and their long-term strategies performed relatively similarly for this metric. Values

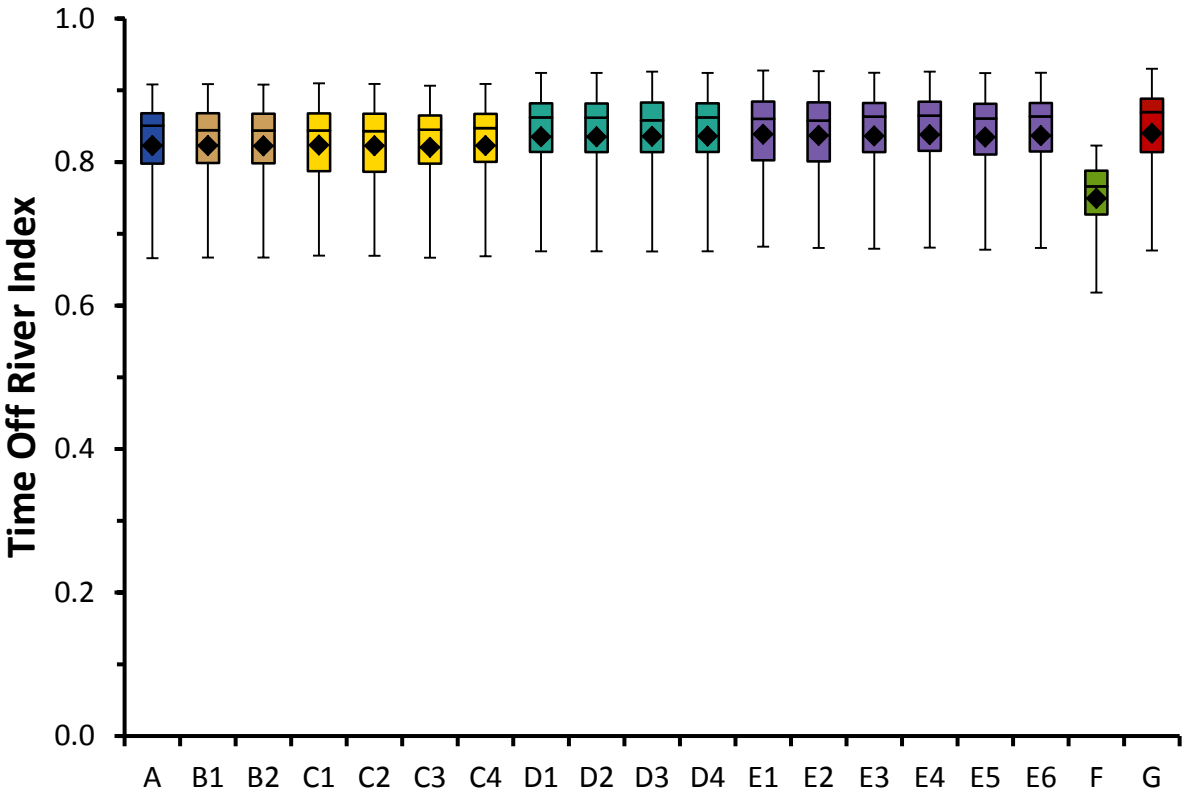

FIGURE H-7 Time Off River Index Values for All LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers) (Index values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

of TORI under long-term strategies B1, B2, C2, and C4 were not significantly different than those under Alternative A. Although Alternatives D, E, and G rank the highest with regard to this value (and thus would be expected to have the lowest impact), the minimal differences in the metric values from Alternative A likely indicate that they would not have noticeable impacts on visitor-site interactions.

The difference between the TORI for Alternative F and the other alternatives is largely due to flows during the spring and early summer that are generally at or above 20,000 cfs, while all other alternatives have daily flows that average between 8,000 and 12,000 cfs. Figure H-8 shows the difference in average discharge between Alternative F and the other alternatives. Although Alternative F has very low flows in December and January, the alternative has flows that are more than 7,000 cfs higher than those under other alternatives in spring and early summer months.

TORI values would be higher in years of high volume (>10 maf) when relatively high equalization flows would be implemented according to the Interim Guidelines (Reclamation 2007). However, these relatively high releases result from high inflow volumes in wet years, are unavoidable, and differ little among alternatives.

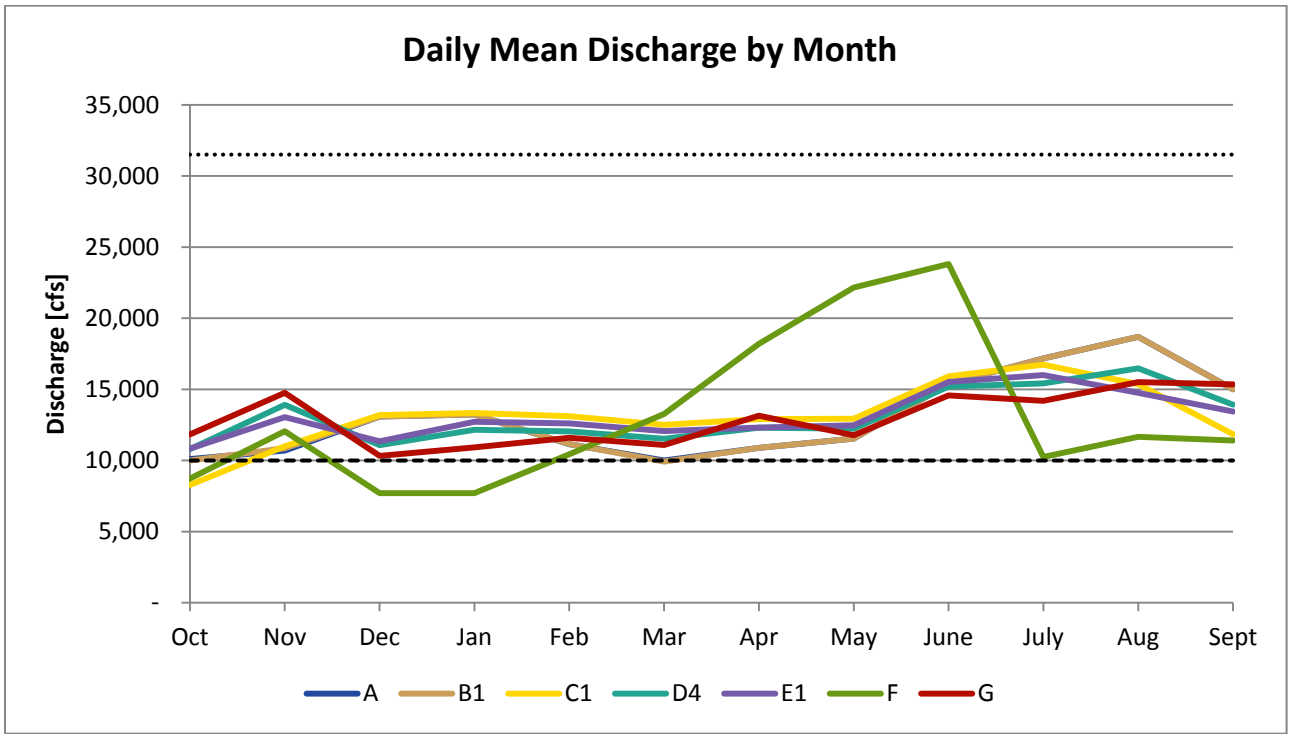

FIGURE H-8 Daily Average Discharge for Representative Long-Term LTEMP Strategies

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APPENDIX I:

TRIBAL RESOURCES TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX I:

TRIBAL RESOURCES TECHNICAL INFORMATION AND ANALYSIS

Section 4.9 of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) assesses and compares the potential impacts of LTEMP alternatives on resources important to federally recognized Tribes. Indian Tribes have been recognized by the courts as "domestic dependent nations." They were sovereign entities before the arrival of Euro-American colonizers and continue to exercise that sovereignty within their reserved lands. Consultation between Tribes and the federal government is consultation between sovereign entities. Even when they have been removed from their ancestral lands, Tribes often retain strong ties to culturally important resources in their traditional homelands. When those resources are located on federal lands or could be affected by federal or federally licensed undertakings, federal agencies are required to take into account those potential impacts in their decision-making (see Table I-1).

The nature and degree of impacts that an undertaking could have on resources important to Tribes are best evaluated with significant input from the Tribes themselves. To this end, the Bureau of Reclamation (Reclamation) and National Park Service (NPS) have sought to include input from all federally recognized Tribes that have traditional, historical, cultural, or religious ties to the canyons. Forty-three Tribes with potential ties to the canyons were notified of the LTEMP EIS project by mail with telephone follow-up and invited to participate. Of these, six chose to become Cooperating Agencies; two Tribes chose to consult, but not as Cooperating Agencies; and nine chose not to actively consult, but to be kept informed of project developments. Thirteen Tribes chose not to participate. There was no response from the remaining twelve Tribes (see Appendix N).

Assessing the comparative impacts of the LTEMP alternatives on Tribal resources presents a challenge both (1) because of the holistic view of the canyons that Tribal members tend to take, in which all elements of the environment are interconnected, so that effects on one part of the environment affects the whole, because there is no single "Tribal view" held by all members of all Tribes, and (2) because knowledge of the location of some of the most sacred places is not shared with outsiders. Not all Tribes agree with each other on all issues, but some common themes and issues did emerge from discussions with Tribal representatives, review of canyon monitoring reports produced by the Tribes, and ethnographic sources produced by or for

TABLE I-1 Federal Regulations and Executive Orders Pertaining to Consultation with Tribes

40 CFR 1506.6 *Cooperating Agencies*
43 CFR 46.225 *How to Select Cooperating Agencies*
E.O. 13175 *Consultation and Coordination with Indian Tribal Governments*
Section 106 of the *National Historic Preservation Act (1966 as amended)*
36 CFR 800.2 (c) (2) *Participants in the Section 106 Process*

the Tribes. For many Tribes, environmental features considered inanimate in Western cultures are seen as imbued with life; in some cases, such as with the Colorado River and the Little Colorado River, they are considered deities. Various Tribes regard the canyons as sacred space, the place where their people emerged into this world, the home of their ancestors, the residence of the spirits of their dead, and the source of many culturally important plant, animal, and mineral resources. Many Tribes view themselves as connected to the Colorado River and its canyons and as stewards over the living world around them, including water, earth, plant life, and animal life. This holistic view encompasses subject areas considered in this EIS, and Tribal perspectives on these resources are found throughout the document. The values the Tribes place on the river and its canyons are significant and real, but often intangible; therefore, they are not easily or are only partially quantifiable. In addition, many of the values and resources that are most important to the Tribes are not directly affected by differences in the patterns of release of water from the Glen Canyon Dam.

Knowledge of some of the most sacred and sensitive places and resources in the canyons is esoteric, known chiefly by elders and initiated religious practitioners. Only they can provide information on what is most sacred and what can be revealed in a public format such as an EIS. Funding was provided to support Tribes in obtaining and providing these important perspectives on the river and the canyons. Appendix N details the efforts undertaken to obtain Tribal input regarding resources important to Tribes that could be affected by the operation of Glen Canyon Dam and proposed associated actions. These efforts included face-to-face meetings, webinars, and conference calls. The Tribes that chose to act as Cooperating Agencies also were afforded the opportunity to provide text for the EIS, and to review and comment on the draft document before it was released to the public.

Although many aspects of the effects on Tribal resources are not quantifiable, quantifiable measures of effects on the canyon environment were found that reflect important Tribal values and could stand as proxies for those values. These include effects on the diversity of riparian vegetation, effects on marshes and other wetlands, effects of large-scale taking of nonnative fish for fish management purposes, effects on Tribal water rights, and factors that could affect Tribal economics. Tribes are concerned with natural resources beyond plant and aquatic life in the canyons. Bighorn sheep, songbirds, and butterflies are among the indicators of canyon health mentioned by Tribal members. Many of these resources are considered qualitatively in the wildlife section of the EIS (Sections 3.7 and 4.7) and can be reviewed and considered by Tribal specialists and representatives.

I.1 QUANTIFIABLE MEASURES USED TO ASSESS IMPACTS ON TRIBAL RESOURCES

I.1.1 Riparian Diversity

Among the quantifiable projected impacts are those on riparian vegetation, the plant life likely to be most directly affected by flow management at the Glen Canyon Dam. The Western concept of "ecosystem" comes close to Tribal views of interconnectedness. Plant life is a

fundamental part of most ecosystems. The state of riparian vegetation is a good indicator of the state of the canyon ecosystem as a whole. Thriving, diverse vegetation communities indicate a healthy ecosystem. Models of future plant diversity along the river provide a quantitative indicator of ecosystem health. Many Tribes give native species and nonnative plant species equal value as forms of life to be respected. Therefore the measure presented here includes plant communities dominated by both native and nonnative plants. For a discussion of diversity in native plant communities, see the Native Diversity Index in Appendix G.

A metric for vegetation community diversity in the riparian zone has been developed based on the results of a state and transition model for Colorado River riparian vegetation downstream of Glen Canyon Dam. This model has been developed to compare the effects of alternative flow regimes on Colorado River riparian vegetation. The model is discussed in Section 4.6.1. For a more detailed discussion of the model, see Ralston et al. (2014) and Appendix G. The model uses characteristics of annual dam operations to predict transitions from one plant community type to another on sandbars and channel margins in the riparian zone. The model projects transitions over a 20-year period for each alternative and long-term strategy analyzed. Relative change in the diversity of vegetation community types on sandbars and in channel margins is projected using the Shannon-Weiner Index for richness/evenness[1] and a diversity score calculated by comparing the final (modeled) diversity to the initial diversity (change in diversity = $\text{diversity}_{final}/\text{diversity}_{initial}$). A healthy ecosystem is characterized by a high degree of species diversity, represented here by diversity in vegetation community types. A total diversity score was calculated that included nonnative (primarily tamarisk) as well as native communities including the invasive arrowweed. Table I-2 shows the seven vegetation states, or plant community types, that were considered. The species associated with a state all respond similarly to Colorado River hydrologic factors such as depth, timing, and duration of inundation.

The model consists of six submodels based on the following landforms: lower separation bars, upper separation bars, lower reattachment bars, upper reattachment bars, lower channel margins, and upper channel margins. Upper and lower landforms are divided at the 25,000 cfs

TABLE I-2 Vegetation States

Vegetation States
Bare Sand
Marsh (Common Reed Temperate Herbaceous Vegetation)
Shrub Wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation)
Tamarisk (Tamarisk Temporarily Flooded Shrubland)
Cottonwood-Willow (Fremont Cottonwood/Coyote Willow Forest)
Arrowweed (Arrowweed Seasonally Flooded Shrubland)
Mesquite (Mesquite Shrubland)

1 For a discussion of the Shannon-Weiner Index, see Appendix G.

flow stage (see Section 3.3.1.1 for a description of these landforms). The model projects transitions between vegetation states, based on a set of rules developed for each submodel, driven by hydrologic events. The model includes a subset of states and transition rules for each submodel. The states and transition rules for the upper portions of the bars and channel margin are the same because of the similarity of plant community types and responses to flow characteristics. The transition rules are based on the effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species. Transition rules are presented in Table G-3 in Appendix G.

Figure I-1 shows the weighted diversity scores for the seven LTEMP alternatives and their associated long-term strategies (described in Appendix C). The higher the score, the greater the diversity of plant community types. A score of 1.0 indicates that the current degree of plant community diversity is projected to be maintained. A score greater than 1.0 indicates increased diversity, less than 1.0 a loss of diversity. The mean scores for each alternative fall into a somewhat wider range than the Native Diversity scores presented in Appendix G. They range from 0.70 under Alternative F to 0.97 under long-term strategy B1. Alternative A (no action alternative) scored 0.95. Alternatives D and E scored above 0.90 under all of their associated long-term strategies.

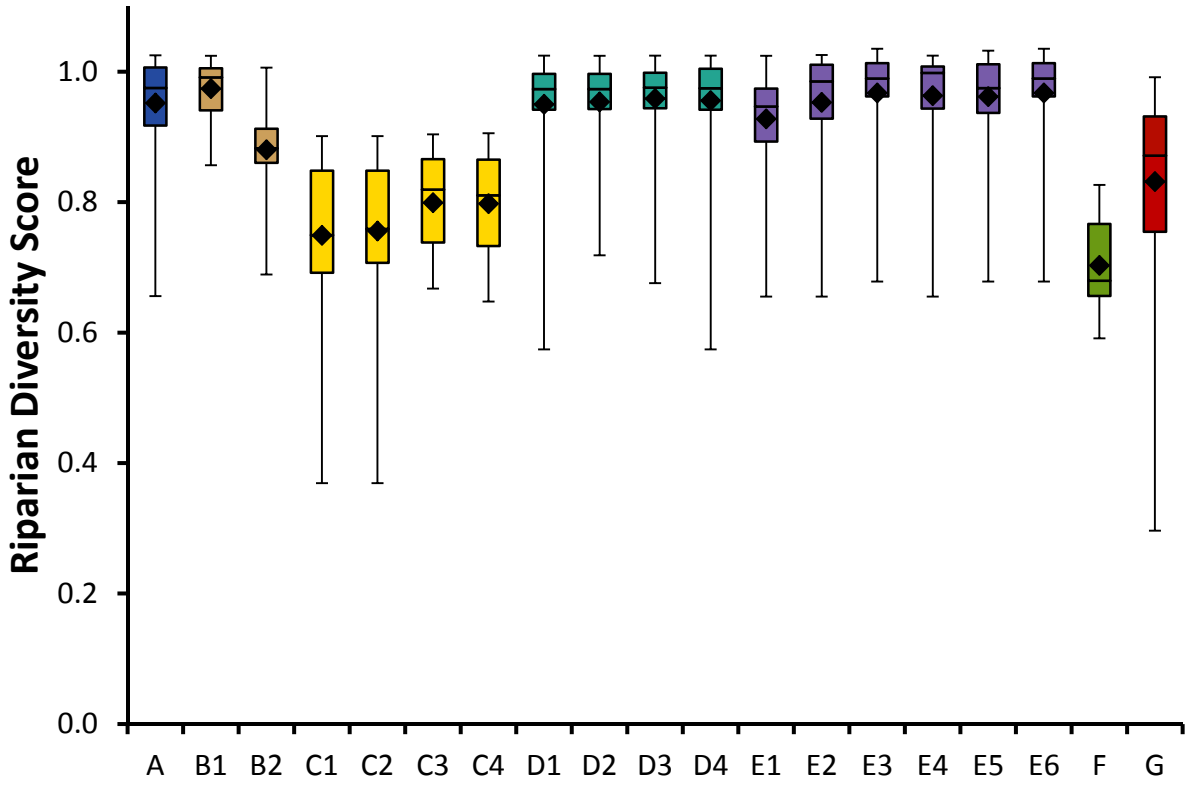

FIGURE I-1 Riparian Diversity for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

The results indicate that on average all alternatives would result in a small decrease in total vegetation state diversity over the 20-year LTEMP modeling period. The loss in diversity would be greatest under those long-term strategies where there is an increase in the area covered by the tamarisk community type (see Table 4.8-3). Alternatives where tamarisk[2] would increase are characterized by high flows (high-flow experiments [HFEs] or ≥30 days with flows >20,000 cfs), which serve to distribute seed, and/or low flows in the growing season (May–September) that allow seedlings to establish themselves. Once established, tamarisk is tenacious. When it does transition, it is most often to bare sand.

Under climate change assumptions, the modeled pattern shows very little difference from the historical-based assumptions (Figure I-2). There is a minimal overall increase in mean diversity scores, suggesting that the difference would be barely perceptible on the ground.

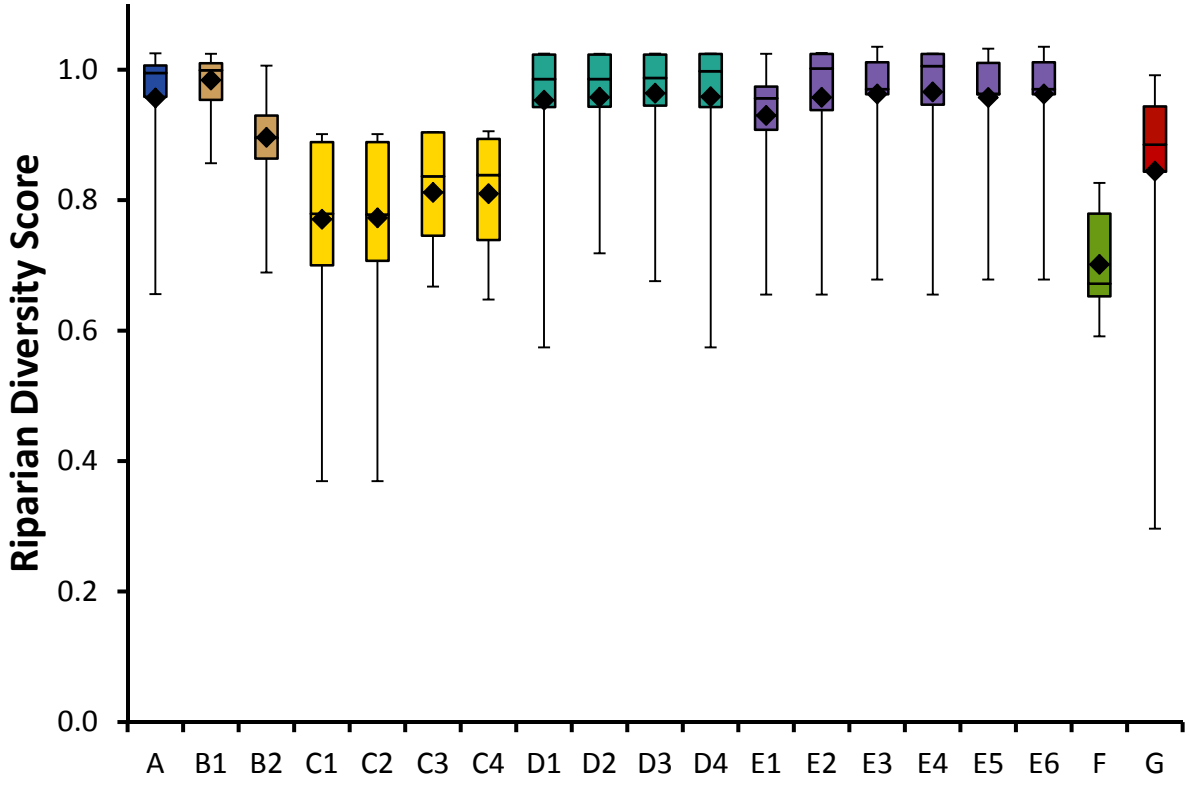

FIGURE I-2 Riparian Diversity under Climate Change Assumptions for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

2 The model takes into account the effects of scouring, drowning, desiccation, and sediment deposition, but does not account for the effects of the tamarisk leaf beetle or tamarisk weevil. These two insect species may result in a reduction in the amount of live tamarisk in the river corridor.

I.1.2 Wetland Abundance

Some Tribes (e.g., the Hopi) see the health of canyon wetlands as an indicator of canyon health (Yeatts and Huisinga 2013). Assessments of the projected state of wetland cover over the next 20 years can be derived from the state and transition model discussed above. Two of the model states listed in Table I-2 are wetland community types: Common Reed Temperate Herbaceous Vegetation, a marsh community; and Coyote Willow-Emory Seep Willow/Horsetail Herbaceous Vegetation, a shrub wetland community.

Wet marsh communities of flood-tolerant herbaceous species that occur on low-elevation areas of reattachment bars have developed in response to frequent inundation. Wet marsh communities (with common reed and cattail the dominant species) occur on fine-grained silty loam soils in low-velocity environments on lower areas of eddy complex sandbars; although they are easily scoured by high flows, they can redevelop quickly. Shrub wetland communities (with coyote willow, Emory seep willow, and horsetail the dominant species) occur on sandy soils of reattachment bars and channel margins, below the 25,000 cfs stage, that are less frequently inundated.

Wetland communities generally transition only from bare sand or other wetlands; they can transition back to bare sand or to arrowweed, tamarisk, or cottonwood-willow communities. An increased occurrence of transitions from bare sand to wetlands and/or maintenance of wetlands (lack of transitions to other community types) would result in greater wetland cover. Large daily fluctuations increase the area of saturated soil and thus the sandbar area available for wetland species establishment. The reduction of daily fluctuations may increase the establishment of wet marsh species at lower elevations and promote the transition of higher elevation marshes to woody species such as tamarisk or arrowweed. Periodic flooding and drying tend to increase diversity and productivity in wetland communities. Although low-elevation plants in marshes in Marble Canyon and Grand Canyon, such as cattail, common reed, and willow, may become buried with coarse sediment, recovery generally occurs within 6 to 8 months. Low steady flows can cause some wetland patches to dry out, resulting in considerable plant loss. Sustained high releases reduce wetland vegetation cover to less than 20% on lower reattachment bars. Extended high flows typically scour herbaceous vegetation; however, most woody plants often remain. Thus, extended high flows followed by extended low flows in the following growing season result in a transition from shrub wetland to a cottonwood-willow community on channel margins. A transition from marsh to shrub wetland occurs on lower reattachment bars with 4 years of consecutive seasons of low fluctuating flows or non-growing season sustained low flows (Ralston et al. 2014).

The relative change in cover of these wetland community types was calculated from the state and transition model results. The number of years each of the wetland states occur in each submodel is projected for the 20-year LTEMP modeling period. The results for the seven alternatives and their long-term strategies are presented in Figure I-3. A mean score of 1.0 indicates no change from initial conditions is expected. A score greater than 1.0 indicates an increase in wetland cover; a score of less than 1.0 indicates a loss in wetlands. Alternative F scored the lowest (0.14), and long-term strategy E6 scored the highest (1.10). Alternative A scored 0.72.

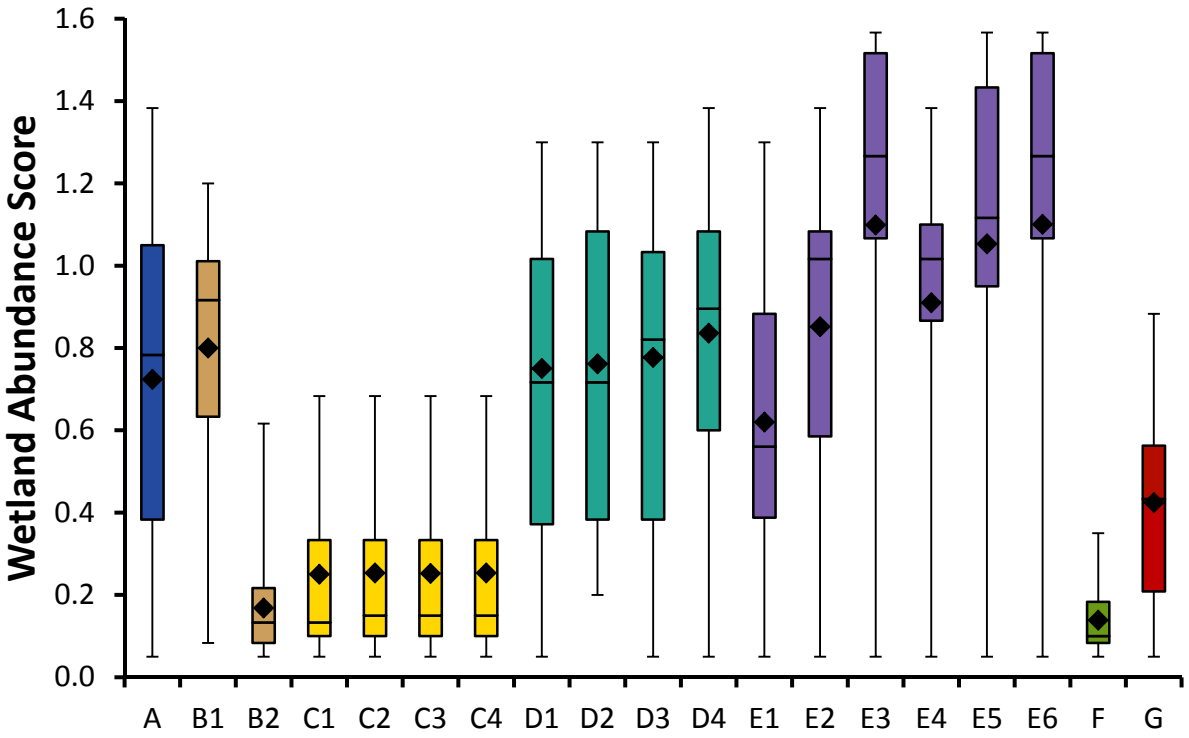

FIGURE I-3 Wetland Abundance for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

Only Alternative E, long-term strategies E3, E5, and E6—none of which have HFEs—show an increase in wetland cover (based on mean scores); all others show a decrease. However, long-term strategies B1, D1, D2, D3, D4, E2, E3, E4, E5, and E6 all scored higher than Alternative A. The alternatives with high scores are characterized by fewer extended high flows (greater than 20,000 cfs) and fewer extended low flows (less than 10,000 cfs) than Alternative A. There is enough water to sustain wetlands, but not too much inundation to support them over time. A large decrease in wetland community cover occurs under B2, all Alternative C long-term strategies, Alternative F, and to a lesser extent Alternative G. Frequent extended low flows or extended high flows followed by extended low flows tend to result in the transition of wetlands to other plant community types. Repeated seasons of extended high flows, or sufficiently high flows during one season, can remove wetlands, resulting in bare sand landforms.

Under climate change assumptions, the overall pattern remains the same for all alternatives, except that the Alternative F score increases slightly, as seen in Figure I-4. On average, scores increased by 0.08, with Alternative F showing only a negligible increase in the mean score (0.0017).

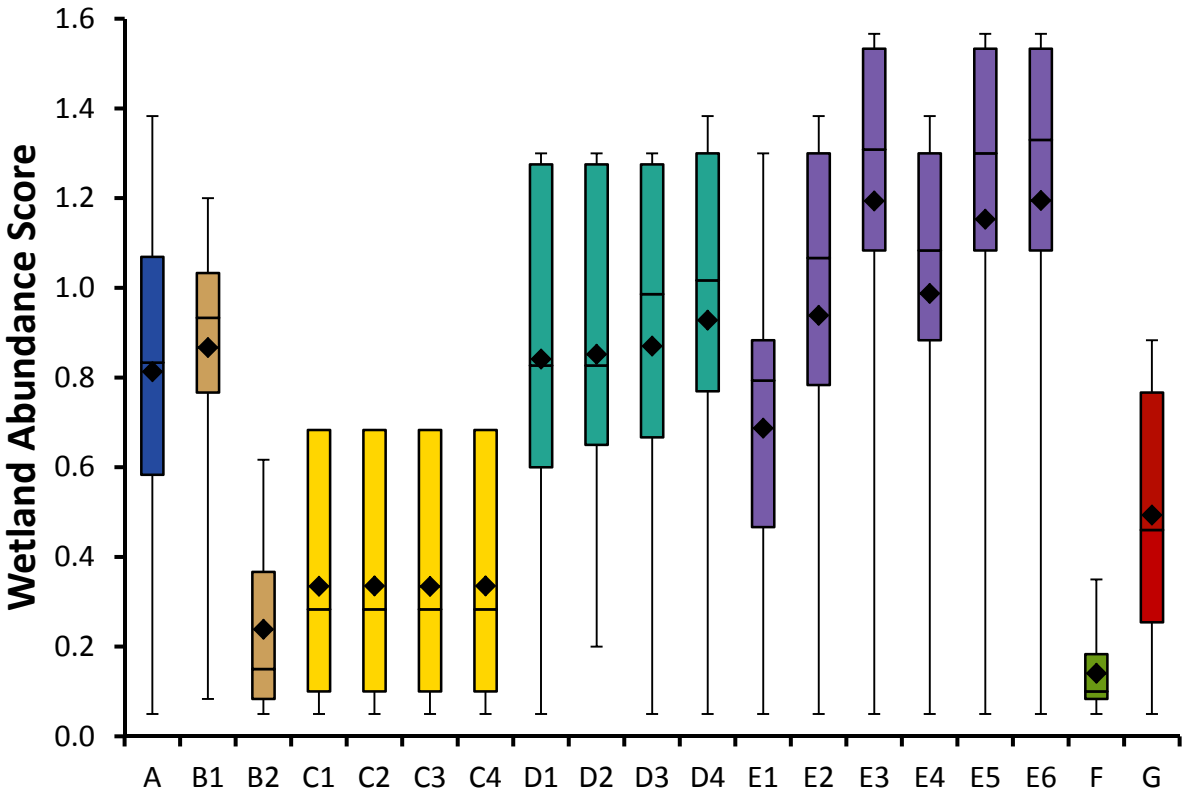

FIGURE I-4 Wetland Abundance under Climate Change Assumptions for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

I.1.3 Trout Management Flows

Reclamation and NPS are required under the U.S. Fish and Wildlife Service (FWS) biological opinion related to the *Non-native Fish Control Downstream from Glen Canyon Dam Environmental Assessment* (Reclamation 2011) to take steps to protect and encourage the recovery of endangered humpback chub (*Gila cypha*) populations in the canyons. The Little Colorado River is the home of a significant population of chub, which interact with rainbow trout at the confluence of the Colorado River and the Little Colorado River. Past and proposed methods for encouraging chub population growth involve reducing the number of nonnative trout, which prey on and compete with the chub. Large-scale killing of trout brings Reclamation and NPS into conflict with the value placed on all forms of life held by some Tribes. Although Tribes differ as to whether they consider the removal of nonnative fish species positively or negatively, many Tribes place a high value on the sanctity of life throughout the ecosystem and see themselves as its stewards. For them life, including fish and animal life, must not be wasted and must not be taken except to sustain human life. The Zuni in particular have important cultural ties to aquatic life in the canyons. The confluence of the Colorado River and the Little Colorado River is particularly sacred.

Aquatic resources models allow the comparison of the number of years trout management flows designed to strand trout larvae and fry would be triggered, and the number of years in which mechanical removal of trout would be triggered across the alternatives and their associated long-term strategies. Details of the models are presented in Appendix F.

A trout management flow is a highly variable flow pattern of water releases at Glen Canyon Dam intended to control the number of young-of-the-year trout in the Glen Canyon reach of the Colorado River. Reducing the number of trout in the Glen Canyon reach would reduce the number of trout emigrating downstream to the confluence with the Little Colorado River and other downstream areas. A typical trout management flow would consist of several days of a relatively high sustained flow (e.g., 20,000 cfs) that would prompt young fish to move into the shallows along the channel margins and, depending on the time of year, would prompt spawning fish to construct redds and lay eggs in nearshore shallow areas. The high flows would be followed by a rapid drop to a low flow (e.g., 5,000 cfs), stranding and killing young-of-the-year trout and, depending on the time of year, possibly exposing eggs in shallow redds, thus preventing them from hatching. Management flows would be triggered during years in which the production of young-of-the-year rainbow trout in the Glen Canyon reach is anticipated to be high (more than 200,000 individuals).

Figure I-5 shows the projected number of years in which trout management flows would be triggered under each alternative and long-term strategy. Trout management flows are not elements of all alternatives and may not occur in many years, even under alternatives that allow them. Under each of the alternatives and long-term strategies in which trout management flows are included, they would first be conducted as tests and then implemented only if they prove to be effective in reducing the trout population in the Glen Canyon reach and emigration to downstream sections of the Colorado River. Trout management flows are not included as elements of nine alternatives/strategies: Alternative C long-term strategies C2, C3, and C4; Alternative D long-term strategy D3; Alternative E long-term strategies E2, E3, E4, and E5; and Alternative F. They would be only tested under Alternative A. In long-term strategies D1, D2, and D4, trout management flow experiments would be implemented without triggers during the first 5 years of the LTEMP period. Figure I-5 assumes experiments in the first 5 years of the LTEMP period. In general, trout management flows would most likely be triggered when spring HFEs, which stimulate the food base, are followed by relatively steady summer flows (May–August). These factors are associated with higher production of young-of-the-year trout and would result in conditions that would trigger trout management flows more often. Where the number of HFEs is limited, as in Alternative B, it is expected that there would be fewer years in which trout management flows would be triggered. Modeling indicates trout management flows would be triggered most often under Alternative G and long-term strategy D2. The mean number of years in which trout management flows would occur are relatively high under long-term strategies D1, D2, and D4 because of the experimental flows that would be implemented, whether trout management flows are triggered or not. If trout management flows prove successful, they would reduce the number of times mechanical removal near the Little Colorado River confluence would be triggered.

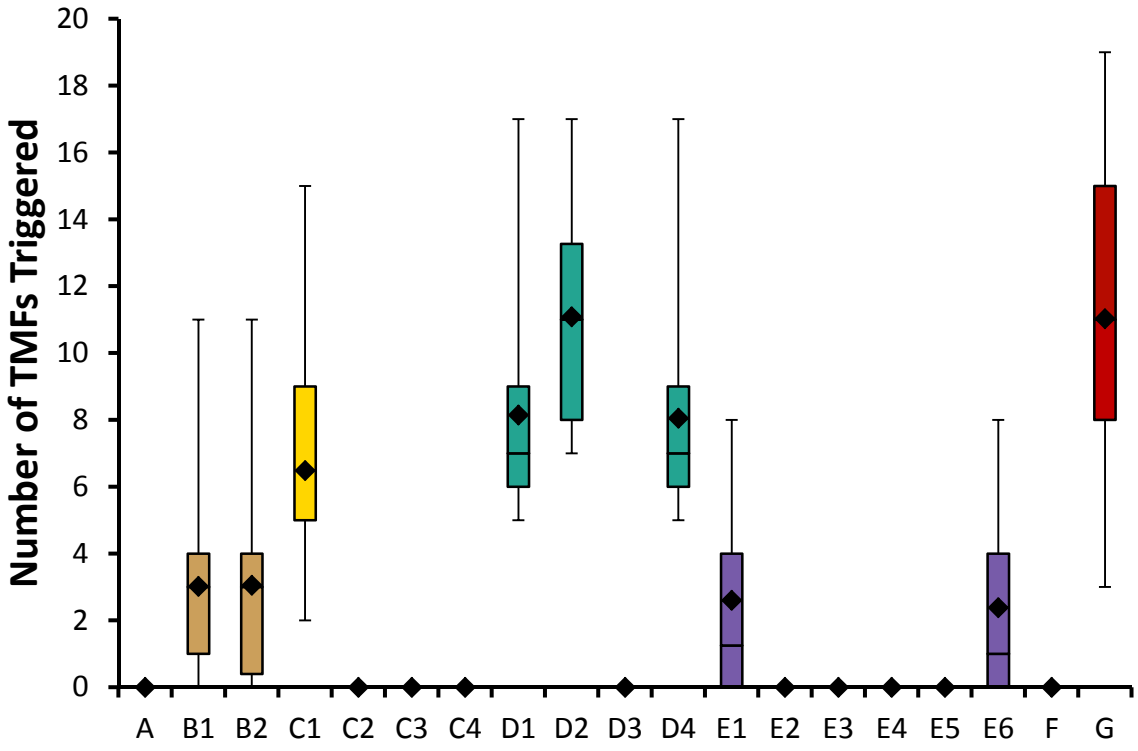

FIGURE I-5 Frequency of Trout Management Flows for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

As shown in Figure I-5, trout management flows would be triggered in just under half the alternative long-term strategies. Among the alternative long-term strategies that include trout management flows, the mean number of years during the 20-year LTEMP period in which trout management flows would occur ranges from 2.4 under E6 to 11.0 under Alternative G; the average number ranges between 2 and 4 years under six out of the nine alternative/long-term strategies where trout management flows are allowed.

Figure I-6 shows the frequency of trout management flows under climate change assumptions. A comparison of Figures I-5 and I-6 shows that the frequency distribution pattern is virtually the same for historical and climate change assumptions. On average, the mean value for each alternative/long-term strategy is 0.49 years less under climate change assumptions; this suggests that there would be somewhat fewer trout in the Glen Canyon reach, perhaps a reflection of a drier, warmer future climate.

I.1.4 Mechanical Removal of Trout

Mechanical removal would be implemented by using electrofishing to stun and remove nonnative fish.

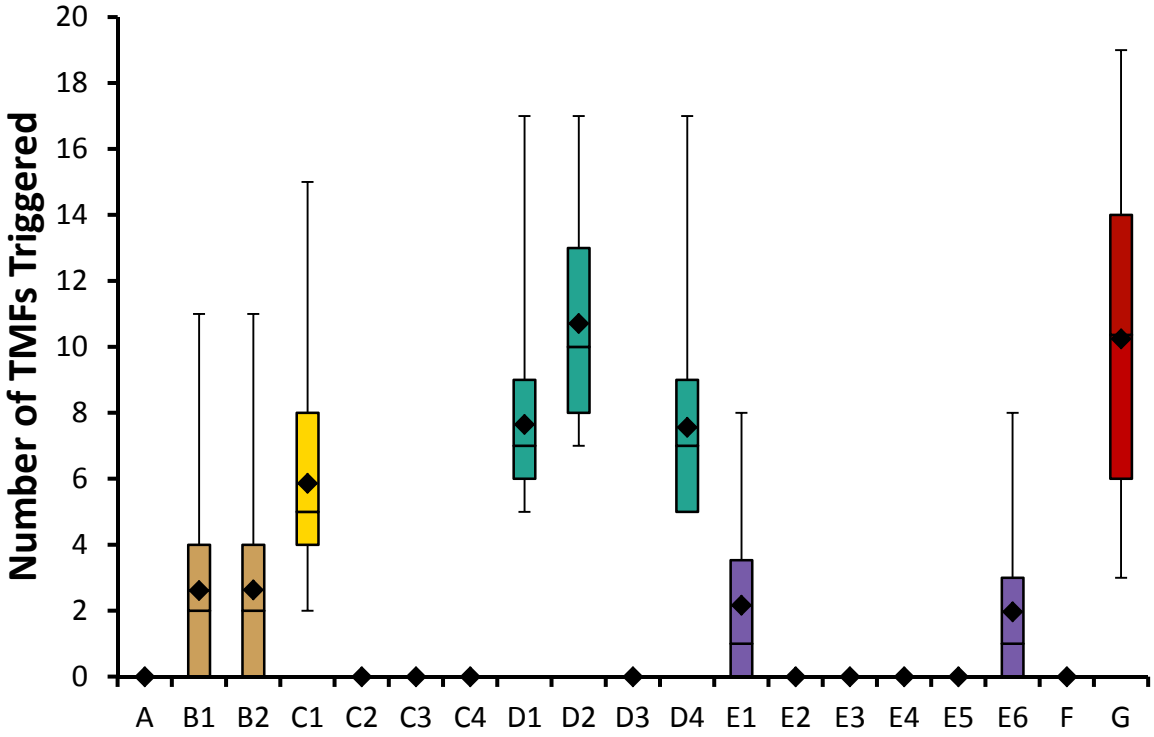

FIGURE I-6 Frequency of Trout Management Flows under Climate Change Assumptions for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

Although this does not kill the fish, usually the removed fish would be euthanized (killed) and put to some beneficial use. For example, in one mechanical removal test, the trout were emulsified and used as fertilizer in the Hualapai tribal gardens (Reclamation 2011). Grand Canyon Monitoring and Research Center (GCMRC) has modeled the number of years in which mechanical removal would be triggered under various alternatives. In the model two factors must coincide to trigger mechanical removal trips: (1) there must be more than 760 adult rainbow trout projected for the test reach in the vicinity of the Little Colorado River confluence (RM 63–RM 64.5), and (2) the projected adult humpback chub population for the canyons must be less than 7,000 individuals.

Figure I-7 shows the projected number of years in which mechanical removal from the Little Colorado River reach would be undertaken. Mechanical removal is not an allowed element of seven alternatives/strategies: Alternative C long-term strategies C1 and C2; Alternative E long-term strategies E1, E2, E5, and E6; and Alternative F. The mean number of years in which mechanical removal is modeled to occur ranges from 0.07 under Alternative A to 3.05 under Alternative G. In general, mechanical removal would be triggered in far fewer years than trout management flows. Modeling indicates that the average maximum number of years in which mechanical removal would be triggered is 6.3 out of 20, the projected maximum under D3. The overall pattern of mechanical removal events would be similar to the pattern of trout management flow occurrences and for similar reasons. Conditions that favor trout production

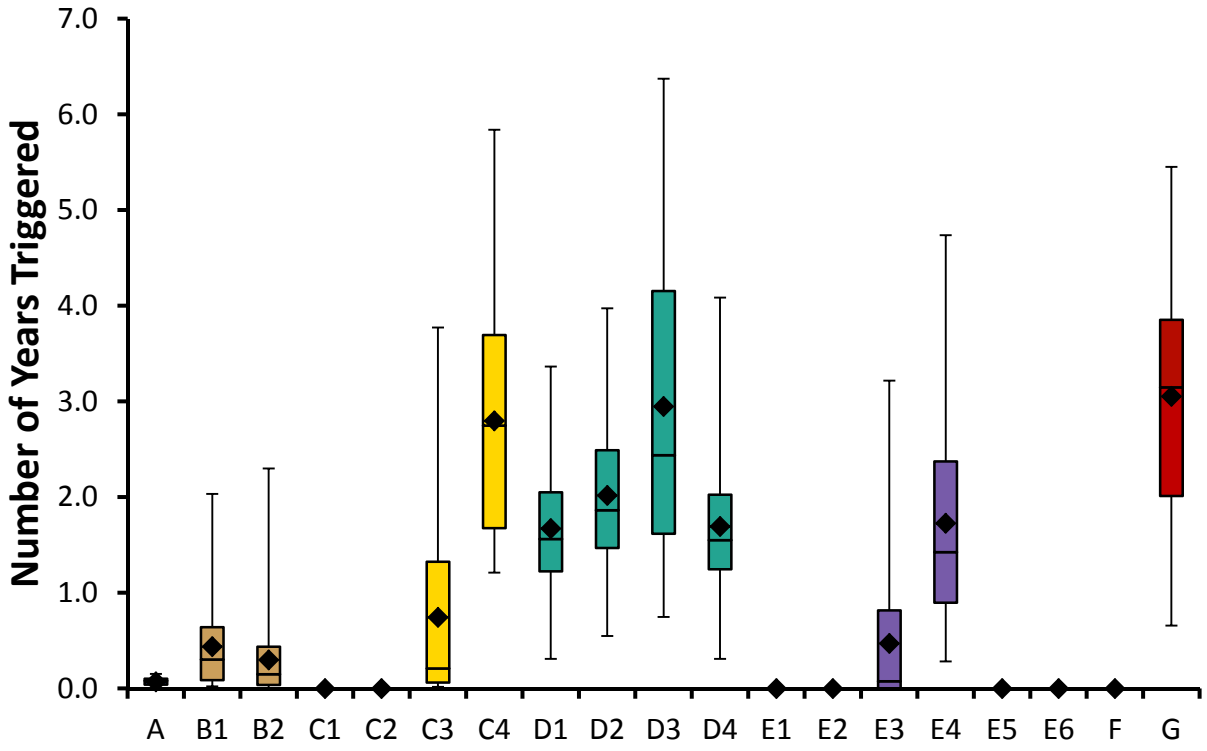

FIGURE I-7 Frequency of Mechanical Removal for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

(spring HFEs and steady summer flows) result in trout population increases in the Glen Canyon reach, thereby increasing the number of trout that move downstream to the Little Colorado River reach and triggering mechanical removal more often.

Figure I-8 shows the frequency of mechanical removal under climate change assumptions. As with trout management flows, the distribution pattern varies very little between the two plots. In all cases except Alternative G there is a slight decline in the mean number of years in which mechanical removal would be triggered. On average, those that score lower under climate change assumptions score 0.13 years less, while Alternative G scores 0.06 years more. This suggests that with the exception of Alternative G, river conditions would be slightly less favorable for trout production under climate change conditions.

I.1.5 Water Levels at Lake Powell

The domestic water supply for the LeChee Chapter of the Navajo Nation is obtained from Lake Powell through pumping and conveyance facilities that were first constructed at the time Glen Canyon Dam was built between 1957 and 1964 (NPS 2009). The current system relies on either an intake on the face of the dam at 3,480 ft above mean sea level (AMSL), or an intake off the penstocks, which are at an elevation of 3,470 ft AMSL at Lake Powell. Therefore, 3,470 ft

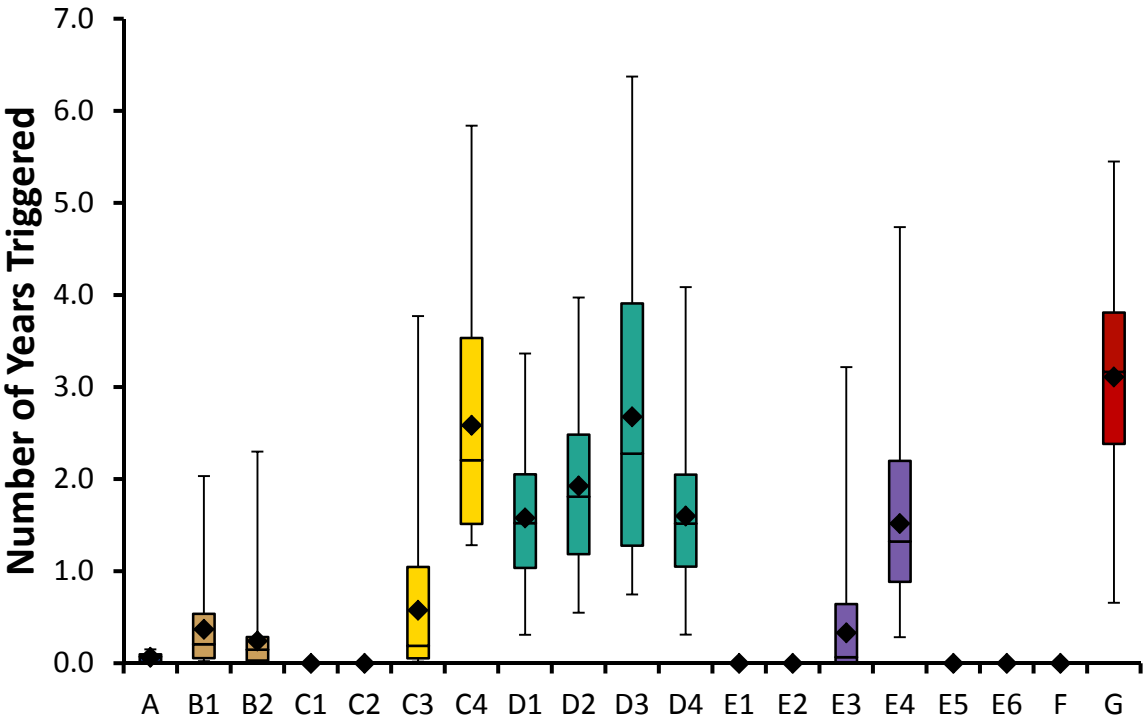

FIGURE I-8 Frequency of Mechanical Removal under Climate Change Assumptions for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

AMSL is the minimum elevation necessary for the LeChee Chapter to draw water from Lake Powell, even while penstock units are down or are undergoing maintenance.

An environmental assessment (EA) done in 2009 addresses possible future construction to provide a backup water supply to the area (NPS 2009). Three designs for new water supply systems from Lake Powell for the City of Page and the LeChee Chapter were evaluated. The EA eliminated two of the designs and narrowed the options to either no action or an entirely new pumping system which calls for six 48-in. intake pipes reaching the lake at an elevation of 3,373 ft AMSL.

The Colorado River Simulation System (CRSS) model was used for the LTEMP process to project future river and reservoir system conditions on a monthly time-step.

Because there are no known restrictions within the model for the intake pipes, an analysis was conducted to identify modeled minimum Lake Powell elevations in order to address concern regarding the LeChee Chapter's ability to draw water under LTEMP. End-of-the-month Lake Powell elevations were created as part of the LTEMP analysis (see Appendix E) for all the different hydrologic and sediment inputs (see Section 4.1 for a presentation of the overall modeling approach). A script within the MATLAB® scripting program was created to retrieve the minimum elevation possible within each alternative.

As shown in Figure I-9, there is little variation projected for Lake Powell water levels among the LTEMP alternatives. The mean water level for Lake Powell under all alternatives and long-term assumptions falls between 3,540 ft AMSL and 3,560 ft AMSL, well above intake elevations. More importantly, the minimum elevation of the lake modeled for all different input combinations and alternatives was 3,480 ft AMSL. This is the same elevation as the intake on the dam face and 10 ft above the elevation of the penstock intakes and well above elevations for any planned future intakes. Although there is always potential for modification of dam operations based on circumstantial conditions, the LeChee Chapter is projected to retain its water supply from Lake Powell under all LTEMP alternatives, with average levels slightly higher under Alternative F than the other alternatives.

As seen in Figure I-10, with the exception of Alternative F, climate change assumptions mean lake elevations are projected to fall just below 3,540 ft AMSL. Mean lake levels under Alternative F would be just above 3,540 ft AMSL. Even under climate change assumptions, minimum lake elevations are never projected to fall below 3,480 ft AMSL and are project to remain at least 10 ft above the minimum required to supply the LeChee Chapter with water. Only under Alternative F would the minimum projected Lake Powell elevation be above 3,490 ft AMSL.

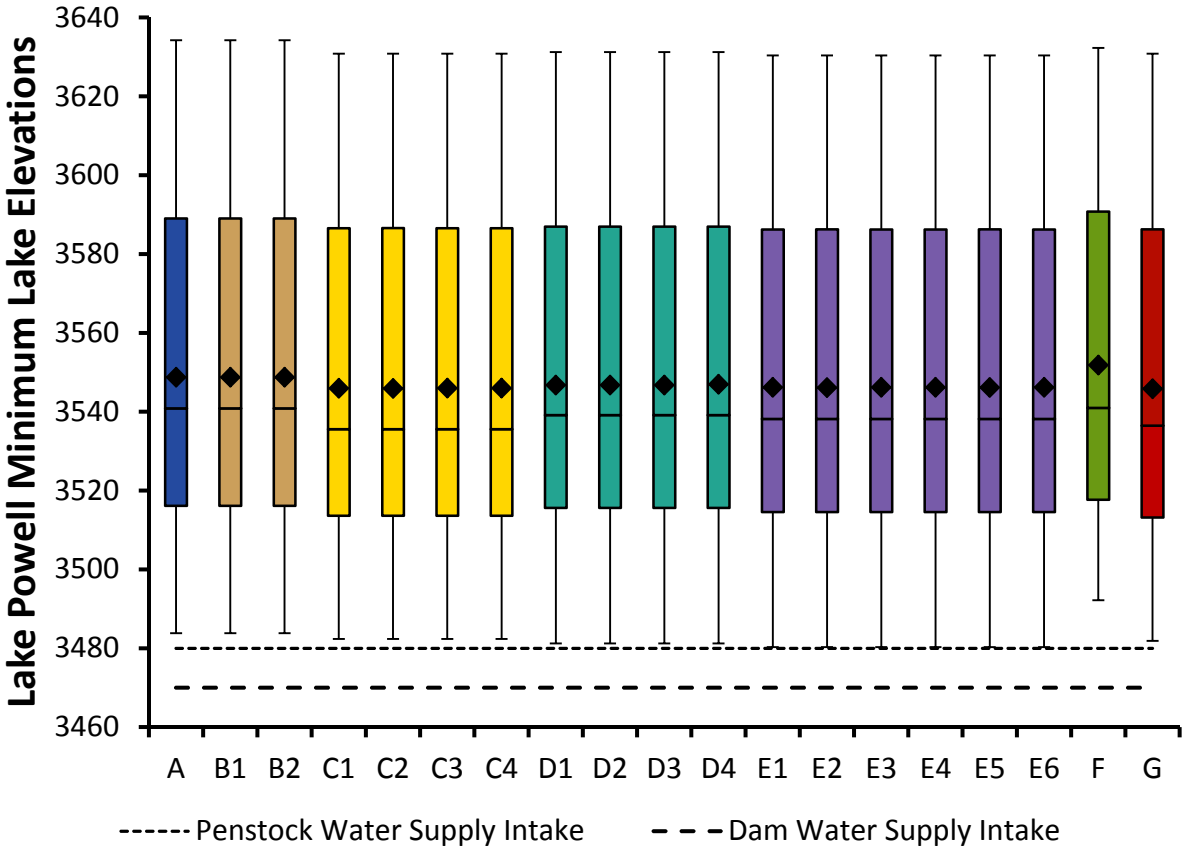

FIGURE I-9 Lake Powell Water Levels for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

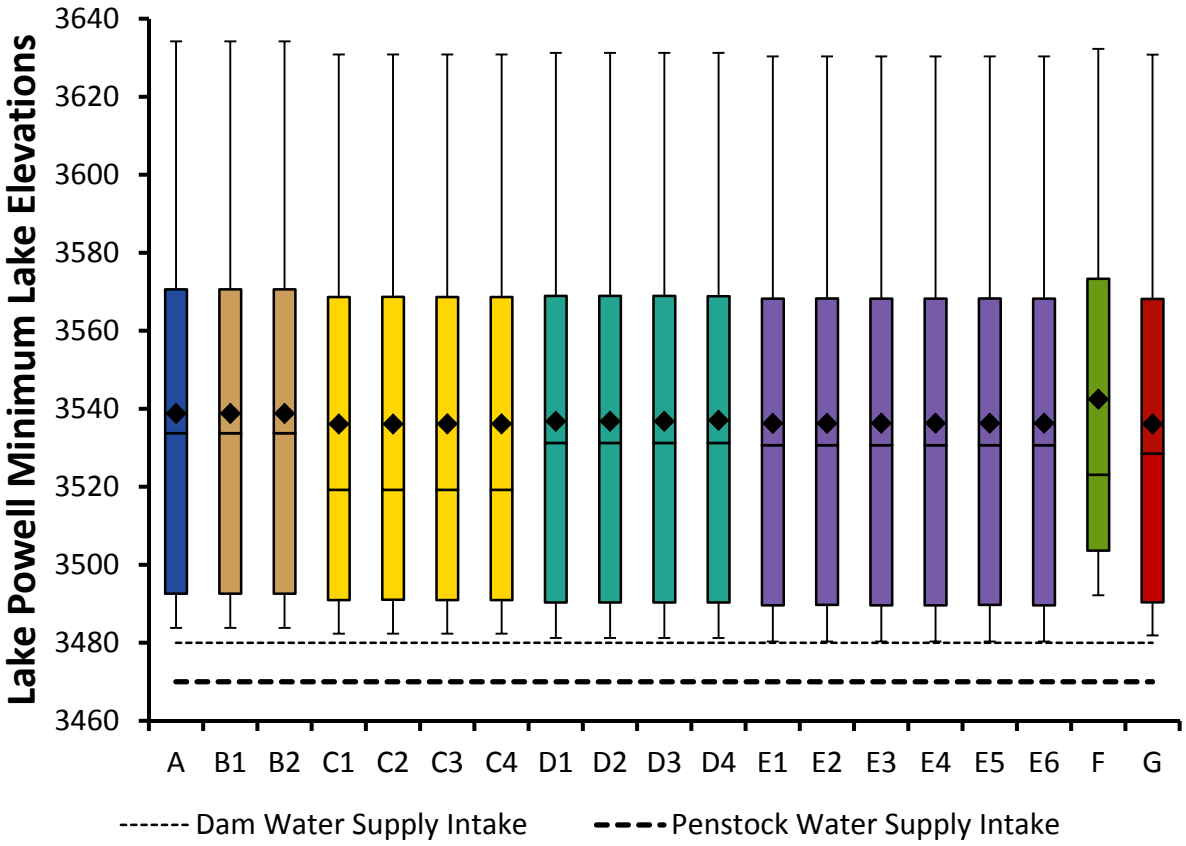

FIGURE I-10 Lake Powell Water Levels under Climate Change Assumptions for the LTEMP Alternatives (Letters) and Associated Long-Term Strategies (Numbers)

I.1.6 Access to Resources

Access to culturally important sites and resources has the potential to be a significant factor in assessing impacts from the alternatives. Resources important to the Tribes include plant resources important for food, medicinal, and ritual purposes; minerals including salt and pigments that are ritually important; and sacred places including springs and offering sites. Potential access interruption is tied to the frequency of HFEs. HFEs could cause temporary loss of access to culturally important resources through inundation of the resources or trails leading to them. These temporary interruptions can be mitigated by communication between Reclamation and the Tribes so that Tribes have notice of impending HFEs. Of the LTEMP alternatives, Alternative F and Alternative G have the most HFEs. Under the latter alternative, there are HFEs that last as long as 2 weeks. Alternative C long-term strategies C1 and C2 have a similar number of HFEs as the steady flow alternatives. Alternative C long-term strategy C4 and Alternative E long-term strategies E1, E2, and E4 have a moderate number of HFEs. Alternative A and Alternative B long-term strategies are projected to have a small number of HFEs (seven or fewer over 20 years). No HFEs are projected for Alternative C long-term strategy C3 or Alternative E long-term strategies E3, E5, and E6.

Potential impacts on archeological sites important to Tribes are discussed in Appendix H of this EIS.

I.2 REFERENCES

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APPENDIX J:

RECREATION, VISITOR USE, AND EXPERIENCE TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX J:

RECREATION, VISITOR USE, AND EXPERIENCE TECHNICAL INFORMATION AND ANALYSIS

The Glen and Grand Canyons of northern Arizona provide a unique experience of extraordinary geologic landscapes, diverse wildlife and vegetation, and over 12,000 years of human history for visitors from across the globe. The area offers a variety of recreational activities including flatwater and whitewater boating, hiking, and angling. This Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), developed by the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), has identified the recreational experience goal as being to "maintain and improve the quality of recreational experiences for the users of the Colorado River ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon" (Section 1.4). Past recreational studies have shown that Glen Canyon Dam operations can affect the experience of recreationalists in the downstream Glen and Grand Canyons (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). In an effort to quantitatively assess the downstream impacts on recreational activities of the LTEMP alternatives, six performance metrics were created to address recreational concerns. This appendix explains the metrics and compares the performance of the LTEMP alternatives as indicated by the metrics.

The alternatives encompass 19 long-term strategies, which include various combinations of experimental components (Appendix C). A full range of potential hydrologic and sediment conditions were modeled for the 20-year LTEMP period. Twenty-one potential Lake Powell in-flow scenarios (known as hydrology traces) for the 20-year LTEMP period were used to generate twenty-one 20-year hourly release patterns for each alternative and long-term strategy. In addition to these twenty-one hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record were analyzed that represented low, medium, and high sediment conditions. In combination, the twenty-one hydrology traces and three sediment traces resulted in an analysis that considered sixty-three possible hydrology-sediment conditions.

In the presentation of results below, LTEMP alternatives are identified by the alternative letter designation (Alternatives A through G) and, if the alternative includes multiple long-term strategies, a number designation (1 through 6, depending on the number of long-term strategies for an alternative) that denotes a particular long-term strategy within an alternative. See Appendix C for descriptions of the long-term strategies.

J.1 RECREATIONAL EXPERIENCE METRICS

The analysis of potential impacts on recreational experience is based primarily on the evaluation of six quantitative metrics that were developed for the assessment, but also on more qualitative information and experience of GCNRA and GCNP staff and on the studies that served as the basis for quantitative metrics. The metrics were developed through consultation with

subject matter experts, findings in published papers and reports, and with consideration of comments from the Cooperating Agencies.

J.1.1 Grand Canyon Metrics

Of the six evaluation metrics, four address issues important to visitor use and experience in Grand Canyon National Park (GCNP) downstream of Lees Ferry, while the remaining two metrics address the Glen Canyon reach between the dam and Lees Ferry. The metrics are:

- *Camping Area Index (CAI):* Accounts for optimal campsite area building and maintenance flows and sediment load (also used as input to the assessment of campsite crowding).

- *Navigational Risk Index (NRI):* Measure of navigation difficulty based on the number of days during which the daily minimum flow was less than 8,000 cfs (also used as input to the assessment of campsite crowding and encounters with other groups).

- *Fluctuation Index (FI):* Measures the degree to which combinations of flows and fluctuations are within a range identified as preferable by experienced boat guides.

- *Time Off River Index (TORI):* Relates the level of flows to visitors being able to spend time ashore visiting attractions.

J.1.2 Glen Canyon Metrics

- *Glen Canyon Rafting Metric (GCRM):* Estimates the number of visitors unable to participate in day rafting in Glen Canyon due to high flows.

- *Glen Canyon Inundation Metric (GCIM):* Accounts for flows that impact recreational sites and recreational uses within the Glen Canyon reach.

Some of the metrics evaluate non-tangible, qualitative aspects of the recreational experience. Such metrics may be based on results of recreational surveys of visitor experience under various flow and fluctuation conditions, which overlap dam operations under LTEMP alternatives (Hjerpe and Kim 2001). These and other metrics used in the analyses and described elsewhere in this EIS (see Appendices B and C) based on relative performance are expressed as an index having values from 0 to 1, where increasing values indicate increasing performance with respect to the associated resource goal. Metrics employing an index include the CAI, NRI, FI, TORI, and GCIM. The GCRM is the only metric that uses an absolute scale. It is the number of potential lost visitor trips for day-use rafts in Glen Canyon due to high flows during high-flow experiments (HFEs).

The metrics all rely on the hourly Glen Canyon Dam discharge computed by the GTMax-Lite model (Reclamation 2007) with the incorporation of a sediment analysis (Russell and Huang 2010) to account for HFE implementation (Appendix E). GTMax-Lite produces a trace (20 years of hourly discharge) for each combination of hydrology and tributary sediment traces input into the model. For each metric, all 7 alternatives and any associated long-term strategies were analyzed for all 63 traces (see Section 4.1 for more detail). The following sections explain the calculation of recreation metrics for an individual trace.

In all metrics but the GCRM, the index value is weighted to emphasize seasons with greater recreational use over the course of a year. Percent of annual recreation use was determined to be 15% in the winter months of November, December, January, and February; 31% in the spring and fall months of March, April, September, and October; and 54% in the summer months of May, June, July, and August (based on monthly visitation statistics presented in https://irma.nps.gov/Stats/Reports/Park/GRCA).

J.2 METRIC DEFINITIONS, ANALYSIS METHODS, AND RESULTS

J.2.1 Camping Area Index

Campsites are primarily located on sandbars along the shoreline of the river, and they provide open, flat areas ideal for camping. Crucial for multi-day trips, campsites can limit the visiting capacity (the number of people to maintain a desired natural visitor experience) for high-demand downstream rafting trips (Kearsley et al. 1994). The management of campsites is therefore of particular concern to river managers (NPS 2006). To meet the visitor capacities established in the NPS Colorado River Management Plan, it is necessary to develop and retain medium (16–25 people) and large (>25 people) campsites, which maintain and potentially improve visitor experience based on preferences expressed in surveys of visitors. Commercial and private trip leaders preferred large beaches for camping compared to smaller beaches (Stewart et al. 2000). A study by Kaplinski and others monitoring campsites from 1998 to 2012 reported a decrease of average campsite area by 36% with any decrease in area noted at 29 out of the 37 study sites (Kaplinski et al. 2014).

Dam operations have been shown to have significant effects on campsite area. HFEs have proven to temporarily increase campsite area due to sandbar deposition (Grams et al. 2010; Hazel et al. 2010). In the Grand Canyon Monitoring and Research Center (GCMRC) *Fiscal Year 2014 Annual Project Report* (GCMRC 2015), Kaplinski and others concluded, “sandbar deposition associated with high flows results in increases in campsite area, while post-HFE erosion causes decreases in campsite area.” Currently, it is perceived that lower discharge reduces erosion to campsites, while also exposing campsites that are covered at higher discharges. A decrease of discharge from 25,000 cfs to 15,000 cfs during normal flows increased campable area by 73%; a further increase of 46% in campable area was seen when discharges further decreased to 8,000 cfs (Kearsley and Warren 1993).

J.2.1.1 Camping Area Index—Methods

The CAI evaluates the conditions conducive to increased camping area in the Grand Canyon, which is a function of the amount of sand deposited and retained and campsite area exposure as a function of river level (flow rate). The output from the sand load index (SLI), which simulates sediment conditions between RM 0 and 30 provides a proxy for indicating whether the alternatives are likely to create the conditions conducive to creating/retaining campsite area (Appendix E). The CAI is the product of the SLI and a Seasonally Weighted Flow Factor (SWFF):

$$CAI = Average(SWFF)_{2014-2033} \times SLI$$

Both the SLI and SWFF are indices ranging from 0 to 1, as is the resulting CAI, where a value of 1 indicates the greatest potential to increase camping area. As the metric output is a generalization of sediment conditions throughout the canyon, it does not predict conditions at any particular site. Erosion is not taken into account in the CAI. Daily flow level is accounted for in the SWFF, as discussed below. Lower flows provide more camping area (i.e., there is more camping area at 8,000 cfs than at 25,000 cfs because more sand is exposed at lower flows [Kearsley and Warren 1993]). The minimum flow within the daytime period (7 am to 7 pm) is 8,000 cfs under most LTEMP alternatives.

The SLI is an index of the potential sand deposited on sandbars along the river channel in Marble and Grand Canyons above normal stage elevations (31,500 cfs). The SLI is calculated as the ratio of the cumulative sand load at flows greater than 31,500 cfs relative to the total cumulative sand load at all flows modeled (Appendix E). The sand load, or the mass of sand in transport by the river, is calculated at RM 30 and is computed by a version of the Sand Budget Model (Wright et al. 2010) for the 20-year LTEMP period. A larger SLI (on a scale of 0–1), indicates a greater potential for sediment deposition. The SLI was calculated using the following equation:

$$SLI = \frac{\sum_{2014-2033} Sand\ Load\ at\ dam\ discharges > 31{,}500\ cfs}{\sum_{2014-2033} Sand\ Load\ at\ all\ dam\ discharges}$$

The SWFF is a yearly value representing the relative amount of river bank exposure available for camping areas dependent on the Glen Canyon discharge. Low river flows will expose more campsite area while higher flows will submerge campsite area and potentially cause erosion (Kearsley and Warren 1993). Flows above 8,000 cfs are considered to increasingly reduce camping area and to submerge most campsite areas at 31,500 cfs. Camps above 25,000 cfs are considered high campsites in Kaplinski (2014). With no data on the exact location of all campsites relative to the river, an informed assumption is made here. The daily maximum flow is used to evaluate the extent to which flows may cover campsites at any point in the day.

Modeled daily flows are assigned a 0–1 index value, referred to as the daily flow factor (FF_{Daily}):

$$FF_{Daily} = \begin{cases} \text{if } Q_{max} \leq 8{,}000 \text{ cfs}; & 1 \\ \text{if } 8{,}000 < Q_{max} < 31{,}500\ cfs; & 1.34 - 0.0000425 \times Q_{max} \\ \text{if } Q_{max} \geq 31{,}500 \text{ cfs}; & 0 \end{cases}$$

where Q_{max} refers to the daily maximum discharge released from the Glen Canyon Dam in cfs and FF_{Daily} is equal to the value in the right column if the equation in the left column is satisfied.

The yearly index value (SWFF) is the ratio of the index values for each season:

$$\text{SWFF} = \left\{0.15\left(\frac{\sum_{\text{winter}} FF_{daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{\text{spring\&}fall} FF_{daily}}{\sum Days_{spring\&fall}}\right) + 0.54\left(\frac{\sum_{\text{summer}} FF_{daily}}{\sum Days_{summer}}\right)\right\}$$

J.2.1.2 Camping Area Index—Results

CAI values for all 19 LTEMP long-term strategies are shown in Figure J-1. All of these have higher CAI values than Alternative A (no-action alternative). Long-term strategies B2, C3, E3, E5, and E6 rank below Alternative A. With the exception of B2, HFEs are not conducted for these long-term strategies, and therefore flows above 31,500 cfs, the primary mechanism for sediment deposition, occur rarely, if at all. Experimentally increased flow fluctuations (hydropower improvement flows) under B2 cause it to rank below Alternative A.

The CAI is fairly insensitive to SWFF because SWFF values typically range only between 0.55 and 0.77. Consequently, the CAI is strongly dependent on the SLI, and therefore to the number of HFEs under a given alternative or long-term strategy (see Appendix E). The strong dependence of CAI on SLI can be seen by comparing Figure J-1 and Figure J-2.

Alternative G has the highest CAI, a value 3.2 times that of Alternative A. This result is attributed to the highest number of HFEs and relatively even year-round daily flows under Alternative G, conditions conducive to conserving sediment and increasing camping area through deposition and retention of sediment. Ranking second-highest, Alternative F, with a CAI 2.9 times that of Alternative A, has low flows in non-summer months and more 96-hour HFEs than other long-term strategies.

Long-term strategy B2 has a slightly reduced CAI compared to B1 attributable to testing of hydropower improvement flows under B2, which reduces CAI through reductions in both SLI and SWFF. The CAI for long-term strategy C4 is reduced relative to that for C1 and C2 due to the absence of spring HFEs and proactive spring HFEs under C4, which reduces its SLI value. C3 is much reduced owing to the absence of spring or fall HFEs, as noted above.

The CAI for long-term strategy D4 is not significantly different from D1, D2, D3, or C1, based on a test of differences between means using a three-factor analysis of variation (ANOVA)

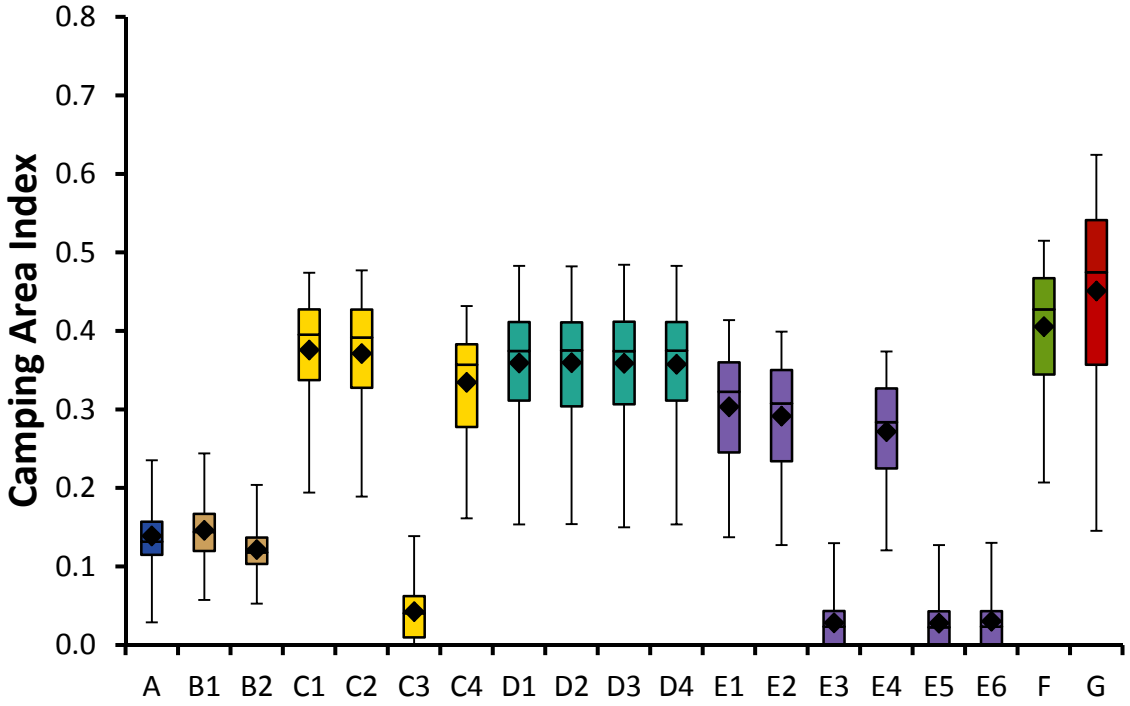

FIGURE J-1 Camping Area Index for LTEMP Long-Term Strategies (Increasing values indicate increasing camping area. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

followed by Tukey's Studentized Range Test. This indicates that low summer flows under D1, D2, and D3 have no effect on CAI, nor does sustained low flows for benthic invertebrate production under D2 or the absence of trout management flows under D3.

The CAI for long-term strategy E4 is slightly lower than that for E1 and E2, indicating a small reduction in sediment retention for E4 due to the absence of spring HFEs in the second 10 years of the LTEMP period, which are conducted under E1 and E2. As noted above, E3, E5, and E6 do not include spring or fall HFEs, explaining their low CAI values.

J.2.2 Navigational Risk Index

Navigating the Colorado River downstream of Glen Canyon Dam at low flows, especially at rapids, can cause difficulties for oar and motor trips. A survey conducted by Bishop et al. (1987) of commercial oar and motor guides indicated that flow levels below 9,200 cfs and 8,400 cfs, respectively, began to compromise boater safety. In the Bishop et al. (1987) study, guides were simply asked for minimum levels of flow for running safely with passengers. Survey respondents noted that at these flows, boat accidents related to exposed rocks are much more probable. A similar survey by Shelby et al. (1992) reported nearly the same

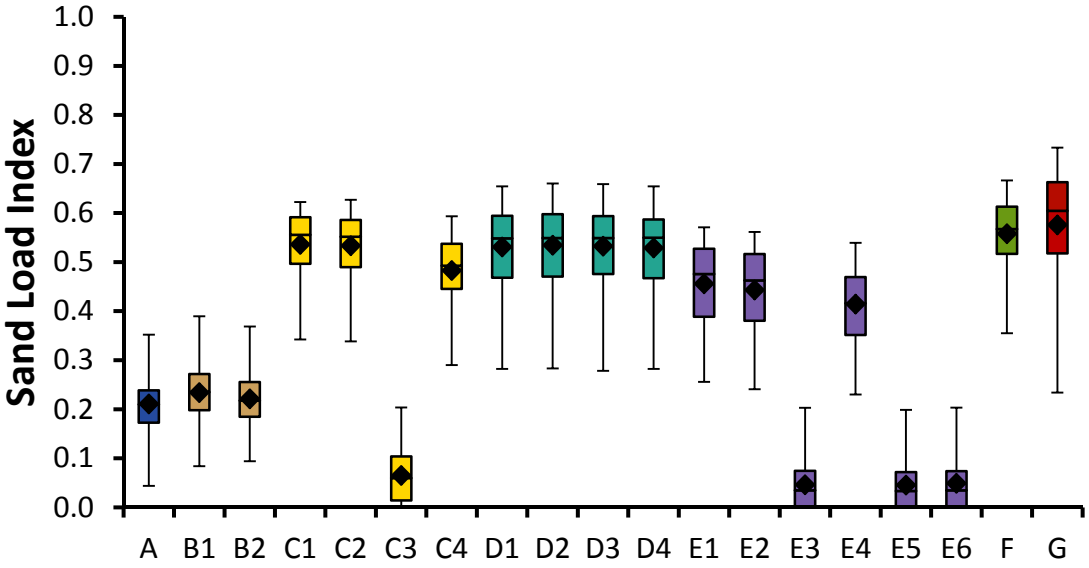

FIGURE J-2 Sand Load Index (see Appendix E) for LTEMP Long-Term Strategies (Increasing values indicate more sediment deposited along river banks. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

values as Bishop et al. (1987), and a more recent survey by Stewart et al. (2000) had similar findings with oar and motor river guides identifying approximately 8,100 cfs and 7,800 cfs, respectively, as minimum flows for what they considered safe river trips. Exposures to experimental low flows of 8,000 cfs in the summer of 2000 further supported the guides' perceptions of potentially dangerous flows, with double the number of boating accidents reported than the previous year, mostly associated with hitting exposed rocks (Ralston 2011).

J.2.2.1 Navigational Risk Index—Methods

To assess the risk due to difficulties of motor rigs navigating rapids at lower flows, the risk (frequency) of daily minimum discharges that are ≤8,000 cfs was determined for each season. To account for the variance in use between the seasons, the yearly value is averaged with weights corresponding to recreational use as used above for SWFF in calculating the CAI. The annual risk was calculated as:

$$Risk = \left\{ 0.15 \left(\frac{\sum_{\text{winter}} Days_{min}}{\sum Days_{winter}} \right) + 0.31 \left(\frac{\sum_{\frac{\text{spring}}{\text{fall}}} Days_{min}}{\sum Days_{\frac{spring}{fall}}} \right) + 0.54 \left(\frac{\sum_{\text{summer}} Days_{min}}{\sum Days_{summer}} \right) \right\}$$

where $Days_{min}$ is the number of days when flows were <8,000 cfs, $Days_{winter}$ is the number of days in the winter, $Days_{spring/fall}$ is the number of days in the spring and fall, and $Days_{summer}$ is the number of days in the summer.

The index is the complement of the risk, where 1 indicates 100% of minimum daily flow above 8,000 cfs and is therefore the least risk to river navigators. Thus, the NRI for a single input trace for the LTEMP period of 2014–2033 is as follows:

$$NRI = Average(1 - Risk)_{2014-2033}$$

While Alternatives A through E restrict minimum flows to 8,000 cfs during day hours (7 am to 7 pm), flows during night hours (7 pm to 7 am) can drop to 5,000 cfs, and these low flows can affect downstream boaters during daylight hours well after the change in discharge rate occurs at the dam due to the transit time required for the change to reach downstream locations. The calculation of daily minimum flow was therefore inclusive of the entire 24-hour period.

J.2.2.2 Navigational Risk Index—Results

NRI values for each alternative are shown in Figure J-3. Long-term strategies C1–C4, D2, F, and G have higher values than Alternative A, while D1, D3, and D4 are only slightly lower than Alternative A. Long-term strategy B2 has the lowest NRI value owing to high flow fluctuations and low minimum flows, while B1 and E1–E6 are also lower than Alternative A.

Alternative G has year-round steady flows of approximately 11,000 to 13,000 cfs, rarely dipping below 8,000 cfs, resulting in an NRI approaching 1 (lowest risk). Alternative F, which also has steady daily flows, has high flows in the months of February through June and lower flows running near or below 8,000 cfs in July through January. However, for the historic water volumes modeled (typically greater than 8.23 maf), higher releases would sometimes occur for equalization purposes at the end of the water year. Primarily for this reason, the average days with flows above 8,000 cfs actually outnumber the days below it for Alternative F. On average, Alternative F has an NRI almost 1.5 times that of Alternative A.

For alternatives with fluctuating flows, the size of daily fluctuations generally differentiates between alternatives, while experimental features drive differences between long-term strategies within alternatives. Daily fluctuations under Alternative C are lower than those under Alternatives A, D, E, and B, resulting in fewest occurrences of flows less than 8,000 cfs and the highest NRI value (lowest risk) of the fluctuating-flow alternatives. The relative ranking of these alternatives in Figure J-3 generally reflects the size of daily fluctuations, which determines the frequency of flows less than 8,000 cfs.

Within alternatives, long-term strategy B2 has a lower NRI (higher risk) than B1 due to high fluctuations and flows less than 8,000 cfs associated with experimental hydropower improvement flows not included in B1. For the same reasons, B2 has the lowest NRI (highest risk) of all long-term strategies. C2 has a slightly lower NRI than C1, C3, and C4 due to the

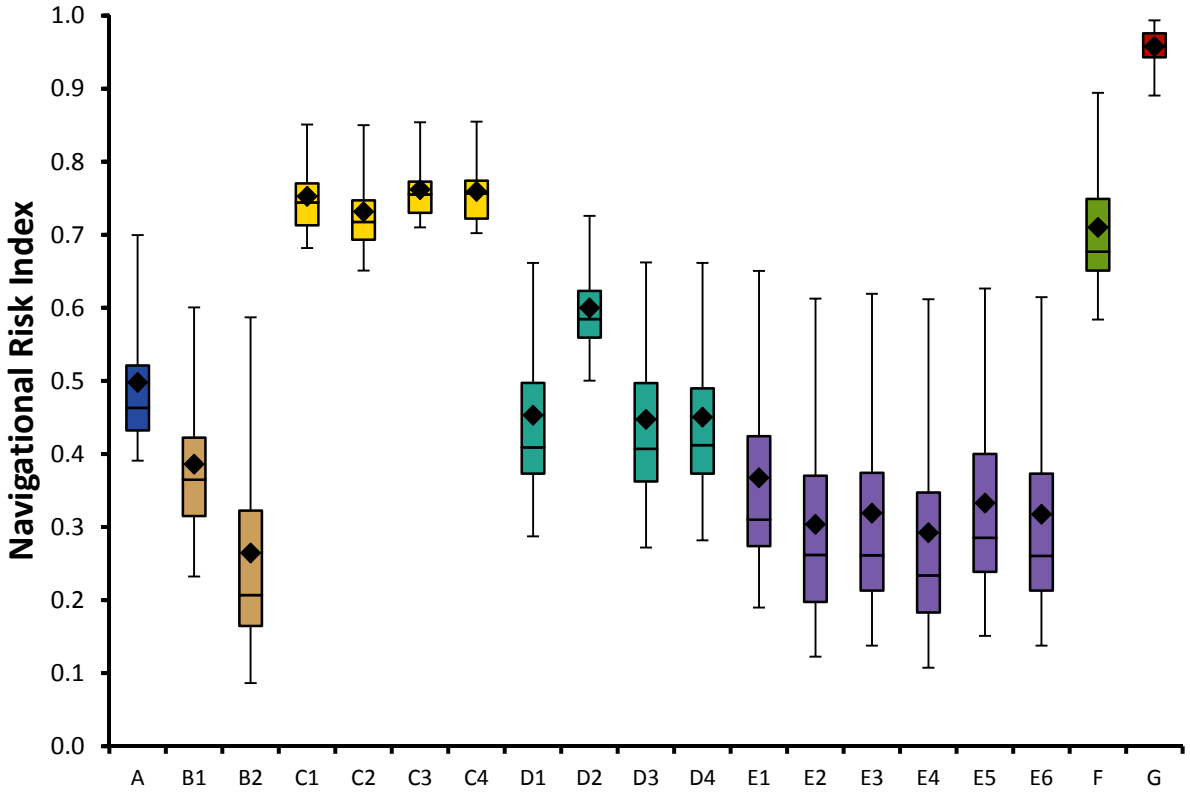

FIGURE J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies (Increasing values indicate improving navigation conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

inclusion of low summer flows, which allows minimum daily flows as low as 5,000 cfs. Low weekend flows to promote benthic invertebrate production during May–August under long-term strategy D2 increase the overall minimum flow during those months, elevating the NRI relative to D1, D3, and D4. Absence of low summer flows under E1, E3, E4, and E6 elevates the NRI for these long-term strategies slightly compared to E2 and E5.

J.2.3 Fluctuation Index

Whitewater rafting guides surveyed by Bishop et al. (1987) indicated that moderate (8,000–25,000 cfs) and severe (1,000–33,500 cfs) daily fluctuations are potentially problematic for rafting trips. Fluctuations can complicate mooring at campsites, and running rapids, and can increase the unpredictability of flows. Bishop et al. surveyed guides and private trip leaders with experiences of both large fluctuations (greater than 15,000 cfs) and steady flows and documented the ranges of tolerable fluctuations at various river flow levels, as shown in Table J-1.

TABLE J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial Motor Guides, Commercial Oar Guides, and Private Trip Leaders Who Have Experienced Daily Fluctuations of at Least 15,000 cfs in the Grand Canyon[a,b]

River flow (cfs)	Commercial Motor Guides	Commercial Oar Guides	Private Trip Leaders
5,000–9,000 cfs			
Mean daily change (cfs)	3,231	*3,412*	*2,428*
Standard deviation (cfs)	2,320	3,180	2,233
Sample size	52	34	45
9,000–16,000 cfs			
Mean daily change (cfs)	4,706	*4,786*	*3,936*
Standard deviation (cfs)	2,094	2,311	2,693
Sample size	52	35	47
16,000–32,000 cfs			
Mean daily change (cfs)	*7,192*	6,708	*6,410*
Standard deviation (cfs)	3,404	2,812	3,679
Sample size	52	36	50
32,000 cfs and above			
Mean daily change (cfs)	*9,760*	*7,903*	8,612
Standard deviation (cfs)	5,375	2,917	6,470
Sample size	52	36	49

[a] Table taken from Table 4-7 of Bishop et al. (1987).

[b] Italicized values indicate the maximum tolerable fluctuation threshold range used in the FI after rounding to the nearest hundred cfs.

J.2.3.1 Fluctuation Index—Methods

Table J-1 is the basis for the FI. It is assumed that (1) the river flow ranges shown in the left-hand column of Table J-1 are based on the mean daily flow and that (2) the maximum tolerable fluctuation threshold (italicized flow values in Table J-1) serves as the level above which fluctuations become increasingly more unacceptable to river users.

A daily flow factor (FF) value of 0–1 was computed using Table J-1 and the mean flow for a given day. The daily flow factor is 1 if the fluctuations are within the acceptable range. Above the threshold, daily FF goes linearly to zero as the fluctuation increases to 10,000 cfs. Daily fluctuation levels greater than 10,000 cfs are clearly noticeable by river users (Bishop et al. 1987). The daily FF is computed as follows, where Q_{avg} is the daily mean flow, Q_{range} is the daily fluctuation, and Q_{tol} is the tolerable fluctuation threshold:

$$FF_{daily} = \begin{cases} \text{if } Q_{range} \leq Q_{tol} & 1 \\ \text{if } Q_{range} > Q_{tol} & \\ \quad where\ 5{,}000 < Q_{avg} < 8{,}999 & 1.515 - (0.00015 \times Q_{range}) \\ \quad where\ 9{,}000 < Q_{avg} < 15{,}999 & 1.923 - (0.00019 \times Q_{range}) \\ \quad where\ 16{,}000 < Q_{avg} < 31{,}999 & 3.571 - (0.00036 \times Q_{range}) \\ \quad where\ Q_{avg} > 32{,}000 & 50 - (0.005 \times Q_{range}) \end{cases}$$

The annual FI is the sum of daily FFs weighted by season according to recreational use, with seasonal weights being the same as for the NRI:

$$FI_{annual} = \left\{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} FF_{Daily}}{\sum Days_{summer}}\right)\right\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$FI = Average\ (FI_{annual})_{2014-2033}$$

J.2.3.2 Fluctuation Index—Results

The results of the FI are shown in Figure J-4. Differences between alternatives reflect differences in levels of daily flow fluctuations under the respective operational regimes. Alternatives F and G have FIs approaching 1 due to the absence of daily fluctuations; G is slightly lower, as it includes trout management flows in years when trout recruitment is high. Alternatives C, A, D, E, and B have rankings in order of increasing levels of daily fluctuations.

Alternative A and all long-term strategies under Alternatives C, D, and E have average index values above 0.5, indicating a high proportion of daily fluctuations that are within the tolerable range. Long-term strategy B1 has an annual FI value roughly half that of Alternative A, while B2 has a value roughly a third of Alternative A. Tests of hydropower improvement flows, particularly during highly weighted summer months, reduce B2 relative to B1, while high fluctuation levels overall contribute to low FI values for B1 and B2. Steady, low weekend flows to promote benthic invertebrate production during May through August elevate the FI for D2 relative to D1, D3, and D4. The slightly higher FI values for long-term strategies E1 and E2 relative to E3–E6 can be attributed to the inclusion of both spring and fall HFEs in EI and E2. Water released for HFEs is not available for load following, thus reducing fluctuations and raising the FI. Likewise, E4, which includes fall but no spring HFEs, has a slightly elevated FI compared to E3, E5, and E6, which have no HFEs.

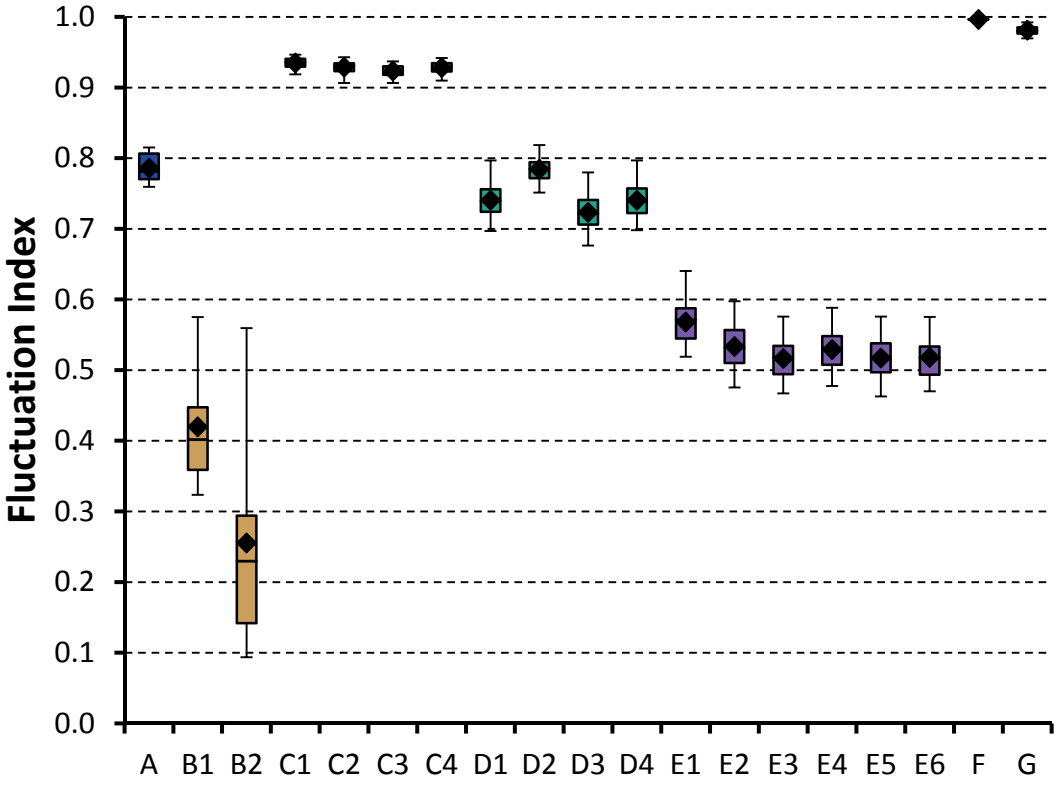

FIGURE J-4 Fluctuation Index for LTEMP Long-Term Strategies (Increasing values indicate more days have tolerable fluctuation levels. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

J.2.4 Time Off River

For rafting visitors, time off river to visit attractions and for other activities is important to the recreational experience (Stewart et al. 2000). Low river flows reduce travel speed for boats. Below a flow of about 10,000 cfs, there may be problems getting to camp on time and not enough time for stops at scheduled locations (Shelby et al. 1992).

J.2.4.1 Time Off River Index—Methods

The TORI is computed using a daily flow factor (FF), which is an index from 0 to 1 that uses a flow threshold of 10,000 cfs. The daily FF is computed as follows, where the value within the brackets in the right column is assigned to the FF if the equation in the left column is satisfied, and where Q_{avg} is the average daily discharge:

$$FF_{Daily} = \begin{cases} \text{if } Q_{avg} \leq 10{,}000; & 0 \\ \text{if } 10{,}000 < Q_{avg} < 31{,}500; & 0.0000465 \times Q_{avg} - 0.465 \\ \text{if } Q_{avg} \geq 31{,}500; & 1 \end{cases}$$

The annual TORI is the sum of the weighted seasonal index values. The seasonal index is the mean of the FF for all days within a given season, as above for NRI and FI:

$$TORI_{annual} = \{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{\text{summer}} \text{FF}_{\text{daily}}}{\sum Days_{summer}}\right)\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$TORI = Average\ (TORI_{annual})_{2014-2033}$$

J.2.4.2 Time Off River Index—Results

Figure J-5 shows the TORI results for all long-term strategies. TORI values for all of the long-term strategies have similar mean and quartile values, due to similar average flows among the alternatives. The exception is the TORI for Alternative F, which is notably higher than for other alternatives. This difference is largely due to elevated flows during March–June under Alternative F, which falls within moderately to highly weighted seasons in the annual TORI computation. Figure J-6 shows elevated average daily discharge rates during March–June for Alternative F relative to the other alternatives. For all other long-term strategies, there would be negligible differences in time off river from current conditions.

J.2.5 Glen Canyon Rafting Use

Day-rafting trips in Glen Canyon are a popular visitor attraction of Glen Canyon National Recreation Area. These day-rafting trips regularly run as full-day, half-day, and rowed trips during March 1 to December 1. Glen Canyon rafting trips are not sensitive to flow levels (Bishop et al. 1987) and can generally operate during all releases up to powerplant capacity

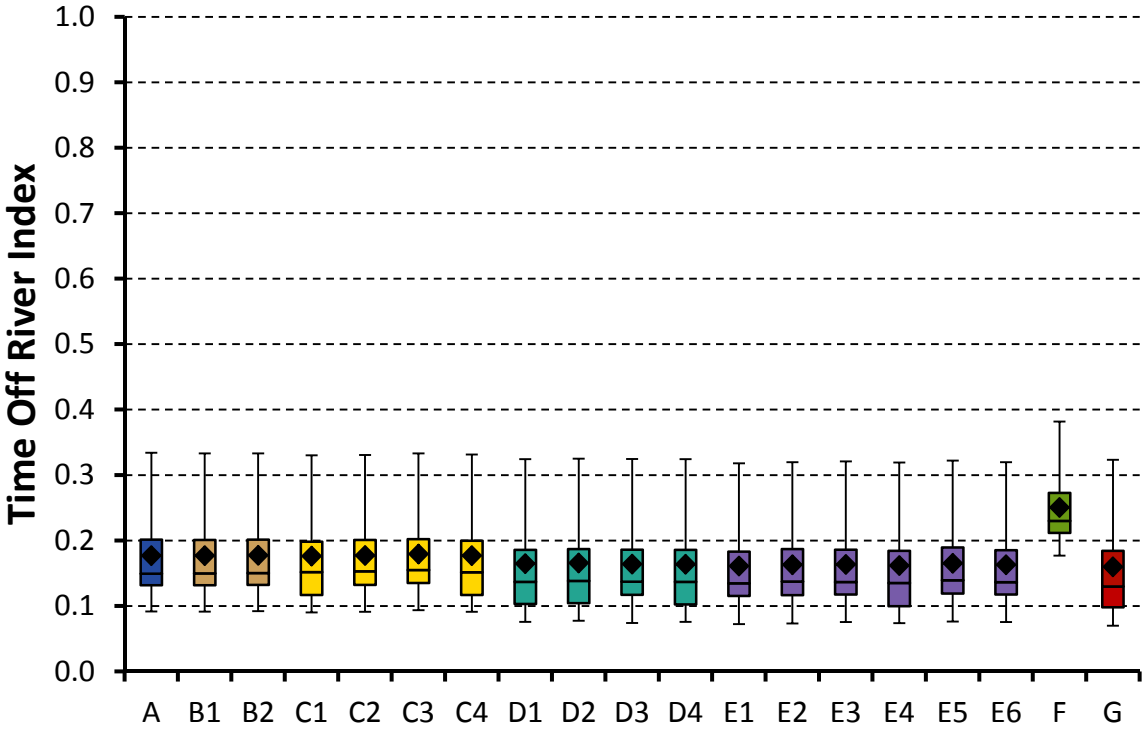

FIGURE J-5 Time Off River Index for LTEMP Long-Term Strategies (Increasing values indicate more time off river. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

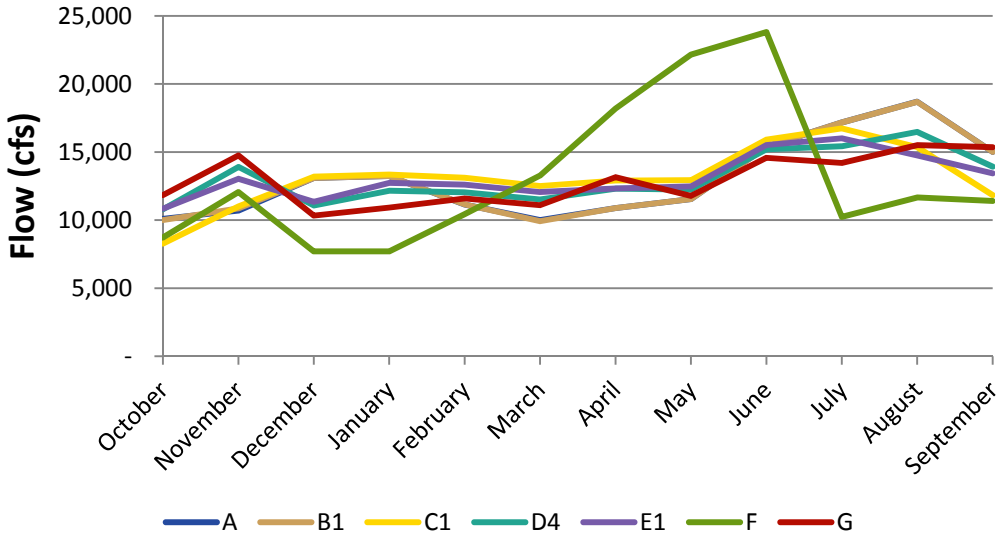

FIGURE J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP Alternatives

(31,500 cfs). However, when HFEs are run and the bypass tubes are activated, the turbulence at the loading dock is too great to safely load passengers and the commercial operator, Colorado River Discovery, ceases day-use rafting operations (Grim 2012).

J.2.5.1 Glen Canyon Rafting Use Metric—Methods

The Glen Canyon Rafting Use Metric (GCRM) represents the number of visitors unable to take day-rafting trips due to HFEs. Monthly passenger logs for Colorado River Discovery from 2011 to 2012 (Blais 2014) were used to estimate the number of daily passengers (*ADV*) for the months in which HFEs occur (March, April, May, October, and November). Data from 2013 was available but was not included because roadway closures that year potentially impacted visitor numbers. HFEs in spring and fall are possible each year. Estimates of the average daily rafting visitor count for lost trips from spring and fall HFEs are approximately 155 and 68, respectively. Thus, spring HFEs would have a much greater impact than fall HFEs due to higher rafting use in spring (more than double the passengers affected for a given HFE duration).

HFEs require day-raft concessioners to pull the boats from the water or relocate them. Therefore, the number of days lost for Glen Canyon rafting because of an HFE (*D*) is equal to the HFE duration plus 2 days prior and 2 days post HFE ($D = T_{HFE} + 4$ days) required to de-mobilize and re-mobilize rafting operations. The total number of lost rafting days (*D*) is multiplied by the estimated visitors per day (*ADV*) to calculate the number of passengers unable to raft due to an HFE. Note that, unlike the other recreation metrics in this appendix, the Glen Canyon Rafting Use Metric (GCRM) is a measure of an absolute effect, the actual number of annual lost visitor trips, as opposed to a relative index.

The operational 24-hr, 45,000 cfs spring high flow under Alternative F is taken into account in this analysis. No other high flows, such as equalization flows, except those distinctly defined as HFEs are considered. For each modeled year, there is the potential for a spring HFE, a fall HFE, or both to occur. The GCRM is calculated as follows for each HFE event.

$$GCRM_{HFE} = ADV\left[\frac{visitors}{day}\right] \times D\ [days]$$

If there are two HFEs within a single year, the number of passengers unable to raft is summed as in the following equation:

$$GCRM_{annual} = \sum_{yearly} GCRM_{HFE}$$

The final metric value is the average number of passengers unable to raft the Glen Canyon reach for the 20-year LTEMP modeling period (2014 to 2033) due to HFEs:

$$GCRM = Average\ (GCRM_{annual})_{2014-2033}$$

J.2.5.2 Glen Canyon Rafting Use Metric—Results

Figure J-7 shows GCRM values for LTEMP alternatives and long-term strategies. As the metric is based on the number of HFEs, the GCRM closely resembles the pattern of HFEs under each alternative. This can be seen by comparing the GCRM values in Figure J-7 with the average HFE count in Figure J-8. Not shown for Alternative F is the annual 24-hr high flow that occurs in years without a spring HFE. This further contributes to increases the GCRM, resulting in the highest number of lost visitor trips for Alternative F. As spring trips have a higher number of passengers than fall trips, spring HFEs have a larger impact on lost visitor trips than do fall HFEs.

As they do not include HFEs, long-term strategies C3, E3, E5, and E6 incur no lost visitor rafting trips. With few HFEs and mostly fall HFEs, long-term strategies A and B1 and B2 have the next fewest lost trips on average, while C4 and E4 have only slightly more, due mainly to the absence of spring HFEs under these long-term strategies. E1 and E2 have more lost trips than E4 due to spring HFEs in the second 10 years of the LTEMP period that do not occur under E4. Long-term strategies C1–C2 and D1–D2 have similar numbers of lost visitor trips owing to similar numbers and durations of HFEs. Alternative G has the second highest number of lost trips at roughly 500 annually, due to a high number of HFEs, an estimated 24.5 over the 20-year LTEMP period, including HFEs of 96 hr or longer duration. Finally, Alternative F has the highest number of lost visitor trips, on average over 900 annually, due to the highest number of HFEs, an estimated 38.1 over the 20-year LTEMP period, including the annual 24-hr release in all summers of years without a spring HFE. In addition, roughly two-thirds of HFEs under Alternative F are of 96-hr duration, representing a large number of days closed to rafting.

J.2.6 Glen Canyon Inundation Metric

The 15-mi stretch of Glen Canyon, from the Glen Canyon Dam to Lees Ferry, along the Colorado River is a hub for recreation within Glen Canyon National Recreation Area. Due to its unique geography, Lees Ferry is the only place directly accessible by car to visitors in hundreds of miles of canyon country. It is therefore an ideal location for boating, fishing, swimming, kayaking, camping, and hiking activities by visitors. However, these activities are directly downstream of the Glen Canyon Dam, and can be impacted by dam operation.

Surveys of users have indicated that the most ideal recreational conditions for Glen Canyon are flows from 8,000 to 20,000 cfs. Bishop et al. (1987) and Stewart et al. (2000) reported that anglers preferred a constant flow of about 10,000 cfs, while more recent information indicated Lees Ferry anglers preferred constant flows from 8,000 to 16,000 cfs (Gunn 2012). Flows within the 8,000 to 20,000 cfs range are ideal for shoreline access for boaters, who primarily only report poor conditions or water level issues with extremely high or low flows. For example, the Colorado River Discovery day rafting service reported operating issues with flows below 3,000 cfs and inoperable conditions when bypass tubes are in operation (above 31,500 cfs), as they create too much turbulence below the dam (Grim 2012). Flows at or

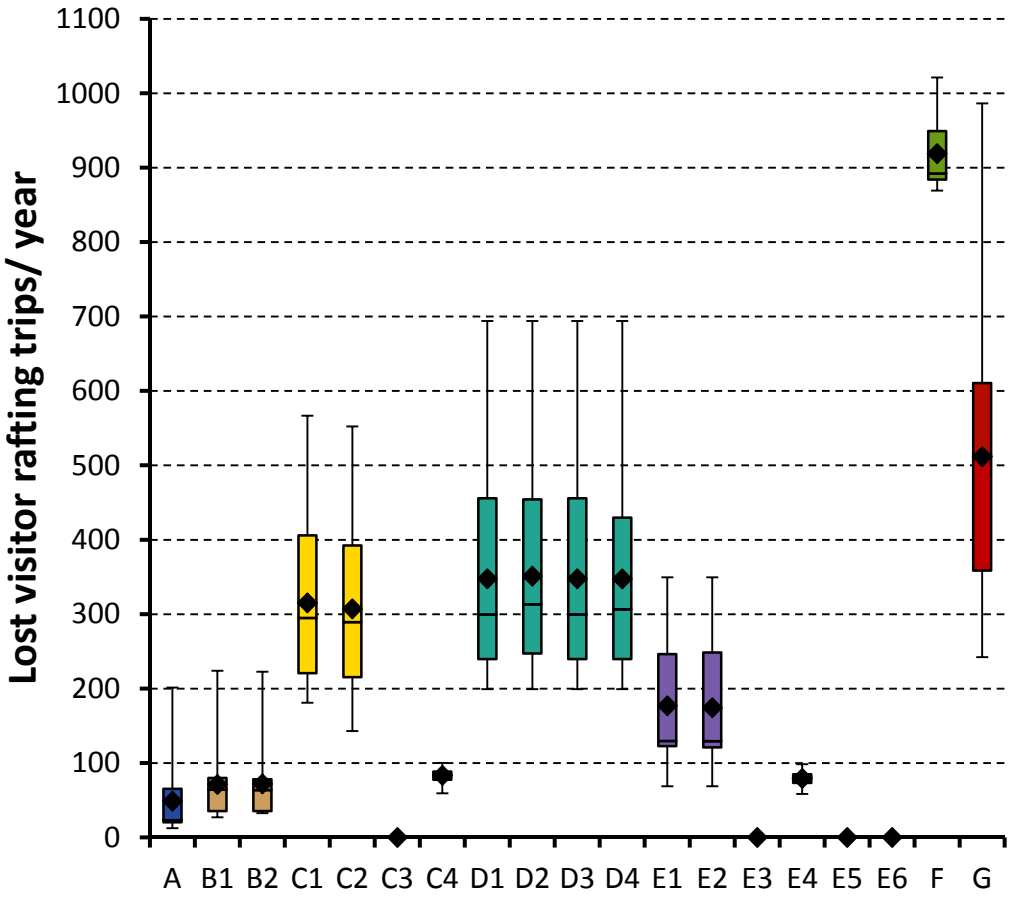

FIGURE J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies (Values are estimated annual lost visitor rafting trips. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

below 8,000 cfs may allow tamarisk tree growth and, as observed in the low summer flows of 2000 (Hjerpe and Kim 2001), may make prime angling spots impenetrable. At flows above 20,000 cfs, reduced participation in upstream fishing has been observed (McGinnis 2014).

J.2.6.1 Glen Canyon Inundation Metric—Methods

The Glen Canyon Inundation Metric (GCIM) represents the percentage of time that flow is at preferred levels for recreational experiences within the canyon, 8,000 to 20,000 cfs. Table J-2 presents a summary of recreational response to various discharge rates. This information was used in the computation of the Glen Canyon Inundation Metric as follows. A flow factor (FF) value from 0 to 1 is computed as a function of daily maximum discharge and

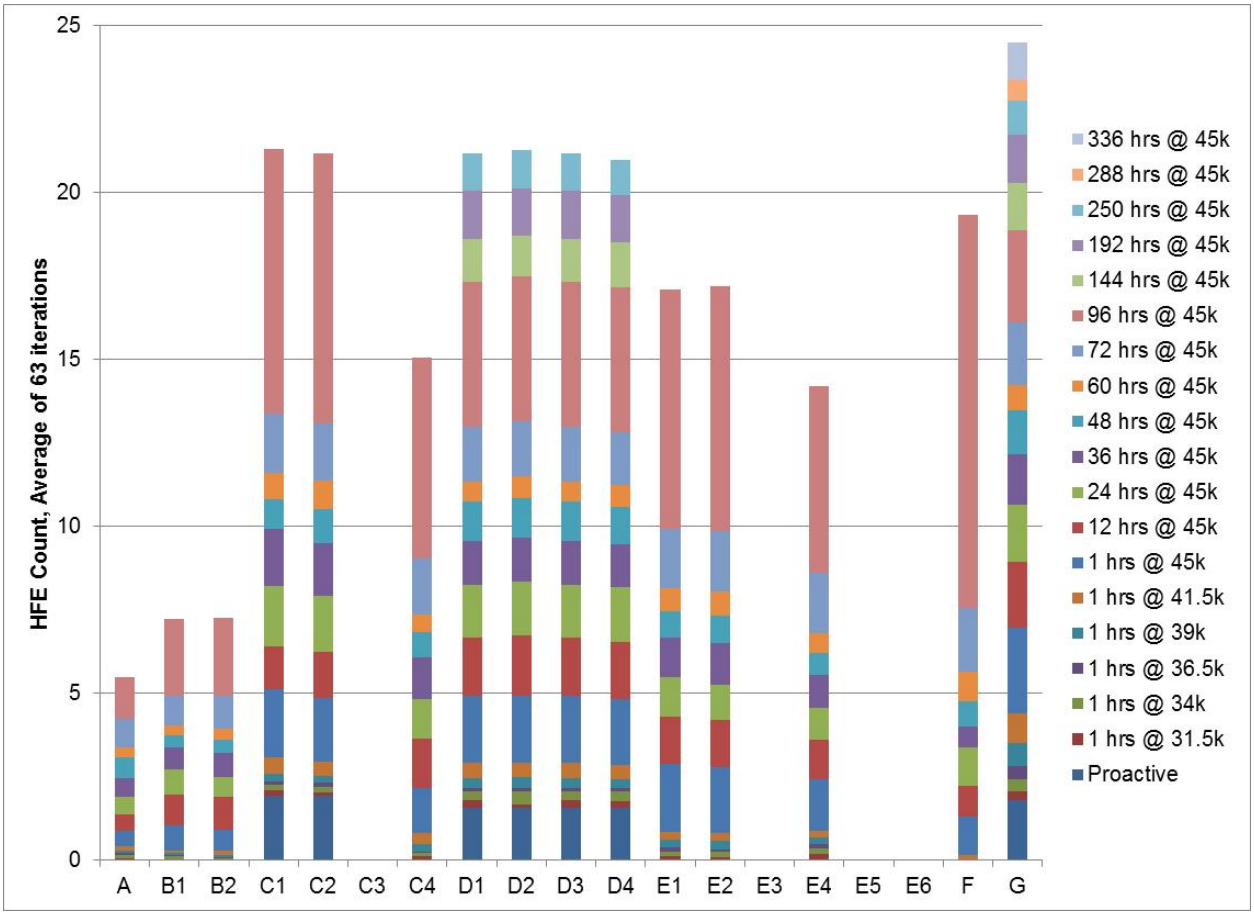

FIGURE J-8 Average Number of HFEs in the 20-Year LTEMP Period for LTEMP Long-Term Strategies

TABLE J-2 Recreation Response to Daily Maximum Flow

Flow (cfs)	Recreational Response
<3,000	Flows below 3,000 cfs are poor for boating and fishing.
3,000–8,000	Flows for fishing and boating get progressively better up to 8,000 cfs.
8,000–20,000	Flows are optimal for boating, fishing, and shoreline access.
20,000–31,500	Flows above 20,000 cfs get progressively worse for fishing and shoreline access.
>31,500	Flows above 31,500 cfs are poor for rafting, campable area, shoreline access, and fishing, and can adversely impact onshore recreational facilities.

the noted recreation responses, with higher values representing improved recreational experience. Daily FF values for discharges of 3,000 to 8,000 cfs and 20,000 to 31,500 cfs ranges were assigned values based on linear interpolation from 0 to 1 and 1 to 0, respectively. The daily FF is assigned as shown below, where the value in the right column within the brackets is assigned to FF if the equation in the left column is satisfied. Q_{max} refers to the daily maximum discharge released from the Glen Canyon Dam in cfs:

$$FF_{Daily} = \begin{Bmatrix} \text{if } Q_{max} \leq 3{,}000 \text{ cfs}; & 0 \\ \text{if } 3{,}000 < Q_{max} < 8{,}000\ cfs; & (Q_{max} \times 0.0002) - 0.60 \\ \text{if } 8{,}000 < Q_{max} < 20{,}000\ cfs & 1 \\ \text{if } 20{,}000 < Q_{max} < 31{,}500\ cfs; & 2.74 - (0.0000870 \times Q_{max}) \\ \text{if } Q_{max} \geq 31{,}500 \text{ cfs}; & 0 \end{Bmatrix}$$

An overall annual mean index value for the 20-year modeling period was computed for each alternative and used as the performance metric.

$$GCIM_{annual} = \{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{\text{summer}} \text{FF}_{\text{daily}}}{\sum Days_{summer}}\right)\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$GCIM = Average\ (GCIM_{annual})_{2014-2033}$$

J.2.6.2 Glen Canyon Inundation Metric—Results

Results for the GCIM for LTEMP long-term strategies are shown in Figure J-9. Results are similar for all of the long-term strategies, except for Alternative F and, to a lesser extent, B2. Overall, index values are all high, above 0.9 for all but Alternative G, which has a mean value of about 0.85. Such high values indicate that discharge rates are in a range preferred for a variety of recreational activities most of the time under all alternatives and long-term strategies. The index value for Alternative F is reduced due to the large number of HFEs overall and to the high percentage of 96-hr HFEs, which together produce a relatively high number of days annually with flows above preferred levels. Similarly, high flows during hydropower improvement tests under B2 reduce its index value relative to B1 and most other long-term strategies. Other long-term strategies have values very close to that for Alternative A, with small deviations both higher and lower.

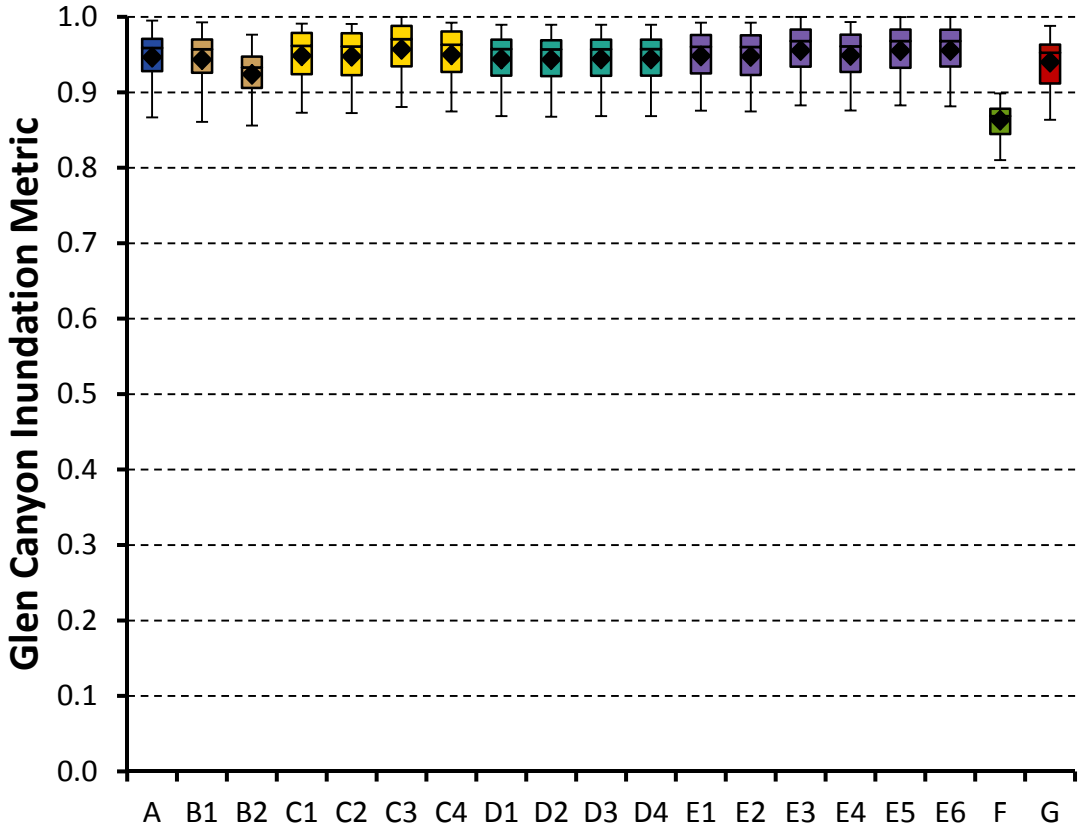

FIGURE J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies (Increasing values indicate increasing frequency of flow levels preferred for recreation. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

J.3 LAKE POWELL AND LAKE MEAD DOCK ACCESS

Lower-than-normal lake levels have been occurring in Lake Powell upstream of the Glen Canyon Dam and in Lake Mead, which lies at the end of the 277-mi stretch of the Colorado River through GCNP. At Lake Powell, low lake elevation has rendered some boat launch sites inaccessible, and, in October 2005, NPS completed a General Management Plan (GMP) Amendment for Low Water Conditions and Finding of No Significant Impact (NPS 2005), which identified a strategy for low-water operations. This amendment ensured the maintenance of the boat launch sites at Lake Mead despite low water levels by either extending or relocating existing launch ramps and marinas so as to be functional down to an elevation of 1,050 feet above mean sea level (AMSL). Similarly, at Lake Powell, a connection channel called Castle Rock Cut, located directly across from Wahweap Bay from the Stateline launch ramp, became inaccessible at lake levels below an elevation of 3,580 ft AMSL in 2014 (Elleard 2014).

Modeled end-of-month lake elevations from 63 historical traces were compared against these two elevations (1,050 ft AMSL for Lake Mead and 3,580 ft AMSL for Lake Powell) to determine the percentage of time that lake levels would potentially fall below these critical levels. The percentage of traces where monthly lake elevation fell below critical elevation for any month within a season over the 20-year LTEMP period for Lake Powell is shown in Figure J-10 for the recreational summer seasons of May, June, July, and August and in Figure J-11 for the recreational fall and spring months of March, April, September, and October. Figures J-12 and J-13 show the analogous percentages for Lake Mead. Note that since these figures were generated by recasting past hydrology, they show the potential future variability and range of lake elevation conditions relative to the access reference elevations, but they do not predict conditions for any particular future year or year-to-year trends. Thus, the year dates on the *x* axis have meaning only in the sense that they show a hypothetical future 20-year period.

These graphs show that monthly lake elevations fall on or below critical elevations during spring and summer months for roughly 22% of historical trace simulations for Lake Powell and roughly 25% of historical trace simulations for Lake Mead for all alternatives and long-term strategies over the LTEMP period. Table J-3 shows the percentages for all alternatives. While rates of access issues are substantial, the difference among alternatives is small, indicating overall impacts at the launch sites of Lake Mead or the Castle Rock Cut connection channel in Lake Powell are driven mainly by hydrology. At Lake Powell, on average over all seasons, all alternatives have slight increases in access impacts relative to Alternative A. Conversely, at Lake Mead, all alternatives exhibit slight decreases in access issues compared to Alternative A. It is not clearly the case, but this behavior might be the result of Alternative A having the lowest number of HFEs of all alternatives. Large volumes of water taken from Lake Powell for an HFE might temporarily drop the lake level below the access threshold when the lake level is near the threshold, while similarly reducing the frequency of access issues at Lake Mead, which receives an input pulse from an HFE.

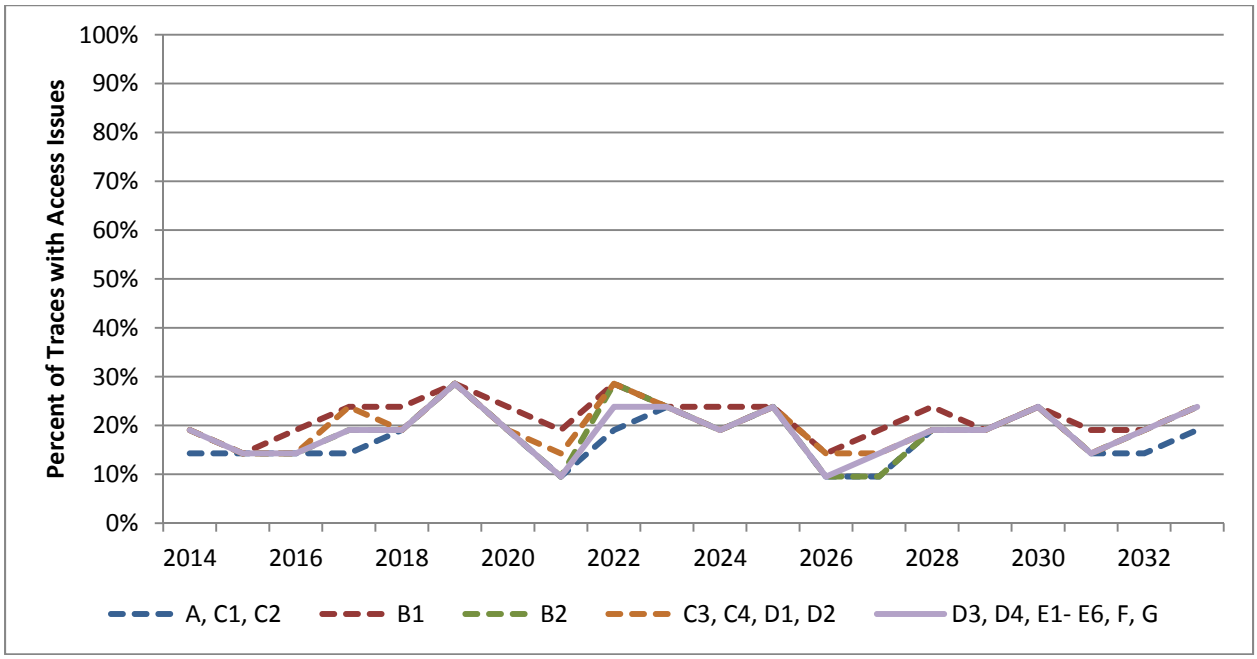

FIGURE J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Summer Season

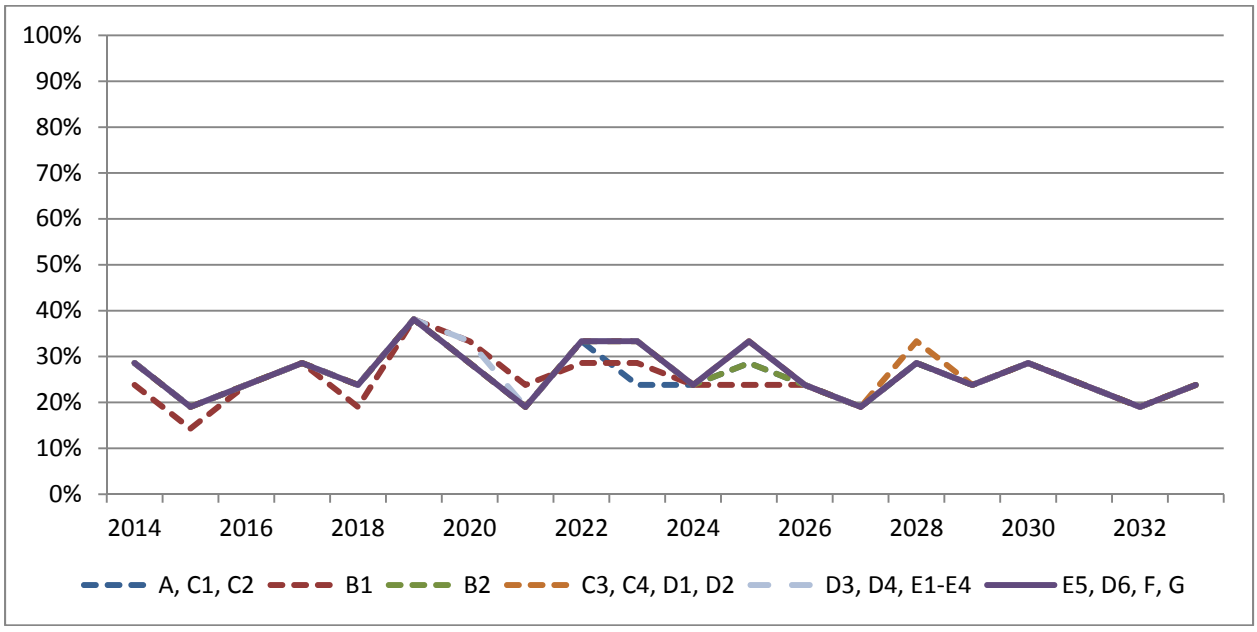

FIGURE J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Fall and Spring Seasons

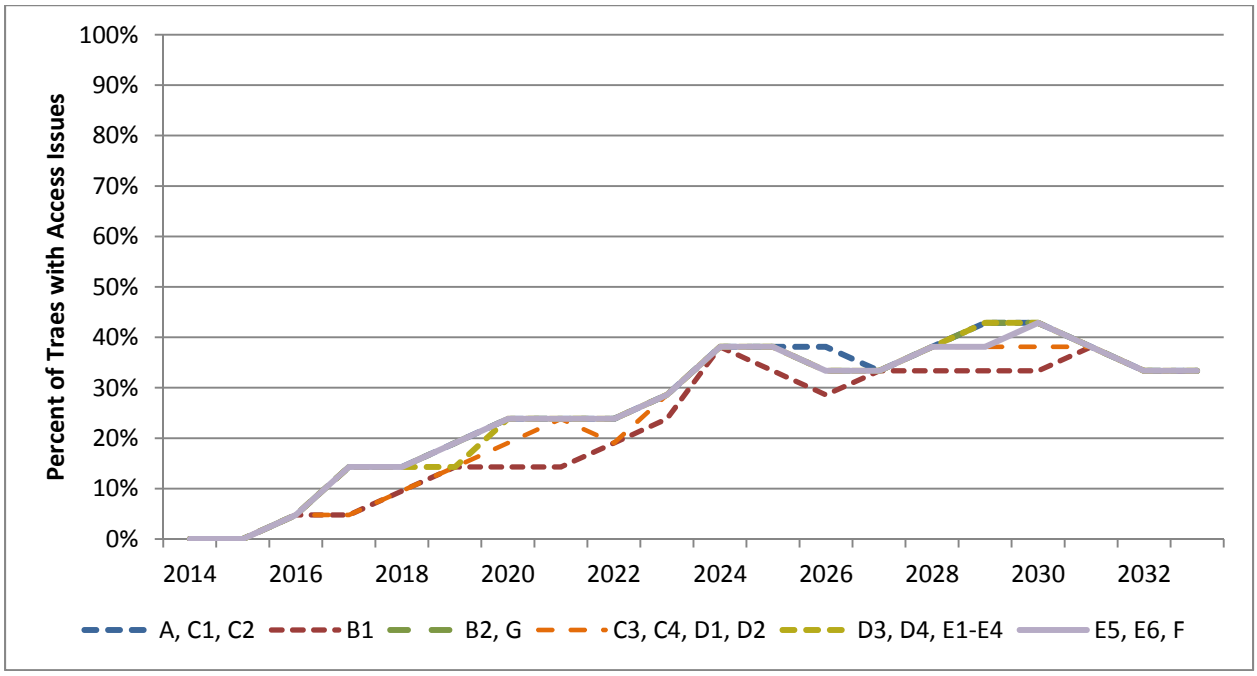

FIGURE J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Summer Season

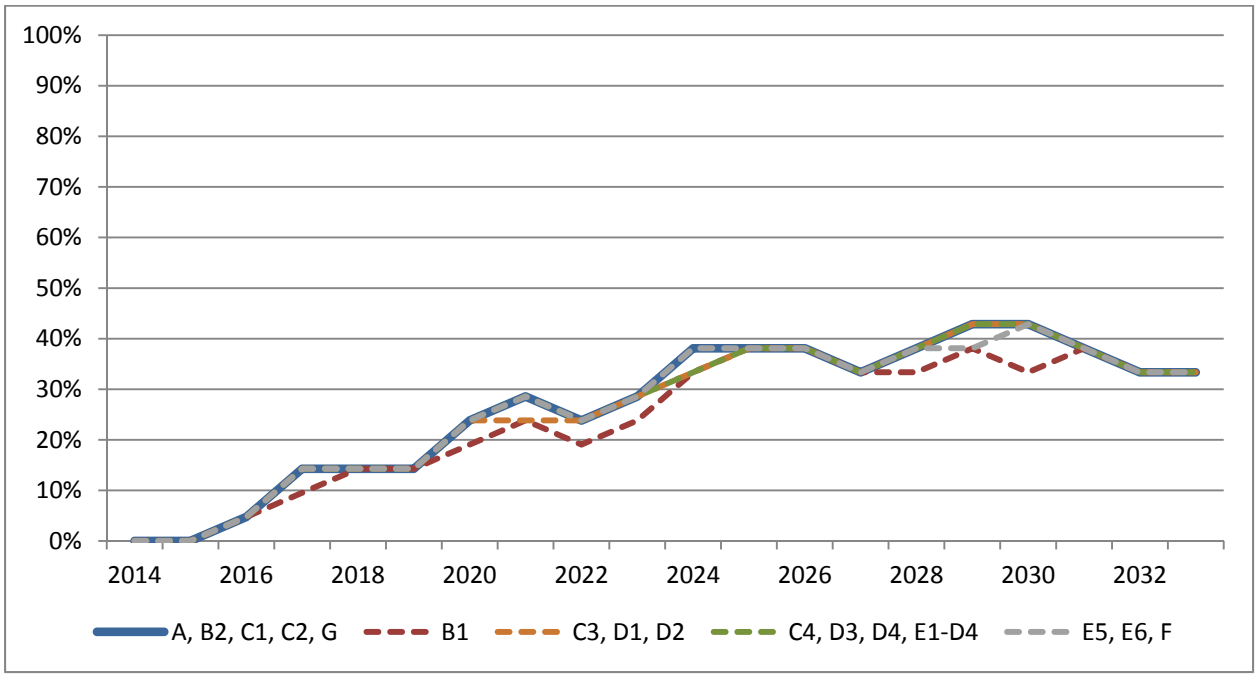

FIGURE J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Fall and Spring Seasons

TABLE J-3 Summary of Recreation, Visitor Use, and Experience Metrics

Alternative/ Long-Term Strategy	CAI	NRI	FI	TORI	GCRM	GCIM	Lake Powell[a]	Lake Mead[a]
A	0.14	0.50	0.79	0.18	49	0.95	0%	0%
B1	0.15	0.39	0.42	0.18	71	0.94	2.5%	-10.6%
B2	0.12	0.26	0.26	0.18	72	0.92	4.4%	-3.5%
C1	0.38	0.75	0.93	0.18	315	0.95	0.37%	-0.31%
C2	0.37	0.73	0.93	0.18	307	0.95	0.37%	-0.31%
C3	0.04	0.76	0.92	0.18	0	0.96	5.5%	-4.4%
C4	0.33	0.76	0.93	0.18	83	0.95	5.5%	-4.1%
D1	0.36	0.45	0.74	0.16	347	0.94	4.7%	-3.5%
D2	0.36	0.60	0.78	0.16	351	0.94	5.5%	-4.1%
D3	0.36	0.45	0.72	0.16	347	0.94	5.1%	-2.5%
D4	0.36	0.45	0.74	0.16	347	0.94	5.1%	-2.5%
E1	0.30	0.37	0.57	0.16	177	0.95	5.1%	-1.3%
E2	0.29	0.30	0.53	0.16	174	0.95	5.1%	-2.5%
E3	0.03	0.32	0.52	0.16	0	0.96	5.1%	-1.3%
E4	0.27	0.29	0.53	0.16	79	0.95	5.1%	-1.3%
E5	0.03	0.33	0.52	0.17	0	0.96	4.7%	-2.5%
E6	0.03	0.32	0.52	0.16	0	0.96	4.7%	-2.5%
F	0.41	0.71	1.00	0.25	919	0.86	4.7%	-2.5%
G	0.45	0.96	0.98	0.16	512	0.94	4.7%	-1.9%

[a] Percentage difference from Alternative A in frequency of access issues; Alternative A has predicted access issues in 21.75% of future seasons for Lake Powell and 25.48% of future seasons for Lake Mead based on historical hydrology.

J.4 SUMMARY

Values for the means of the six metrics and frequency of Lake Powell and Lake Mead access issues discussed above are summarized in Table J-3. An index of 0 to 1 is used for CAI, NRI, FI, TORI, and GCIM, while GCRM is the estimated number of actual visitor trips lost due to HFEs. Access issues for Lake Powell and Lake Mead are the percent differences from Alternative A in the expected frequency of traces in which lake elevation falls below access thresholds in at least one month in either the spring–fall or summer seasons. The values shown in the table are mean values for 63 modeled hydrology–sediment conditions. Quartile values and minimum and maximum values for the six metrics can be seen in the respective box-and-whisker plots (Figures J-1 to J-9).

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APPENDIX K:

HYDROPOWER SYSTEMS TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX K:

HYDROPOWER SYSTEMS TECHNICAL INFORMATION AND ANALYSIS

This appendix provides details on three analyses that are related to hydropower system electricity production, powerplant capacity, costs, and electricity service charge rates and that are conducted for the Glen Canyon Dam Long-Term Experiment and Management Plan (LTEMP) Environmental Impact Statement (EIS). The first analysis (presented in Section K.1) evaluated the impacts of changes in Glen Canyon Dam operations associated with LTEMP alternatives on the economic value of the powerplant's capacity and energy production. The impacts were measured in terms of changes in the value of regional power system capacity (the power system comprised of Western Area Power Administration's (WAPA's) long-term firm (LTF) customers) and overall system-level electricity production costs (the entire Western Interconnection). The second analysis (presented in Section K.2) studied how system resources and operations under LTEMP alternatives affect the wholesale electricity rates paid by LTF customers that receive federal preference power produced by Glen Canyon Dam. The third analysis (presented in Section K.3) studied the effects of alternatives on electricity rates paid by retail customers.

K.1 ECONOMIC VALUE OF GLEN CANYON DAM POWERPLANT CAPACITY AND ENERGY PRODUCTION

This first analysis studied the impacts of changes in Glen Canyon Dam Powerplant operations associated with LTEMP alternatives on the economic value of its capacity and energy production. Power system impacts are measured in terms of increases in capacity expansion expenditures and overall electricity production costs that would result from changing current Glen Canyon Dam operating criteria to different operating criteria as defined under LTEMP alternatives.

K.1.1 Power Systems Background

The Glen Canyon Dam Powerplant generates large amounts of energy that yield economic benefits to the grid. It also provides the grid with firm capacity that contributes to system reliability. Argonne National Laboratory (Argonne) staff conducted a power systems analysis of Glen Canyon Dam's economic benefits under each of the LTEMP alternatives. These alternative-specific operating criteria are summarized in Table 2-1 of the EIS.

The total water release volume from Lake Powell during each water year (WY) is nearly identical under all alternatives (see Section 4.2). However, at varying restriction levels, alternative criteria define the daily and hourly operational flexibility at Glen Canyon Dam, and affect Lake Powell reservoir elevations and monthly water release volumes. LTEMP alternatives also differ in their inclusion of various experimental releases such as high flow experiments (HFEs) and trout management flows (TMFs). The frequencies of these experimental releases differ among the alternatives.

Glen Canyon Dam energy production serves the electricity demands (loads) of a dynamic system that responds to its operations. Therefore, economic impacts of changes in Glen Canyon Dam operations are measured for the system as a whole. Some of the responses to changes in Glen Canyon Dam operating criteria, such as system unit dispatch adjustments, would occur very quickly. System dispatch refers to the amount of generation that each powerplant unit produces over time to match system loads plus system energy losses. In contrast, other system responses are much slower. For example, Glen Canyon Dam operating criteria affect its maximum output at times of peak load, and therefore system-wide capacity expansion pathways; that is, the timing and type of new units that will be built in the future. This methodology measures the spectrum of system economic impacts from hourly time intervals to multi-year processes.

The system modeled consists of 11 hydropower plants (including the Glen Canyon Dam Powerplant) marketed and scheduled by the Colorado River Storage Project (CRSP) Management Center of WAPA, the loads of all LTF power customers, and the resources owned and operated by the eight LTF power customers that have the largest allocations of capacity and energy (see Section K.1.3.2 for more detail). The combined loads and resources of these entities are referred to at the Salt Lake City Area Integrated Projects (SLCA/IP) market system.

The economic impacts of LTEMP alternatives on the value of electricity within the Western Interconnection were determined, but the financial impacts on individual grid participants were not. Impacts on individuals are analyzed in the rate payer and wholesale rate analyses presented in Section K.3. The economic analysis presented here focuses on the total differences in the economic value of SLCA/IP federal hydropower resource among alternatives benchmarked to existing operating criteria (Alternative A). This difference is referred to as the economic cost of an alternative and is quantified as the net present value (NPV) of the cost that would be accrued during the 20-year LTEMP period. System interactions within the broader Western Interconnection are also represented. It should be noted that this is an economic analysis that measures the net cost difference for the system as a whole, not a financial analysis of individual entities (e.g., a utility company) that operate within the system.

Operating criteria impact power economics because they affect the timing and routing of water releases through the dam. From a system dispatch perspective, power produced by Glen Canyon Dam yields the highest economic benefits when the limited amount of water released during a WY is routed through the powerplant's generating turbines to produce power during seasons of the year and times of the day when it displaces either energy generation or demand curtailment from expensive grid resources. For example, Glen Canyon Dam has a high economic value when the energy it produces either reduces or eliminates the operation of a generating unit with a high production cost. On the other hand, it has a much lower value when it displaces lower-cost power generation.

During most HFEs, water release rates from Glen Canyon Dam are greater than the maximum flow rate of the powerplant's turbines. Therefore, some water is released through the dam's hollow jet tubes, bypassing powerplant turbines. Non-power water releases such as these produce no electricity and therefore yield no energy value. Because water is limited, the bypass water reduces the overall economic value of power because this water could have otherwise been

stored in Lake Powell and released to produce energy at another time to displace the dispatch of more costly system resources.

Glen Canyon Dam capacity also has considerable value because the powerplant can generate energy during times of peak demand. Without the Glen Canyon Dam Powerplant, other resources would need to be constructed or acquired in order to ensure that load-serving utilities have adequate generating capabilities available to reliably meet system loads. Operating criteria that affect the Glen Canyon Dam Powerplant's firm capacity may impact WAPA's firm commitment levels to load-serving entities that purchase its capacity. In turn, contractual obligations affect the amount of capacity load-serving utilities can rely upon to meet system peak loads and will impact their long-term integrated resource plans, including the timing and amount of new power plant construction.

The methodology used for power systems analysis mimics decisions that could be made by system entities based on contractual and financial considerations that affect economic outcomes. For example, the borrowing rate for capital may impact both capacity expansion decisions and therefore economic outcomes. Economic costs include the following components: (1) energy production costs for the entire system and (2) capital investment plus fixed O&M costs for constructing and operating units built for system capacity expansion. Energy production costs are comprised of fuel expenditures, variable O&M costs, and unit startup expenses. All costs are estimated over the 20-year LTEMP period starting at the beginning of calendar year (CY) 2015 and extending through the end of CY 2034. To be consistent with the analyses performed for other resource areas, the start of the study period was adjusted to CY 2015. Please refer to Section K.1.9 for a description of how the adjustment was made. Emphasis is placed on accurately estimating the cost of an alternative compared to Alternative A in terms of both economic ranking and the relative magnitude of cost differences. Therefore, costs such as fixed O&M costs are not computed for existing units that remain unchanged across all alternatives.

K.1.2 Glen Canyon Dam, Reservoir, and Powerplant Background

Glen Canyon Dam is a U.S. federal resource that was built by the Bureau of Reclamation (Reclamation) between 1956 and 1964 as part of the CRSP that was authorized by the Colorado River Storage Project Act on April 11, 1956. The Act authorized the Secretary of the Interior to develop the water resources of the Upper Colorado River Basin by constructing, operating, and maintaining the CRSP and other participating reclamation projects. The dam is a 710-foot–high concrete arch structure with a crest length of 1,560 ft, containing 4,901,000 yd^3 of concrete. The thickness of the dam at the crest is 25 ft, and its maximum base thickness is 300 ft. The reservoir formed by the dam, Lake Powell, has a total water storage capacity of 27 million acre-feet (maf), with an active capacity of approximately 20.9 maf when full. Under normal water surface elevation levels, the reservoir has a length of 186 mi and a surface area of 161,390 ac. The dam controls a drainage basin approximately 108,355 mi^2 (Harpman and Rosekrans 1996).

Currently, there are eight generating units at Glen Canyon Powerplant with a total sustained operating capacity of approximately 1,320 megawatts (MW). The first two Glen Canyon units began generating power in September 1964, and the eighth and final unit came

online in February 1966, as recorded in Power Operations and Maintenance Form 59 (Form PO&M-59). When water is released from the reservoir through power plant turbines, the energy generated partially serves the electricity demands of the SLCA/IP wholesale customers.

Lake Powell was filled for the first time in 1980, when it reached a maximum reservoir water elevation of 3,700.6 ft. Displacing power generation and associated air emissions mainly from powerplants that burn fossil fuels such as coal, oil, and natural gas, the average annual gross electricity generation from the Glen Canyon Dam Powerplant between CY 1980 and 2013 was about 4,716.5 GWh. This statistic does not include generation production for years prior to 1980, because a portion of water inflows into Lake Powell were used to fill the reservoir prior to that time. From 1980 through 2013, annual generation has varied by more than a factor of 2.6. Generation was at a low of 3,299 GWh in CY 2005 and at a high of 8,703 GWh in CY 1984. The high level of annual generation variability of the Glen Canyon Dam Powerplant since 1980 is attributable to variations in Lake Powell inflow levels, which are strongly influenced by precipitation. Hydrologic variability and uncertainty reduce generation value. Therefore, other resources need to be made available to serve system loads and reliability requirements.

Operational limitations at Glen Canyon Dam were minimal from 1964 through May 1990. Minimum releases from Lake Powell were 1,000 cfs from Labor Day to Easter and 3,000 cfs during the rest of the year. These minimums are only a small fraction, approximately 3% to 9%, of the physical maximum turbine flow rate of 33,000 cfs at full reservoir. There were no institutional limitations on maximum flow rates, hourly ramping, or daily changes in flow. The relatively low minimum release rate requirement, combined with limits that were only constrained by the physical powerplant and dam characteristics, allowed for flexible operations that maximized the hydropower generation.

Legislation was introduced in Congress in 1990 addressing dam operations after the Glen Canyon Environmental Studies Program published its report in 1987 describing the impacts of dam operation on the national and recreational resources of the Grand Canyon. Reclamation began to restrict operations on June 1, 1990, when it conducted research discharges as part of the Glen Canyon Environmental Studies. Numerous test flows were conducted during a 14-month period that concluded at the end of July 1991. The purpose of these research releases was to collect and analyze data at different flow levels in order to investigate the effects of flow patterns on the riverine environment downstream of Glen Canyon Dam. Interim flow operating constraints were imposed at Glen Canyon Dam on August 1, 1991, and were in effect until February 1997, when the 1996 Glen Canyon Dam Environmental Impact Statement Record of Decision (ROD) was implemented.

The 1996 ROD requires releases from Lake Powell to be at least 8,000 cfs between the hours of 7:00 a.m. and 7:00 p.m., and 5,000 cfs or more during all other hours of the day. The maximum allowable release is limited to 25,000 cfs. In very high release months, the maximum limit can be exceeded, but the release rate must be constant during the entire month. The 1996 ROD operating criteria also limits release fluctuations during all rolling 24-hour periods. The fluctuation level permitted depends on the amount of water that will be released from Glen Canyon Dam during a month. The allowable daily fluctuation is 5,000 cfs/24 hr when the monthly scheduled water release is less than or equal to 600 kaf. Daily fluctuations are restricted

to 6,000 cfs/24 hr for those months in which the scheduled release is equal to or greater than 600 kaf but less than 800 kaf, and at 8,000 cfs/24 hr for months with releases equal to or greater than 800 kaf. Finally, the 1996 ROD operating criteria also limited the rate at which Lake Powell water release are allowed to ramp up and down. The maximum ramp rate is 4,000 cfs/hr when increasing, and 1,500 cfs/hr when decreasing. Operating criteria reduced the flexibility of operations, diminished dispatchers' ability to respond to market price signals, and decreased the economic power benefits of the Glen Canyon Dam. Between 1997 and 2005, this decrease in economic benefit was estimated to range from $38 million to $50 million per year (in 2009$) (Veselka et al. 2010). This range may not be indicative of future economic costs due to a number of factors including changes in power market structures and utility fuel prices. It should be noted that all of the LTEMP alternatives are significantly less flexible than actual operations prior to the 1991 interim operating criteria. Only Alternative B has slightly less operating restrictions than current operations.

The 1996 ROD operating criteria include "emergency exception criteria" that recognize the fact that the Glen Canyon Dam Powerplant is an important grid resource. When emergency exception criteria are invoked, normal operations are suspended until the emergency has ended or WAPA has been cleared of its North American Electric Reliability Corporation (NERC) emergency operation responsibilities. Emergency exception criteria allow Glen Canyon Dam to dispatch up to all of its available capacity at Glen Canyon Powerplant, depending on the severity of the system emergency, by rapidly increasing generation output in response to events such as insufficient system generating capacity, transmission system problems, and system restoration.

In addition, Glen Canyon Dam generators provide system regulation to WAPA as the operator of the Western Area Colorado Missouri (WACM) balancing authority (BA) area. The Glen Canyon Dam Powerplant responds to a regulation signal developed and electronically transmitted to the dam by WAPA for continuous response to power system load and frequency changes. WAPA is required to react to moment-by-moment changes in system frequency, time error, and tie-line loading within the WACM BA via powerplant automatic generation control (AGC) equipment at Glen Canyon Dam and some of the other SLCA/IP federal hydropower plants to adjust the power output of the generators to match variations in system load in accordance with prescribed NERC criteria. The degree to which WAPA responds to these system changes is computed by an area control error (ACE) equation.

The ACE signal that is sent to Glen Canyon Dam adds to or subtracts from the existing scheduled hourly generation set point. Therefore, at any instant in time, the powerplant is typically producing more or less power than the current hourly scheduled set point. Deviations from the set point typically fluctuate from negative to positive values many times during any hour. However, the resulting output from Glen Canyon generators on average approximates the hourly scheduled level. Because post-ROD operating criteria specify release restrictions in terms of hourly average levels, Glen Canyon Dam can provide regulation services while scheduling set point levels at minimum and maximum allowable flow limits. It can also ramp set points within up and down limitations (see http://www.wapa.gov/crsp/planprojectscrsp/gcopswhite.html).

The 1996 ROD operating criteria currently restrict Glen Canyon Dam operations in terms of both the operational range of water releases and the rate at which water releases are permitted to change over time. It also provides the operating criteria for Alternative A.

K.1.3 Power Systems Geographic Scope

The Glen Canyon Dam Powerplant is part of a large dynamic power grid that responds to its operations. It is also a component of WAPA's SLCA/IP, which is composed of 11 federal hydropower facilities marketed and scheduled by the CRSP Management Center. WAPA markets these facilities as a bundled resource. Therefore, power economic impact analyses are based on a systems approach that measures the collective responses of system components to changes in Glen Canyon Dam operating rules and experimental releases. The focus area is on SLCA/IP federal hydropower resources, and the utilities operated by WAPA's SLCA/IP LTF power customers. For the purpose of this appendix, this primary impact area is referred to as the SLCA/IP market system (or SLCA/IP system). However, as described in more detail below, the methodology also recognizes that this system does not operate in isolation. Instead, it interacts with the much larger Western Interconnection power grid.

The power systems method uses a three-tiered approach. All simulate the system on an hourly basis over the 20-year LTEMP period. The top tier models the loads and resources of the entire Western Interconnection to gain a broad perspective on the future development of the larger overall system (see Section K.1.3.1). Both Western Interconnection system capacity expansion and economic system dispatch are modeled.

The middle tier models SLCA/IP LTF customer utility loads and resources along with future Western Interconnection interactions via non-firm bilateral energy transaction. It also projects SLCA/IP market system future capacity additions, determines day-ahead unit commitments, and performs economic dispatch. It focuses on SLCA/IP customer resources at a higher level of fidelity than the Western Interconnection tier. The top and middle tiers both rely on projections found in the *Annual Energy Outlook* (EIA 2014) published by the U.S. Energy Information Administration (EIA). The *Annual Energy Outlook* uses an even broader perspective that incorporates overall U.S. and global macroeconomic drivers into the projection of U.S. energy futures.

The bottom tier focuses on SLCA/IP federal hydropower resources. It models the long-term management and routing of water resources within the Colorado River Basin. Future water management is compliant with all applicable laws and water rights. Given this projection of long-term water management, simulation of powerplant dispatch is performed based on market price drivers projected by the Western Interconnection tier and key physical and institutional constraints on reservoir operations and powerplant dispatch. Hourly dispatch is subject to numerous physical and institutional constraints, including those specified under an LTEMP alternative.

The top tier represents a large geographical area, but at a relatively low level of fidelity. Increasing attention to detail and accuracy is paid as the geographical coverage becomes more

focused. By using this approach, power systems comparative analyses are able to determine how changes in Glen Canyon Dam Powerplant operations affect its economic value. This top-down modeling approach is further described below. More details about the selection of the power system's geographical scope and detail are provided in Attachment K.1.

K.1.3.1 Top Tier: General Western Interconnection Perspective Modeling

North America is comprised of two major and three minor alternating-current power grids. The Western Interconnection is the major power grid that stretches from Western Canada south to Baja California in Mexico, and eastward from the Pacific Ocean to the Rockies and the Great Plains. All of the electric utilities in the Western Interconnection are electrically tied together during normal system conditions and operate at a synchronized frequency that averages 60 Hz. The Western Electricity Coordinating Council (WECC) region of NERC facilitates regional transmission expansion planning for the interconnection, and the Western Governors' Association acts as a state/provincial steering committee. These entities work collaboratively to develop long-term electricity supply futures, estimate transmission requirements, and prepare long-term interconnection-wide transmission plans (see http://energy.gov/oe/services/electricity-policy-coordination-and-implementation/transmission-planning/recovery-act-0). These plans are voluntarily created and serve to provide a high-level look at possible futures.

Argonne power system analysts modeled the long-term capacity expansion, unit commitments, and hourly unit dispatch of Western Interconnection resources using the AURORAxmp model (referred to as AURORA). The Western Interconnection topology and supporting model inputs were provided by EPIS, Inc., the AURORA model developers. A depiction of this topology is shown in Figure K.1-1. Each "bubble" in the diagram roughly represents groups of utilities, single BAs, or combinations of BAs. Bidirectional limits on the links that connect bubbles restrict network energy transfers. User-defined limits can vary hourly. The location of SLCA/IP federal hydropower resources in the AURORA Western Interconnection topology is indicated in the figure. The Glen Canyon Dam Powerplant is labeled "GC," and the Flaming Gorge and Fontenelle Powerplants are labeled "FG" and "FN," respectively. The location of powerplants in the Wayne D. Aspinall Cascade and all other SLCA/IP hydropower plants is labeled "Aspinall & Others."

The primary driver of many variables that define Western Interconnection future developments were based on projections published in EIA's 2014 *Annual Energy Outlook* (hereafter 2014 AEO; EIA 2014) for the reference scenario that was released in April 2014. Model results are consistent with state integrated resource plans (IRPs). A more detailed description of AURORA is provided in Section K.1.5.9.

In addition to estimating the capacity expansion pathways and system production costs, AURORA also projects future locational marginal prices (LMPs) throughout the Western Interconnection. The LMPs measure the incremental cost to serve an additional 1 MW of load at a specific point in the grid; that is, the cost to change the dispatch of system resources to serve a slightly higher load. This typically involves increasing the power generation at one of more units or reducing loads via a demand response management (DSM) agreement.

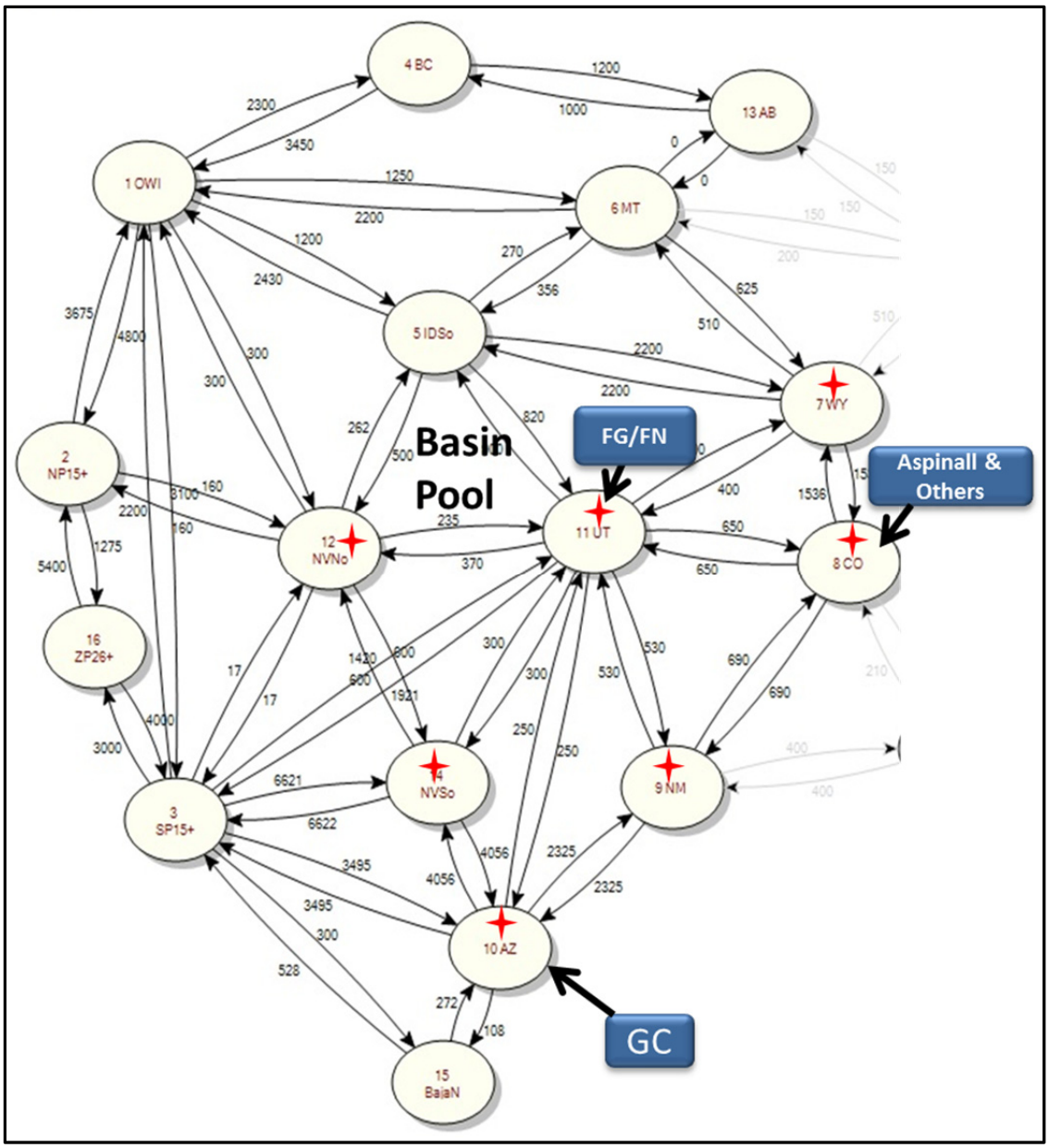


FIGURE K.1-1 Network Topology Used by the AURORA Western Interconnection Model

AURORA Western Interconnection projections of hourly LMPs at the Palo Verde marketing hub are used by the LTF customer and Western SLCA/IP federal resource tiers (i.e., middle and bottom tiers). This hub was selected as a representative point for LTEMP EIS modeling because prices at this location are often used by schedulers at the Western's Montrose Energy Management and Marketing Office (EMMO) as a benchmark for short-term bilateral transactions. Palo Verde hub prices have also been used extensively in the past for other economic and financial analyses of SLCA/IP hydropower resources (see http://www.usbr.gov/lc/region/programs/strategies/FEIS/AppO.pdf and http://www.usbr.gov/uc/envdocs/eis/

AspinallEIS/Vol2-Appdx-D.pdf). As discussed in Attachment K.1 (Geographic Scope of the Analysis), alternative operations at Glen Canyon Dam are expected to have a negligible impact on prices within the Western Interconnection and patterns outside of the SLCA/IP market system, and are therefore assumed to be static (i.e., given values) and identical under all alternatives.

LTEMP alternatives will have a relatively small impact on bilateral market interactions between the SLCA/IP market system and the rest of the Western Interconnection; that is, a maximum decrease of about 4.3% for power sales and decrease of 1.4% for power purchases. The use of LMPs to measure the economic impact of changes in Western Interconnection transactions yields a very good approximation because the LMP represents the system resource cost to serve the marginal load at a specific point. Therefore, a SLCA/IP market system sale to the Western Interconnection displaces higher cost generation in the interconnection. Likewise, a power purchase by the SLCA/IP market system displaces higher cost generation in the SLCA/IP system by increasing production in the interconnection at a cost that approximately equals the LMP at the Palo Verde hub minus transmission costs.

K.1.3.2 Middle Tier: LTF Customer Utility Systems

The primary focus of the power systems analysis is the SLCA/IP federal hydropower resources and the utilities operated by its LTF power customers. The SLCA/IP federal hydropower resources that the CRSP Management Office markets and the Montrose EMMO schedules are described in more detail in Section K.1.3.3. This section describes the approximately 138 customer entities that have SLCA/IP LTF contractual agreements with WAPA.

WAPA sells power to wholesale power customers on both a firm and non-firm basis, including cities and towns, rural electric cooperatives, public utility and irrigation districts, federal and state agencies, investor-owned utilities, power marketers, and American Indian Tribes (Tribes). In total, these entities provide retail electric service to millions of consumers in the Western Interconnection. However, others are end-use customers, including federal and state agencies, and irrigation districts that use power directly for their own purposes. Various laws, including the Reclamation Project Act of 1939 and the Federal Power Act, require WAPA to give preference to certain types of nonprofit organizations seeking to purchase federal power. Those entitled to preference status include cities and towns, state and federal agencies, irrigation districts, public utility districts, rural electric cooperatives, and Tribes (see https://www.wapa.gov/About/Pages/customers.aspx).

For economic analysis purposes, the system modeled in the middle tier includes LTF customers that are categorized as either large or small. Accounting for about 75% of WAPA's LTF energy and capacity sales, the eight largest customers, in terms of capacity and energy allocation, are Deseret Generation and Transmission Cooperative (Deseret), the Navajo Tribal Utility Authority (NTUA), Salt River Project (SRP), Utah Associated Municipal Power Systems (UAMPS), Utah Municipal Power Agency (UMPA), Platte River Power Authority (PRPA), Tri-State Generation and Transmission Association (Tri-State), and Colorado Springs Utilities

(CSU). Except for NTUA, all large LTF customers own and operate generating resources. About 130 remaining customers were aggregated for the analysis into two "small customer" entities accounting for the remaining 25% of LTF sales. Individually, each small customer receives less than 2.5% of WAPA's total SLCA/IP LTF capacity and energy sales. Lastly, WAPA has LTF contracts to serve project use loads such as pumping for irrigation. Serving these loads has the highest priority for delivery.

In CY 2013, the eight large SLCA/IP LTF power customers owned and contracted for the use of specific physical resources. Based on data contained in EIA Form-860 and information obtained from both IRPs and the EPIS AURORA database, the total firm capacity of these resources was approximately 12,670 MW. As discussed in more detail in Section K.1.7.5, firm capacity in this power systems study is based on the maximum output level that a resource is expected to reliably produce during the time of peak demand. For some generating units, the firm capacity is significantly different from the nameplate capacity.

As shown in Figure K.1-2, over 50% of this capacity is owned by SRP and another 19% is owned by Tri-State. The remaining six large customers account for the remainder. In addition to these supply resources and the aforementioned SLCA/IP LTF contracts, additional firm capacity for is secured through other federal power purchases from WAPA's Loveland Area Projects and the Desert Southwest Offices and through non-federal power contracts. In addition, DSM measures are credited as firm capacity resources. Based on data contained in Federal Energy Regulatory Commission (FERC) Form-714 and utility IRPs, these resources and non-firm energy transactions were used to serve combined service territory loads of almost 61 TWh in CY 2013.

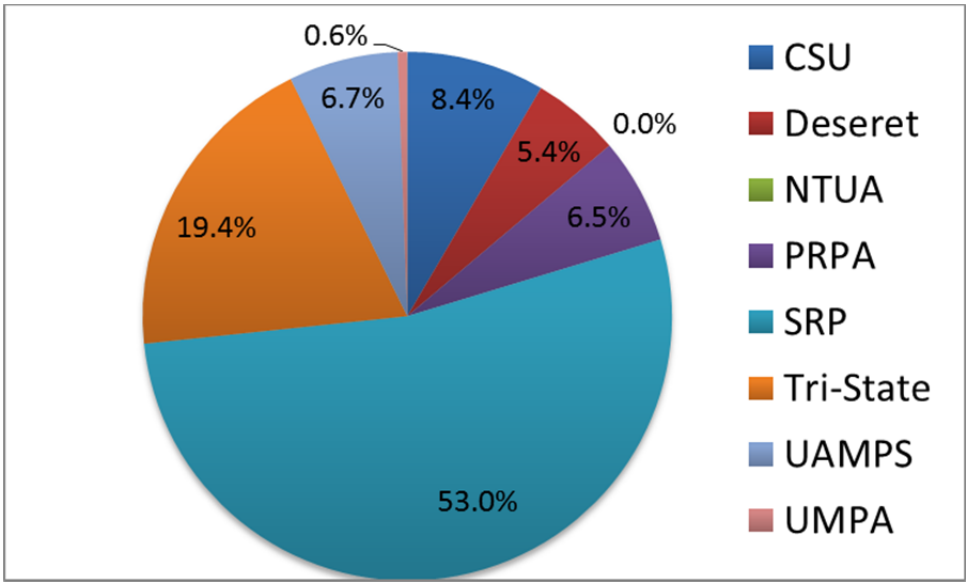


FIGURE K.1-2 Percentage of Total Generation Resources Owned by Individual Customers

Figure K.1-3 shows a simplified topology for the SLCA/IP market systems that was used by the AURORA model. It contains both large and small LTF customers. Where applicable, bubbles for large customers (shown as Pool A in Figure K.1-3) contain both loads and resources. Depending on the customer's location, loads and resources are designated as east or west regional entities. In the figure, small customer and project use bubbles only contain loads that have been aggregated by location. Energy flows among entities via system linkages. Some links have limitations and/or associated costs. More details about the SLCA/IP market system topology are described in Section K.1.6.

It should be noted that the Glen Canyon Dam Powerplant and all other federal hydropower plants are modeled as resources that are directly available to WAPA's customers. In reality, energy and capacity from these resources are sold by the CRSP Management Center to customers through LTF contracts. Argonne staff, in consultation with WAPA, Reclamation, and the NPS, decided not to include a representation of these contracts in the modeling process because the vast majority of the SLCA/IP federal resource is under contract to ultimately serve LTF customer loads and capacity needs. Financial complications associated with covering short-term and hourly long and short energy positions would have made the modeling process significantly more expensive and time consuming. It was also judged to have little impact on the assessment of the relative impacts of LTEMP alternatives. Given the time and budget

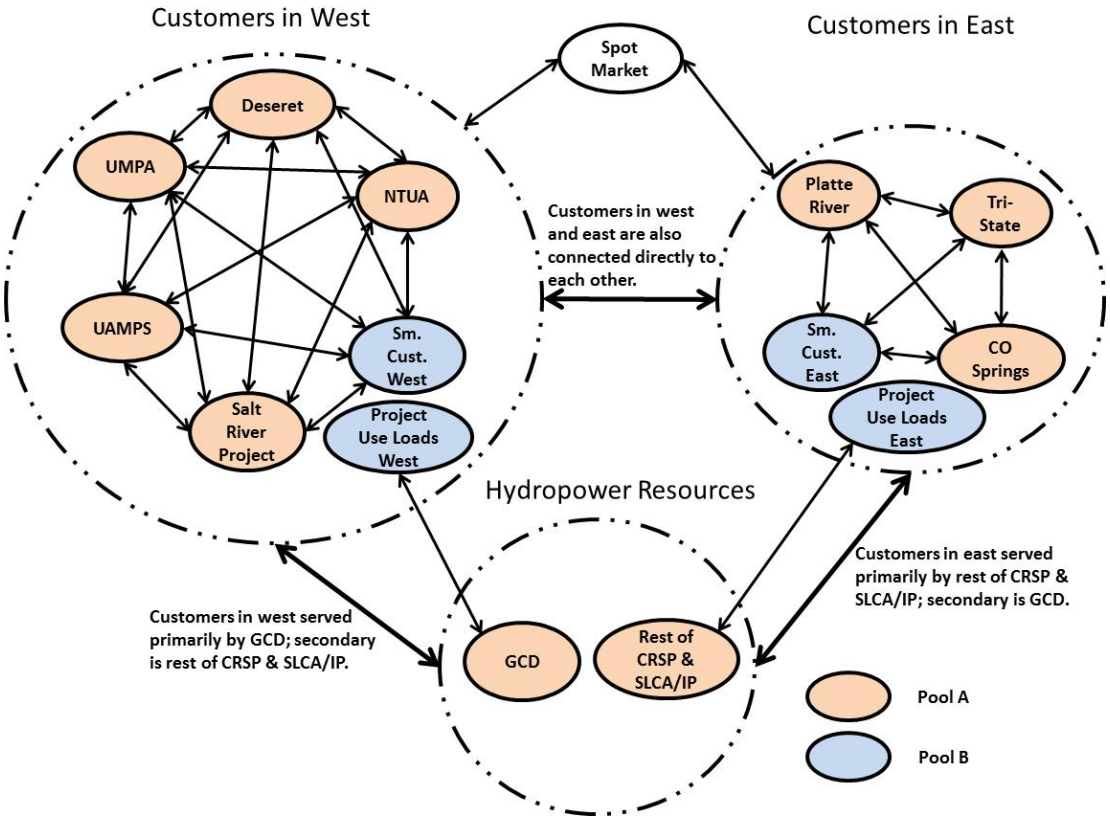


FIGURE K.1-3 Simplified Network Topology of the SLCA/IP Market System

constraints, it was decided that the more direct approach of modeling hydropower resources was sufficient.

Power systems modeling of the SLCA/IP market system assumes a very high level of cooperation and coordination among WAPA and its LTF power customers. Capacity expansion planning, unit commitment schedules, and least-cost hourly dispatch for the entire system were based on a "single operator/decision maker" model. This is a higher level of cooperation and coordination than what actually occurs. However, WAPA and its customers do cooperate on a number of different levels. For example, several large LTF customers jointly own capacity of some of the same facilities. They also buy and sell energy through long-term, day-ahead, and hour-ahead bilateral agreements using various market signals. The SLCA/IP market system topology also includes energy transfer costs that dampen power transfers relative to a "single-decision maker" model that does not incur these costs.

The AURORA topology of the SLCA/IP market system does not model physical transmission constraints. It does, however, limit flows on some links between bubbles. Energy flows on links connecting SLCA/IP federal hydropower resources to LTF customer loads are limited by contract rate of delivery (CROD) allocations (WAPA 2015). CROD is the firm capacity the CRSP Management Center agrees to have available for delivery. It may or may not be accompanied by energy supplied by WAPA (see https://www.wapa.gov/crsp/opsmaintcrsp/dictionary.htm#c). When not all of the CROD is being utilized for WAPA power deliveries, a customer can use the remainder to schedule the delivery of other energy transactions. In addition, 5% of the energy that flows on these links is lost between the point of injection and the delivery point. This represents EMMO current transmission losses for SLCA/IP federal hydropower deliveries. Under wet hydrological conditions in which SLCA/IP total federal hydropower generation exceeds the total CROD, the excess energy flows on links that represent shorter term WAPA energy transactions with its LTF customers.

Regardless of the amount of firm capacity that is available from SLCA/IP federal hydropower resources, WAPA's CROD is assumed to be identical under all alternatives. Currently, some customers voluntarily use the difference between the CROD and sustainable hydropower (SHP) on WAPA's transmission system for customer displacement power (CDP). The SHP is the minimum amount of power and energy the EMMO must deliver to its LTF customers regardless of SLCA/IP federal hydropower conditions. The CDP replacement option is specified under an amendment to the SLCA/IP firm electric service contract to accommodate replacement power decisions. Therefore, it is assumed that any loss in firm capacity under an alternative will free up transmission capacity for CDP transactions (Loftin et al. 1998).

Transfers of energy among LTF customers are virtually unconstrained, which may lead to an overestimation of the amount of energy transfers and underestimation of cost impacts among LTF customer utilities. However, there are significant on- and off-peak costs for energy flows on lines that connect customers to each other. These costs tend to dampen bulk power transactions among the bubbles. Information from WAPA regarding hourly transmission rates for five of WAPA's large customers and six other investor-owned utilities in the surrounding area (Wicks 2014) was used to set transfer costs on links between any two firm electric service customers to $6.5/MWh and $3.5/MWh for peak and off-peak, respectively.

Lastly, it is assumed that additional capacity built by customers as a result of any losses at Glen Canyon Dam will be located to help alleviate transmission congestion. Note that Glen Canyon Dam is remotely located from major load centers. This may also result in a somewhat lower energy loss on the transmission lines since more heavily loaded lines during peak hours have higher losses than during cooler off-peak periods. For example, replacement capacity for SRP would likely be built closer to the Phoenix load center than the Glen Canyon Dam. Because the LTEMP analysis was an economic analysis and not a financial one, it did not address the impacts of siting each potential replacement power plant. See the discussion in the section "Capacity Expansion Candidate Unit Characteristics" in Section K.1.6.3.

Assumptions and simplifications associated with the topology and representation of the SLCA/IP market system will affect modeling results. However, the intent of the power systems analysis is to perform a comparative economic study to identify the relative ranking and magnitude of alternative impacts using Alternative A as a benchmark. Because any inconsistencies in results will be present in the evaluation of all alternatives, the relative differences among alternatives are expected to be robust. Despite the simplifying assumptions and potential effects on modeling results, the AURORA dispatch model does provide reasonable results for LTEMP power systems analyses. As discussed in more detail in Section K.1.6.2, a 2013 benchmark analysis of utility-level generation by fuel type for the eight large customers modeled by AURORA were very similar to values reported by each utility in EIA Form-923. This result assured Argonne modelers that, from a production cost standpoint, the modeling approach and the results obtained were reasonable.

K.1.3.3 Bottom Tier: WAPA SLCA/IP Hydropower Resources

Of the three analysis tiers, the bottom tier is modeled at the finest level of granularity. It simulates the hourly operation of WAPA's 11 SLCA/IP powerplants that are marketed and scheduled by the CRSP Management Center. For this study, six of these facilities are classified as large plants. The largest is at Glen Canyon Dam. Its powerplant consists of eight generating units with a combined capacity of about 1,320 MW. As shown in Figure K.1-4, Glen Canyon Dam accounts for about 72% of WAPA's total SLCA/IP federal hydropower nameplate capacity. Other SLCA/IP federal hydropower plants in the system that are classified as large SLCA/IP federal hydropower facilities include powerplants contained in the CRSP and the Seedskadee Project. All large plants except Fontenelle are in the CRSP. The Blue Mesa Powerplant has two generators, the total capacity of which is 86.4 MW. Located 12 mi downstream from Blue Mesa on the Gunnison River, the Morrow Point Power Plant has two units with a combined capacity of 165 MW; another 6 mi farther downstream, the Crystal Powerplant has an installed capacity of approximately 32 MW from one unit. Blue Mesa, Morrow Point, and Crystal are part of the Wayne D. Aspinall Cascade (also referred to as the Aspinall Cascade). The Fontenelle Powerplant has a nameplate capacity of 10 MW and it is the only powerplant associated with the Seedskadee Project. Flaming Gorge Dam is located on the Green River downstream of Fontenelle Dam. The Flaming Gorge Powerplant has three generating units. Each unit has a nameplate capacity of 50.65 MW for a total of approximately 152 MW. However, because of turbine limitations, the operable capability of the powerplant is approximately 141 MW.

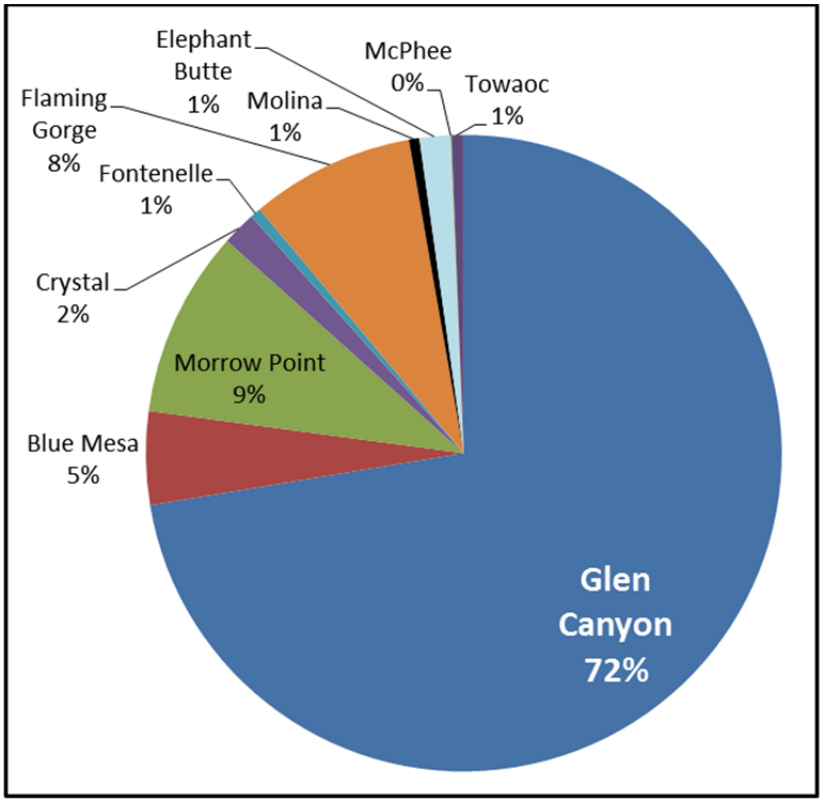


FIGURE K.1-4 Percentage of SLCA/IP Federal Hydropower Nameplate Capacity by Facility

The SLCA/IP hydropower facilities that are classified as small include the Upper and Lower Molina complex in the Collbran Project with a combined nameplate capacity of 13.5 MW, the Elephant Butte Powerplant in the Rio Grande Project with 28 MW, and in the Dolores Project, the McPhee and Towaoc Powerplants with total of 11.5 MW. Combined, these small facilities account for less than 3% of WAPA's SLCA/IP hydropower resources.

Modeled hourly energy production from federal hydropower resources are input into the SLCA/IP market system as a time series of power injections and from bubbles indicated in Figure K.1-3 as "Hydropower Resources." As discussed in more detail in Section K.1.5, both the middle and bottom tier models use a consistent set of LMP projected by the Western Interconnection model (top tier).

K.1.4 Overview of Power Systems Methods

The Argonne team of power system analysts and modelers developed a collection of tools that are linked together to evaluate the economic costs of LTEMP EIS alternatives. The processes by which these tools were used and information flows among them are summarized in this section. The next section describes each tool in more detail, and the ones that follow provide more information on model input data and applications.

Incorporating all aspects of the three tiers discussed earlier, Figure K.1-5 shows the modeling sequence and data flows for the power systems analysis. Using Western Interconnection topology depicted in Figure K.1-1, the AURORA model models the top tier. Palo Verde market hub LMPs produced for CY 2013 are calibrated to closely match observed levels. LMP calibration factors are discussed in more detail in Attachment K.2 and are applied to future years through the end of the study period.

The bottom tier, which represents WAPA's SLCA/IP federal hydropower plants, is modeled next. Due to the complexities of SLCA/IP hydropower operating criteria and mandates unrelated to power production, AURORA could not directly model either the firm capacity or the hourly operations of the larger and more complex SLCA/IP federal hydropower resources. Therefore, the Colorado River Simulation System (CRSS) model, the Sand Budget Model (SBM), a simplified version of the Generation and Transmission Maximization (referred to as GTMax-Lite) model, and spreadsheet tools were used to project powerplant-specific hourly production levels over the study period at a level of detail sufficient for estimating power economic impacts that would potentially occur from alternative Glen Canyon Dam operations.

The CRSS model developed by Reclamation models the future operations of water-related resources on the Colorado River. Power systems analysis utilized 21 CRSS projected monthly hydrological futures for large WAPA SLCA/IP federal hydropower plants including Glen Canyon Dam. Separate CRSS model runs are made for each alterative, resulting in unique projections of monthly reservoir elevation and water volume releases for Glen Canyon Dam. The monthly operations of all other SLCA/IP dams are unaffected by an alternative.

A simplified version of the Generation and Transmission Maximization model (called GTMax-Lite) developed by Argonne optimizes the economic value of hourly energy produced by both Glen Canyon Dam and all other large SLCA/IP federal hydropower facilities. The dispatch depends on unit availability as simulated by an outage model, LTEMP EIS operating criteria, SBM monthly water releases, and a time series of energy market prices.

For each alternative, the GTMax-Lite configuration that represents Glen Canyon Dam was run for all traces under two different conditions. The first condition assumes that no distinctive release events such as HFEs will occur in the future; that is, CRSS monthly results and Western Interconnection calibrated LMPs drive hourly SLCA/IP operations. No TMFs or HFE are conducted in this first set of model runs. Using these initial results from CRSS and GTMax-Lite, the Reclamation SBM schedules various HFEs that differ in terms of peak water release rate, duration, and timing. The SBM also reallocates CRSS monthly water release volumes among the months of a single WY in order to enable higher water releases during months with experiments. Due to the reallocation of monthly water releases and the scheduled TMFs and HFEs, the GTMax-Lite model that represents Glen Canyon Dam must be run a second time using the SBM results. It is this second GTMax-Lite run that is used for Glen Canyon Dam for all power systems economic analyses.

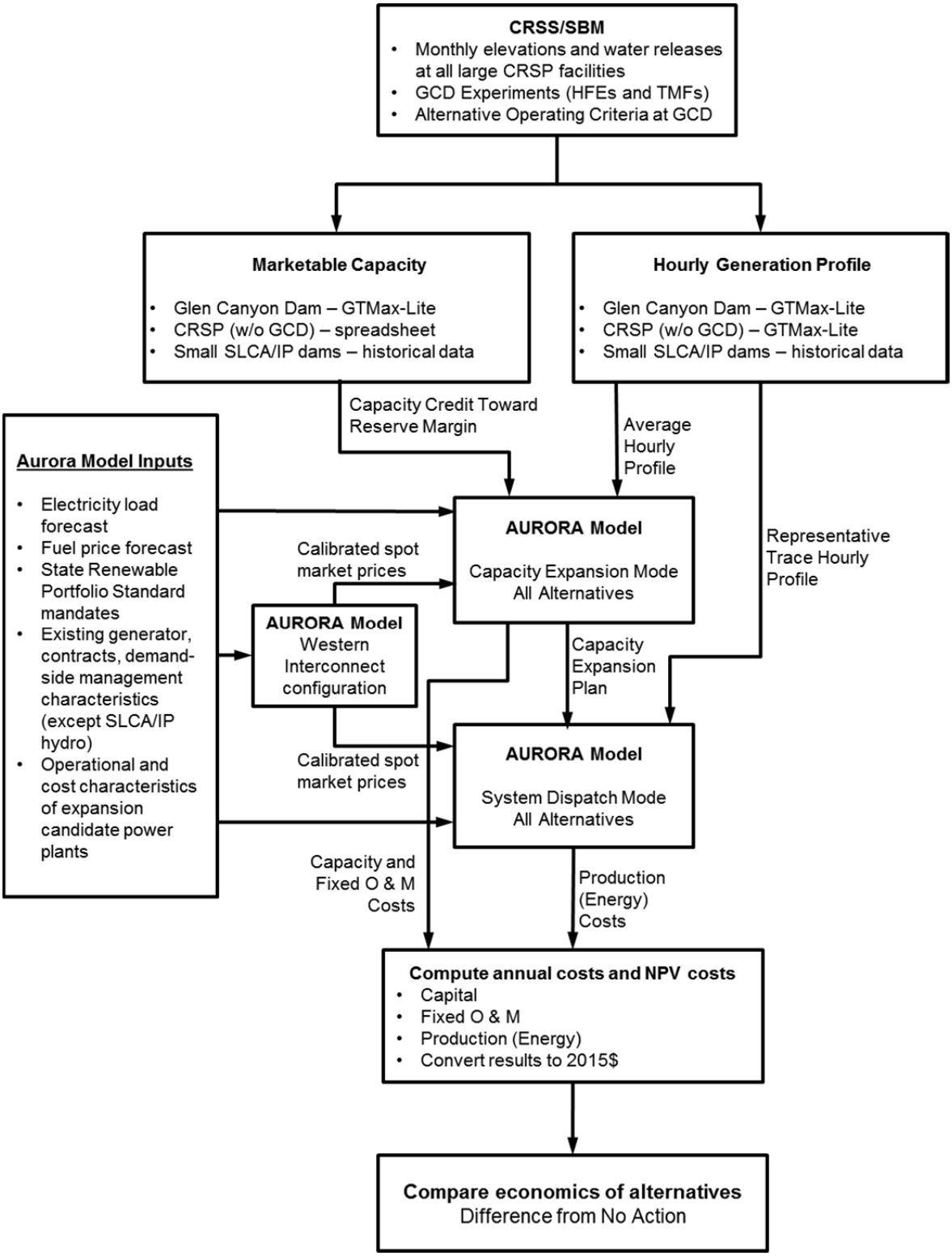


FIGURE K.1-5 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS

A second configuration of GTMax-Lite configuration simulates the operation of other large SLCA/IP powerplants. It also uses input data from the CRSS model and calibrated Western Interconnection LMPs. The Glen Canyon Dam LTEMP EIS alternative operating criteria and experimental releases conducted at Glen Canyon Dam do not impact the operations of these upstream resources; therefore, the SBM does not consider these resources in the determination of when HFE events will occur. GTMax-Lite optimization for these plants was performed for a condition that represents an average hydrological condition as projected by CRSS and for the CRSS projection, also known as a trace, which was judged by Argonne staff to be "representative" of the 21 projections. The selection of this representative trace is described in Attachment K.3.

The firm capacity of WAPA's SLCA/IP federal hydropower resources is computed by spreadsheet tools that estimate the maximum potential output of these resources during the time of peak system load. Depending on an alternative's operating criteria, the maximum output level at the Glen Canyon Dam Powerplant is suppressed. For example, flat flow alternatives are associated with relatively low firm capacity levels, while higher firm capacity levels are attained under less stringent operating criteria such as under Alternative B. As described in more detail in Sections K.1.5 and K.1.7, determination of Glen Canyon Dam Powerplant capacity is based on GTMax-Lite hourly results for all 21 projected futures. Other large SLCA/IP hydropower plant firm capacities are based on CRSS projected futures and power equations that estimate maximum output levels.

The middle tier is modeled by the SLCA/IP market system configuration of AURORA. This configuration contains all of the loads and resources that are in the utilities operated by SLCA/IP LTF wholesale customers and a point that represents a connection to the rest of the Western Interconnection. At this interconnection point, energy is bought and sold at the calibrated Palo Verde market hub price. Hour-by-hour energy injections into the system from WAPA's hydropower resources are prescribed as determined by GTMax-Lite.

For each alternative, AURORA was used for two major purposes: (1) to determine the cost of capacity expansion pathway over time during the study period for the SLCA/IP market system; and (2) to compute production costs associated with a least-cost unit commitment and system dispatch for a given expansion pathway and a single representative hydrology future or trace. Therefore, AURORA is run in two modes. The first, or "expansion," mode is used to determine the type of technologies that will be built in the SLCA/IP market system and the time when system capabilities will be expanded. It also considers scheduling the retirement of existing generating units. The second, or "dispatch," mode determines unit commitments and performs a system dispatch of a static set of both existing and new resources. This static resource set was determined by previous AURORA capacity expansion runs.

As shown in Figure K.1-5, calibrated market prices are used by both the capacity expansion and system dispatch modes for all alternatives. However, the AURORA capacity expansion model runs use the hourly energy production from WAPA's SLCA/IP hydropower resources, based on an average hydropower condition, while AURORA dispatch runs use generation level projected by the representative trace.

Results of the AURORA dispatch model consist of costs to produce the electrical energy to meet the system load demand. Production costs are the sum of powerplant fuel costs, variable O&M costs, unit startup costs, and the cost of power purchased from the spot market minus spot market sales revenues. Results from the AURORA expansion and dispatch models (namely capital, fixed O&M, and production or energy costs) were combined to determine the total annual costs for each alternative. The NPV stream of costs was also calculated to facilitate comparisons among alternatives. This single lump-sum value was based on a discount rate of 3.375%, a rate that is used by Reclamation for cost-benefit studies of projects. The use of this discount rate was in part based on information contained in Attachment K.4, which was provided by Reclamation staff. At the recommendation of WAPA staff, a second discount rate of 1.4% was used in a sensitivity study.

K.1.5 Description of Individual Power System Models

As described in the previous section, Argonne used several tools and models of varying levels of detail and complexity to estimate the economics of LTEMP EIS alternatives. Additional information on each of these tools and models, along with a description of other supporting algorithms, is provided below.

K.1.5.1 Colorado River Simulation System Model (Bottom Tier)

The CRSS model was developed by Reclamation to model future operations of water-related resources on the Colorado River, including both the upper and lower portions of the basin. The Glen Canyon Dam is the lowest reservoir in the upper basin. For the LTEMP EIS, CRSS projected 105 monthly hydrological futures over a 48-year time period from 2013 through 2060, inclusive. Each future or trace is based on a historical time series of hydrological conditions. Power system analyses utilize the first 21 years of CRSS projections of reservoir elevations and water release volumes for CRSP and the Seedskadee Project; that is, the set of large plants. Of the 105 traces projected by CRSS, a common set of 21 was used by all EIS research areas including power systems analyses.

For the initial structured decision-making exercises, all of the simulation cases included three separate options for sediment conditions (high, moderate, and low), effectively multiplying the number of simulations required by a factor of three. Once the detailed results were generated, the three sets of findings were assigned relative weightings in order to combine and condense the findings into weighted averages. For expediency in the power systems analysis, all of the simulation runs will be based on a single sediment option (the moderate case, also designated "s2" in previous treatments), which was weighted by 63.1% for combining the detailed results. This greatly reduces the number of cases to be examined, and based on previous findings it does not affect comparisons or conclusions regarding impacts of the alternatives.

Separate CRSS model runs are made for each alterative, resulting in a unique projection of monthly reservoir elevation and water volume releases for Glen Canyon Dam. However, monthly operations of all other SLCA/IP dams are identical under all alternatives. Therefore,

operations for all large SLCA/IP federal hydropower plant model runs of GTMax-Lite used CRSS results for Alternative A.

K.1.5.2 Representative Trace Tool (Bottom Tier)

The Representative Trace Tool contains supplemental software written by Argonne specifically for the LTEMP EIS. It assists in the selection of a single hydrological trace for the detailed hourly dispatch of WAPA's large SLCA/IP hydropower plants. The trace chosen best meets a set of criteria for being "representative." The representative trace must have annual variations in hydrological conditions at Glen Canyon Dam that are similar to the hydrological distribution of the entire population of the 21 common trace set for sediment condition 2. The mean Glen Canyon Dam annual water release of the representative trace must also be approximately equal to the mean of all 21 traces. For consistency, the selected trace is also applied to the other five large SLCA/IP federal hydropower plants.

K.1.5.3 Hydropower Outage Model (Bottom Tier)

The Hydropower Outage model and supporting spreadsheets are used to simulate unit outages at all six large SLCA/IP federal hydropower powerplants. This includes both scheduled outages and forced outages that are caused by random mechanical and electrical events. Designed and written by Argonne, a methodology was developed to incorporate the number, cause, and duration of forced outages that may potentially occur during the 20-year study period. The model uses a random number generator to simulate the timing and cause of forced outages using data contained in the NERC Generating Availability Data System (GADS). Several instances of the model were run. The time series of random outage selected for LTEMP analyzes was the one that closely matched GADS statistical averages. The outage methodology is discussed in more detail later in Section K.1.7.3 and in Attachment K.5. The same time sequence of representative outages was used under all alternatives.

Reclamation provided Argonne with maintenance schedules over the study period for large SLCA/IP facilities. The timing and length of outages at large SLCA/IP powerplants is in general the same under all EIS alternatives. However, during HFEs and TMFs, it was assumed that a scheduled maintenance outage would not be conducted.

K.1.5.4 Generation and Transmission Maximization-Lite (Bottom Tier)

GTMax-Lite is a simplified version of the full GTMax model. Both were developed by Argonne. GTMax-Lite has limited scope and data requirements compared to the full version of GTMax. The two versions of GTMax-Lite used for the LTEMP EIS represent only the physical characteristics of hydropower plants, downstream flow requirements, and both water release and reservoir operating criteria. The primary modeling objective of the lite version is to maximize the economic value of hydropower resources. This differs from the full GTMax model, in which the full model represents other factors such as customer power delivery requests sent to the EMMO,

short-term purchase and sale commitments, and non-economic EMMO dispatch goals and guidelines. Although full GTMax and GTMax-Lite differ, they share many of the same features and in general produce similar generation patterns and estimates of hydropower economic value.

The GTMax-Lite model configuration used for LTEMP power systems analyses optimizes the economic value of hourly energy produced at both Glen Canyon Dam and all other large SLCA/IP federal hydropower facilities. Operations depend on both unit availability as simulated by the outage model and a set of operating criteria. For the LTEMP EIS, two configurations of the model were constructed. One represents the operation of only Glen Canyon Dam, and the other optimizes the operation of the remaining large hydropower facilities.

GTMax-Lite was used because many thousands of weekly runs with hourly time steps need to be performed rapidly. It was customized to address a specific problem by tailoring the objective function, the input and output routines, and the model constraints to be consistent with LTEMP modeling needs; that is, it models federal hydropower resources without LTF contractual obligations. Multiple model runs and data handling are controlled by a Microsoft Excel® spreadsheet, and the objective function is optimized using the Lingo software, which simultaneously identifies the best pattern of hourly energy production over time that satisfies all operational constraints. The Lingo optimization software was developed by LINDO Systems and is widely used by educational institutions and large corporations.

Glen Canyon Dam Configuration

The Glen Canyon Dam GTMax-Lite model was run thousands of times in support of the structured decision analysis (SDA) process (Appendix C). This includes nearly 1,000 LTEMP scenario optimizations (combinations of 19 long-term strategies based on the 7 alternatives [see Section 4.1], 21 hydrology traces [based on 105 years of historical data], and three sediment traces [based on 50 years of historical data]) that optimize water releases (each run consisting of 180,000 hr of Glen Canyon Dam flows). The GTMax-Lite hourly water release results were used by analysts in each resource area, such as sediment, fish, recreation, and riparian vegetation. Analyses of power systems economics leverages the outputs produced by this process.

Initial SDA exercises used all of the simulation cases, including the three separate sediment input traces (high, moderate, and low input). The power systems simulation runs used a single sediment trace (the moderate case). This reduced the number of cases to be examined by two-thirds, and, based on previous findings, does not affect comparisons or conclusions regarding impacts of the alternatives.

GTMax-Lite simulated operations at Glen Canyon Dam were made for all 21 projected hydrological futures over the entire study period. As described below, all runs were performed twice. The Glen Canyon Dam configuration uses hourly AURORA calibrated prices projected by the Western Interconnection configuration to maximize the economic power value of operations during representative 1-week periods for each month during the study period. Hourly prices input into the model are average values based on weekday, Saturday, and Sunday/holiday Palo Verde hub LMP projections. Model results for hourly Glen Canyon Dam generation are greatly

influenced by the hourly LMP profile, a weekly water release requirement, Lake Powell Reservoir elevation, and LTEMP alternative operating criteria.

To achieve more accurate/realistic results, both GTMax-Lite configurations explicitly model scheduled and forced outages. Reclamation provided a maintenance schedule for all six CRSP facilities over the study period (Clayton 2013). A methodology was developed to incorporate the number, cause, and duration of forced outages that would be expected during the study period. Data on forced outages for hydroelectric turbines were obtained from GADS, which is a database of operating data on electric generating equipment maintained by the NERC. This information was input into an algorithm that produced a plausible series of random outages for units at the Glen Canyon Dam Powerplant. For large SLCA/IP federal hydropower facilities, based on the cause of forced outages and associated average down times using data contained in the NERC GADS for hydropower plants that had capacities greater than 30 MW.

Market prices input to LTEMP power system models represent the economic value of hydropower generation at hourly intervals. These prices directly influence the generation schedule produced by the models when optimizing SLCA/IP hydropower resources. To the extent possible, the GTMax-Lite model uses its limited-energy/water resource stored in a reservoir (i.e., Lake Powell at the Glen Canyon Dam) to first generate electricity during on-peak hours when it has the highest economic value. Any remaining energy is scheduled during lower-priced hours.

Model-generated operations comply with any operating constraints and downstream flow targets placed upon the hydropower system for environmental or institutional reasons. Operating constraints include limits on water release up- and down-ramp rates, limits on reservoir water release rate changes over a rolling 24-hour period, ancillary service requirements, and others.

Figure K.1-6 illustrates a typical Glen Canyon Dam GTMax-Lite result for a 24-hour period. The green bars represent hourly Glen Canyon Dam Powerplant production, the total of which is highly influenced by the mandated monthly water release volume. The light green line shows hourly market prices. In general, energy production is the highest when it has the most value. Note that the production levels are such that the total of hourly generation multiplied by the market price (i.e., energy production value) over the day is as large as possible. The production pattern adheres to all operating criteria such that the power output pattern complies with minimum and maximum flow rate constraints, ramp-rate limits, and daily change restrictions. Also note in this example that some of the constraints are binding. In this case, the minimum and maximum generations do not bind the solution; that is, generation levels do not operate at either of these levels. Generation pattern is bound or limited by daily change and both up and down hourly ramp rate constraints. However, when more water is released for power generation, the maximum limit becomes binding because peak generation levels are possible within the daily change constraint. On the other hand, when hydropower generation is low, the minimum constraint becomes binding. Therefore, hydropower conditions often dictate when a constraint is either binding or not binding.

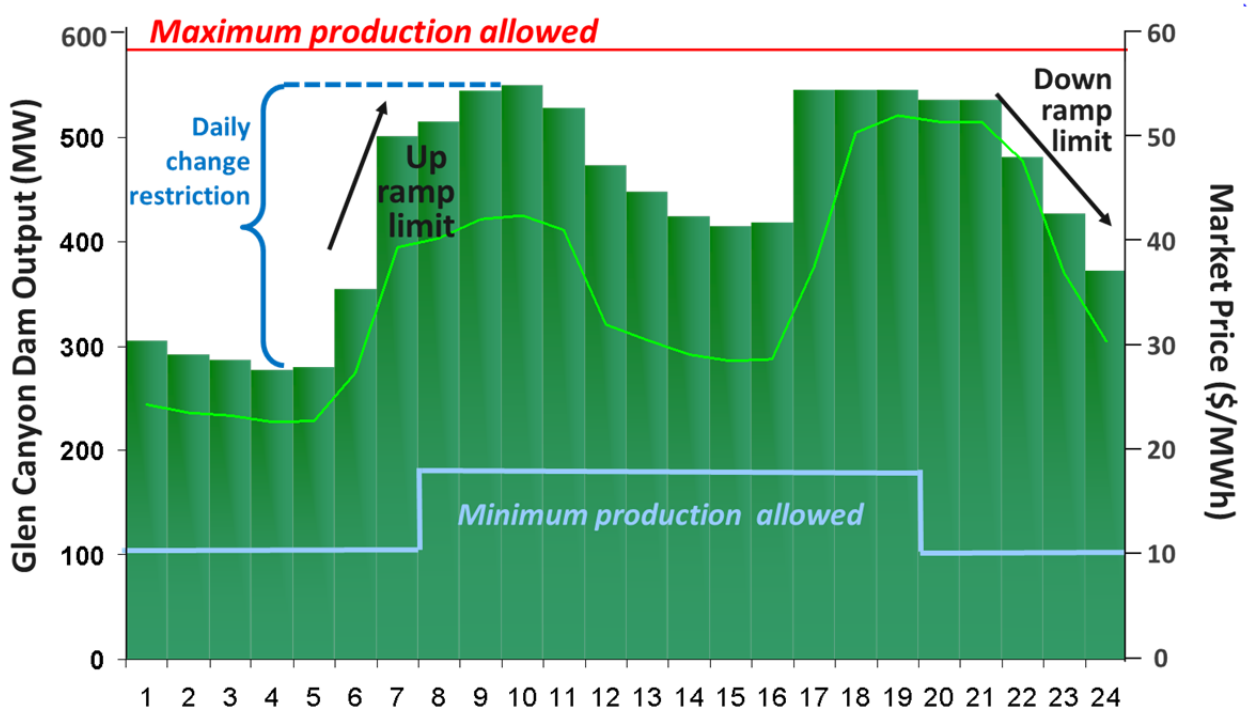


FIGURE K.1-6 Illustration of a Typical GTMax-Lite Result for a 24-Hour Period

More operational flexibility at Glen Canyon Dam always translates into higher or equal economic value. For example, if there was no daily change constraint, powerplant output in Figure K.1-6 would have been at the minimum during the nighttime, when prices are lower, and ramped up over a few more hours to reach the maximum output level when prices are the highest. A further relaxation of operating criteria by removing hourly ramping constraints, lowering the minimum, and increasing the maximum would have resulted in a higher concentration of Glen Canyon Dam generation in the hours with the highest demand. The daily maximum generation level would have also been higher. Therefore, limits not only constrain the economic value of energy, but also impact the maximum output that Glen Canyon Dam produces during system peak loads and therefore reduce its firm capacity.

The Glen Canyon Dam version of GTMax-Lite compresses the full 8760 hr per year into 12 "typical week" periods of 168 hr for each month. Outputs include hourly turbine and non-turbine water release and power generation schedules for a series of representative 1-week time periods (i.e., sequence of 168-hour time periods) that maximize the economic value of hydropower energy resources. The Glen Canyon Dam GTMax-Lite configuration utilizes a "wrap" technique that significantly reduces model end-effects associated with running typical weeks. The technique essentially connects the modeled beginning hours to those at the end of the optimized week. Because the model mathematically repeats the same weekly pattern infinitely, ending model solutions are positioned such that it is starting in a good position for operations during the following week.

Because the GTMax-Lite model only simulates operations for one representative week in each month, the results are repeated to reflect full months of hourly operations for each year of the study. This is accomplished by assigning the typical water and generation release pattern estimate by GTMax-Lite for specific day types to each day of the month. For example, the Sunday optimized pattern is assigned to all Sundays and holidays that occur in a month. It should also be noted that GTMax-Lite is provided with the number of day types that occur in each simulated month. Using this information, GTMax-Lite produces a weekly result such that the repeated daily results over a month release the exact amount of specified monthly water release.

The GTMax-Lite configuration that represents Glen Canyon Dam was run under two different of assumptions. The first assumes that no distinctive release events such as HFEs will occur in the future, in which case CRSS data are used to drive operations. This information was input into the SBM in order for the model to schedule HFEs and adjust CRSS monthly water release volumes and Glen Canyon Dam reservoir elevations. This intermediate solution was only used by the SBM.

For a second run of the Glen Canyon Dam GTMax-Lite model, it is assumed that HFEs will occur as scheduled by the SBM. The LTEMP EIS defines several different types of HFE, each with a unique specified hourly water release pattern. GTMax-Lite models operations when an HFE is *not* scheduled. A separate routine is used to compute Glen Canyon Dam Powerplant generation based on the prescribed HFE water release pattern. This pattern depends on the type of HFE that would be conducted. Under most HFEs, there are time periods when water release requirements exceed the combined maximum flow rate of Glen Canyon Dam Powerplant turbines. Therefore, the routine tracks both turbine water and non-turbine water releases. It also computes power production levels based on Lake Powell's water elevation. During days in a month in which an HFE is not scheduled, Glen Canyon Dam hourly generation simulated by GTMax-Lite accounts for the SBM monthly water release volume, the amount of water that was released during the HFE, and the number of normal operating days (i.e., day without the HFE) in the month.

Other Large Federal SLCA/IP Hydropower Resources Configuration

Because WAPA markets power from combined SLCA/IP facilities, of which Glen Canyon Dam is the single largest component, a second GTMax-Lite configuration was developed. It represents the remaining CRSP hydropower powerplants, including Blue Mesa, Morrow Point, Crystal, and Flaming Gorge, and the Fontenelle Powerplant of the Seedskadee Project. Although Fontenelle is not technically part of CRSP, it is included in this configuration because it is operated as a cascade with Flaming Gorge and the CRSS model projects both monthly reservoir elevations and releases for these facilities. This GTMax-Lite configuration and its key operating constraints, shown in Figure K.1-7 below, were developed specifically for the LTEMP EIS.

GTMax-Lite is a scaled-down version of the full GTMax model. Both represent all the physical CRSP and Seedskadee powerplants and downstream flows at gages in the Green River. However, the lite version omits the representation of SLCA/IP firm contracts. Instead, large

SLCA/IP hydropower plant operations are driven directly by electricity market price signals—not contracts. This streamlined process involves far fewer model operator steps and solves the problem considerably faster than the full GTMax model. The omission of SLCA/IP firm contractual loads has a very minor impact on the dispatch of the Glen Canyon Dam Powerplant because price patterns are highly correlated with loads, and operating constraints under all alternatives restrict the flexibility of Glen Canyon's response to hourly changes in prices and load patterns. Instead, operations follow a general on-peak and off-peak pattern that is restricted by the daily change criterion.

The GTMax-Lite configuration that represents these five large SLCA/IP powerplants was run once for an average hydrological condition to support AURORA capacity expansion model runs, and a second time using the representative trace to support SLCA/IP detailed system dispatch runs. It optimizes operations during all hours of the study period, based on input data from the CRSS model and AURORA Western Interconnection calibrated market prices for the Palo Verde market hub. LTEMP EIS alternative and experimental releases conducted at Glen Canyon Dam, such as HFEs and TMFs, do not affect the operations of these five upstream resources. Therefore, this configuration uses CRSS results for Alternative A. Therefore, the SBM did not adjust CRSS results.

As shown in Figure K.1-7, GTMax-Lite contains two water cascades. The first consists of the Fontenelle and Flaming Gorge Reservoirs and the second consists of the Aspinall Cascade, which includes the Blue Mesa, Morrow Point, and Crystal reservoirs. Operationally, reservoirs in

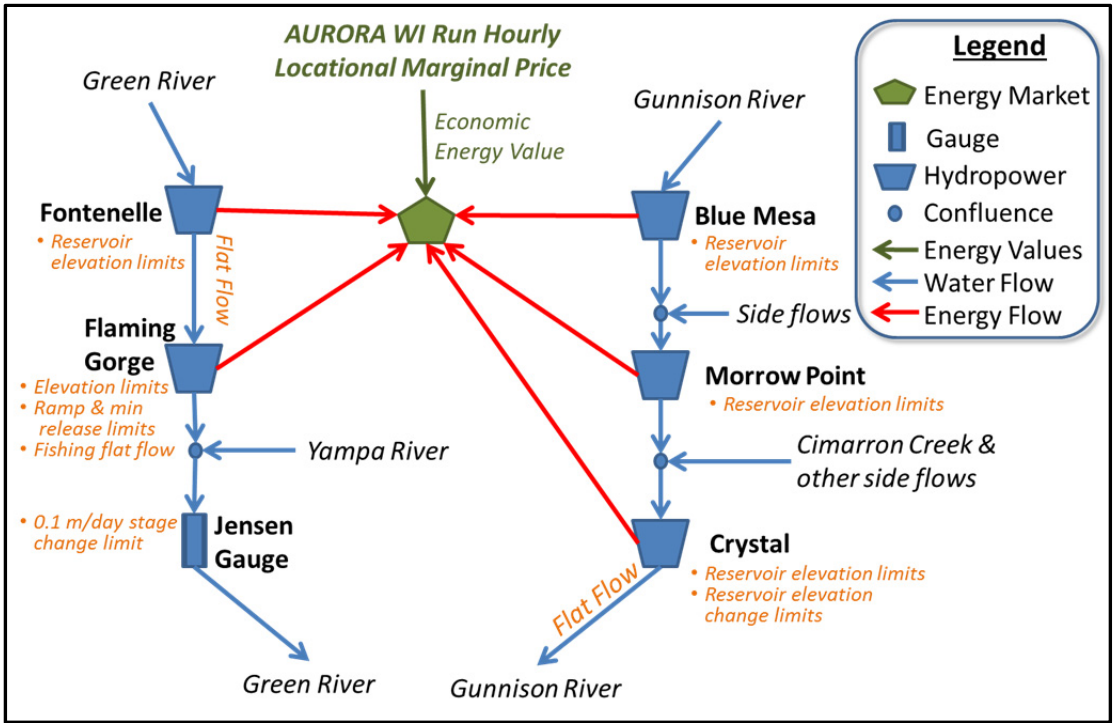


FIGURE K.1-7 GTMax-Lite Network Topology for the Large SLCA/IP Hydropower Resources Other Than Glen Canyon Dam

the first cascade are very loosely connected, but reservoirs in the Aspinall Cascade are very tightly coupled.

Monthly releases and reservoir elevations were obtained from CRSS model results for Alternative A. CRSS also provides information about water inflows into reservoirs, side flows that occur between connected reservoirs, and reservoir evaporation. Other inputs included operating constraints placed on the facilities, such as restrictions on water release ramp rates and flow requirements at the Jensen Gage downstream of Flaming Gorge. The objective function simultaneously maximizes the economic value of the hydropower resource at these five large facilities. The output is an hourly schedule of water releases and electric generation that maximizes the economic value of hydropower resources within the bounds of all operating constraints.

Operating constraints include maximum and minimum limits imposed on all reservoirs and a complex set of restrictions at the Crystal Reservoir that bound the rate of elevation changes over time. In order to ensure that water releases do not violate reservoir operating constraints, the GTMax-Lite model computes hourly water mass balances and reservoir elevations using reservoir elevation-volume functions. Water balancing equations account for water inflows, side flows, evaporation, upstream reservoir water releases, and all releases from the reservoir of interest.

Flows at the Jensen Gage are restricted to daily stage changes of 0.1 meters/day. Because gage flows are directly affected by upstream water releases from the Flaming Gorge Reservoir, GTMax-Lite models gage flows that comply with the daily gage constraint. To optimize Flaming Gorge operations, water travel time distribution (WTTD) functions are used to estimate the time it takes water to flow through Green River reaches, and the attenuation of releases as water travels downstream. For this study, two reaches are defined. The first is from the Flaming Gorge Dam to the confluence of the Green and Yampa Rivers and the second is from this confluence down to the gage. Although WTTD can vary by hydrological condition, for this study a typical WTTD function was derived from Streamflow Synthesis and Reservoir Regulation (SSARR) model outputs. SSARR was written by the Army Corps of Engineers. In general, it takes about 24 hr for the first fractional amount (less than 1%) of a Flaming Gorge release to reach the gage. Typically, all of the water passes the gage 48 hr after the release. Gage readings are computed using a function that relates the flow rate at the gage to the gage stage. Yampa River water flows into the Green River are based on historical monthly data. Based on historical records, for this study a monthly 50% flow exceedance was input into GTMax-Lite.

The temporal modeling methods used by GTMax-Lite for the five large hydropower plants differ from the Glen Canyon Dam configuration because it simulates operations for all hours during every study period day. It was structured and configured differently from Glen Canyon Dam GTMax-Lite because the operating constraints at powerplants and reservoirs in the Aspinall Cascade are fundamentally different from those at Glen Canyon Dam. The imposition of gage constraints at Jensen is also unique. The five-plant configuration of GTMax-Lite needs to be run far fewer times than the Glen Canyon Dam configuration, and therefore it is computationally efficient to model all days.

As shown in Figure K.1-8, time in the five large plant configuration of GTMax-Lite is separated into three periods that include history, primary optimization, and extension. The historical period is required because operations in the past affect future operation. These include operations in the Aspinall Cascade that constrain Crystal Reservoir elevation changes over 1-day and 3-day periods. In addition, operations at the Flaming Gorge Dam need to comply with gage flow constraints. Note that the water travel time from the Dam to the gage is about 2 days. For the first model run, actual historical operations are input into the model. However, for all subsequent optimizations, "history" is obtained from the previous model run. For this study, hourly results for the last 3 days of the primary optimization period are used.

To reduce model end effects and place operations at the end of the simulated period in a good position for the following days, a 1-week extension period is included in each model run. This differs from Glen Canyon Dam GTMax-Lite model runs that apply the previously described wrap technique to reduce model end effects. Results for the extension period are not used by AURORA or in any economic calculations. Instead, results for the extension period are erased and replaced with primary optimization period results from a subsequent model run.

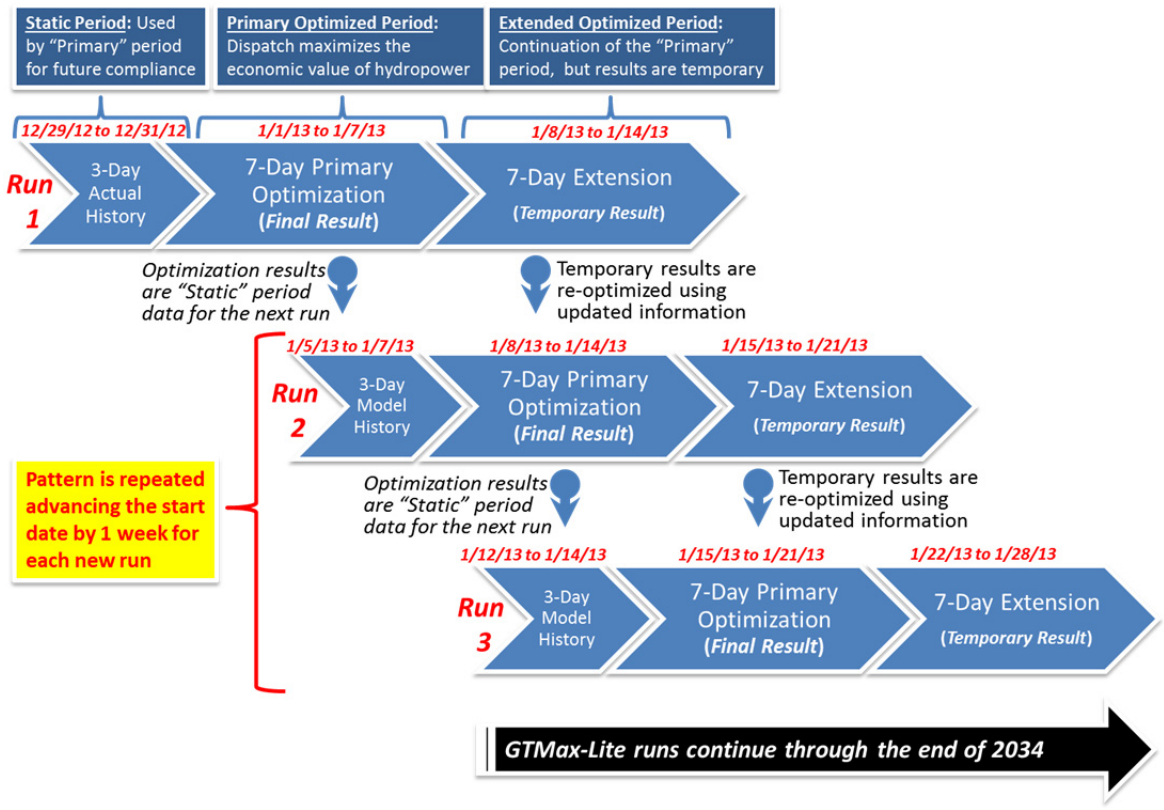


FIGURE K.1-8 Illustration of Temporal Modeling Method Used in the GTMax-Lite Five Large SLCA/IP Plant Configuration

K.1.5.5 Sand Budget Model (Bottom Tier)

The Reclamation SBM schedules various HFEs that differ in terms of peak water release rate, duration, and timing. It uses results from the CRSS model and the intermediate Glen Canyon Dam GTMax-Lite solution. The model is run for each alternative using alternative specific triggers to schedule future HFEs under all 21 hydrological futures and three sediment futures.

SBM maintains the annual WY release volumes specified by CRSS, but reallocates monthly volumes in order to enable higher water releases during months with experiments. Due to the reallocation of water releases, the Glen Canyon Dam GTMax-Lite model is run a second time using the SBM results. It is this second GTMax-Lite run that is used for all economic analyses.

K.1.5.6 Large SLCA/IP Powerplant Spreadsheets (Bridges Bottom and Middle Tiers)

Several spreadsheets were developed by Argonne and reviewed by WAPA for the LTEMP EIS power system analyses. These large SLCA/IP powerplant spreadsheets perform the following functions:

- Create alternative-specific hourly Glen Canyon Dam generation input data for the SLCA/IP market system configuration of AURORA. One set of generation data contains average hourly values computed from GTMax-Lite results for the 21 SBM traces. These values are used for SLCA/IP capacity expansion simulations. The second set of Glen Canyon Dam generation is based on GTMax-Lite results for the representative trace and used for AURORA dispatch model runs.

- Determine the amount of Glen Canyon Dam capacity that will be reserved and available for ancillary services for each day of the simulation period. If these services cannot be entirely fulfilled by the Glen Canyon Dam Powerplant, the amount that needs to be supplied by Aspinall powerplants is computed. Although monthly water release volumes as projected by CRSS are constant among alternatives, the hourly dispatch may be altered at WAPA's discretion during a few hours of the LTEMP period. Therefore computations for Glen Canyon Dam and Aspinall are performed for each alternative.

- Find and store the maximum daily generation level contained in Glen Canyon Dam GTMax-Lite outputs for all alternatives and traces. These data are used by the Firm Capacity Spreadsheet that computes aggregate firm capacity level for SLCA/IP federal hydropower resources.

- Create alternative-specific hourly generation input data for AURORA that represents the five large SLCA/IP powerplants. One set of generation data is

based on GTMax-Lite that models these five large plants based on average monthly releases and reservoir information that is derived from CRSS trace results. These values are used for SLCA/IP capacity expansion simulations. The second set of large SLCA/IP hydropower generation values is based on GTMax-Lite results for the representative trace and used for AURORA dispatch model runs.

- Determine the maximum potential output level from the five large SLCA/IP powerplants. Maximum output levels are computed for all combinations of unit outages at each powerplant based on operating criteria, turbine capacities, forebay elevation, tailwater elevation calculations, and water-to-power conversion factors as a function of head. Except for minor adjustments that account for Aspinall spinning reserve and regulation service duties, maximum output levels are identical across all alternatives. Based on user-defined risk level, spreadsheet results are also used by the Firm Capacity Spreadsheet to set the aggregate firm capacity level for WAPA's SLCA/IP federal hydropower resources.

K.1.5.7 Small SLCA/IP Powerplant Spreadsheet (Bridges Bottom and Middle Tiers)

The capacity and dispatch of relatively small SLCA/IP federal hydropower resources including Deer Creek, Elephant Butte, Towaoc, McPhee, and Molina are estimated using the Small SLCA/IP Powerplant spreadsheet. Estimates of future hourly plant-level generation are on based on historical Form PO&M-59 data and powerplant duty cycle (i.e., baseload or peaking). This spreadsheet is also used to estimate maximum output levels for use in computations of WAPA's SLCA/IP hydropower firm capacity. The same hourly generation and maximum output values are used for all alternatives for both AURORA capacity expansion and dispatch model runs.

K.1.5.8 Loads Shaping Algorithm (Middle Tier)

In order to project hourly customer loads for LTF large and small customers, Argonne analyzed several years of historical load data for the eight large customers that was contained in the FERC Form-714. Normalized loads for CY 2006 were selected to serve as a representative profile and used as the basis for projecting future chronological hourly loads for all LTF customers. The basis for selecting this year is described in more detail in Section K.1.6.3. Normalized profiles cannot simply be multiplied by a constant value (e.g., monthly peak load) to scale loads for a future year, because load factors are projected to change over time as reflected in utility IRPs. The Loads Shaping Algorithm is used to compute hourly scaling factors that, when applied to the normalized profile, produce a time series of chronological hourly loads that simultaneously match both a projected monthly peak load and monthly total load.

The Loads Shaping Algorithm uses a quadratic programming technique that minimizes differences between a normalized load duration curve (LDC) constructed from historical data and a reshaped LDC generated by the model. Figure K.1-9 shows the original LDC, constructed from historical loads for one of the large customers and the reshaped LDC. The reshaped curve is consistent with a projected monthly load factor. Upper and lower load constraints may be specified by the user to bind the model's solution. For each point in the LDC, a scaling factor, shown on the secondary y-axis, is then computed as the ratio of the reshaped load to the original load. Finally, the algorithm constructs a scaled chronological hourly profile based on the load scaling factors and an associated original hourly load. The end product, as shown in Figure K.1-10, is a chronological load time series that exactly matches the monthly projected peak and total load.

K.1.5.9 AURORA (Top and Middle Tiers)

The AURORA model is at the core of the methodology used to identify SLCA/IP federal hydropower interactions with the power grid. It was developed by EPIS, Inc., and it is used by utilities throughout the United States to model capacity expansion pathways, simulate unit commitments, and perform hourly unit dispatch. Based on information contained in the EPIS,

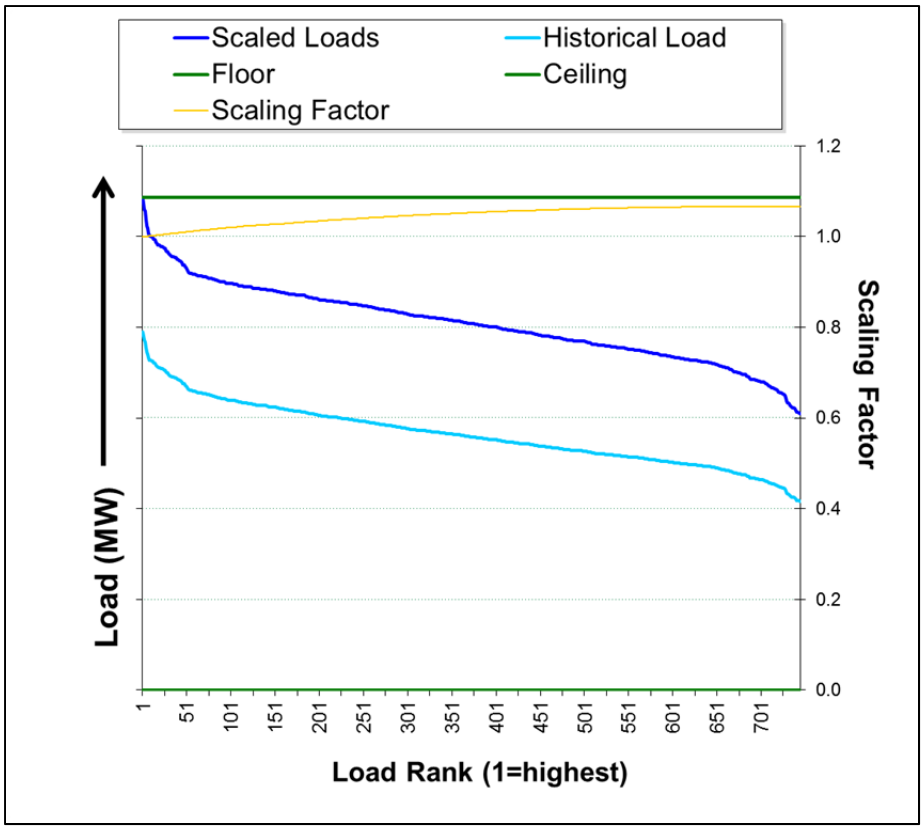


FIGURE K.1-9 Example of the Load Scaling Algorithm LDC

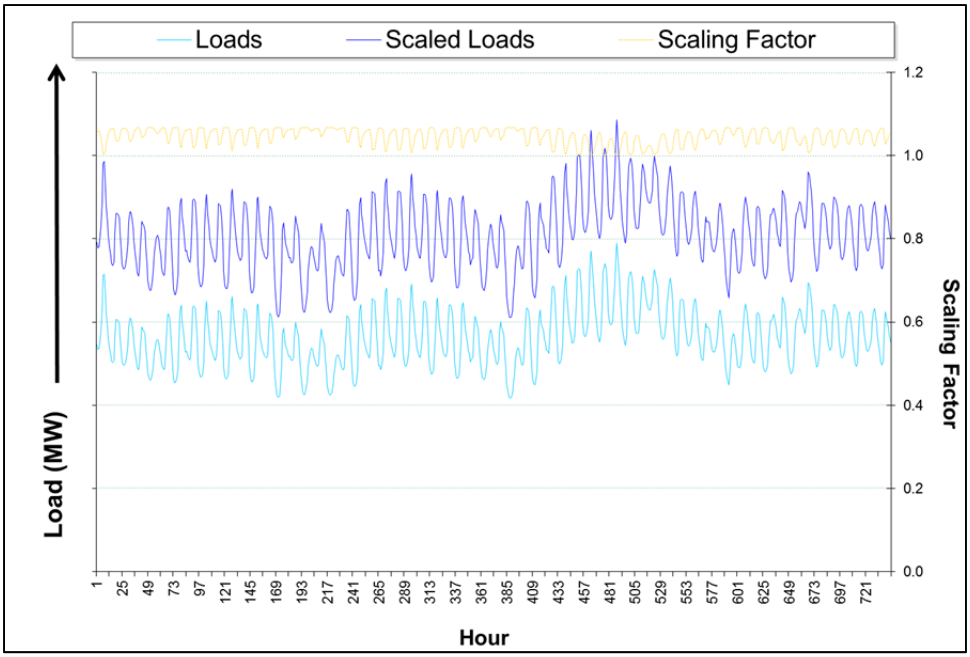


FIGURE K.1-10 Example of the Load Scaling Algorithm Chronological Hourly Loads

Inc., Web page (http://epis.com/AURORA_xmp/long_term_expansion.php), one of the primary uses of AURORA is for lifecycle analysis and resource capacity expansion optimization studies.

AURORA uses hourly demands and individual resource-operating characteristics in a transmission-constrained, chronological dispatch algorithm. This algorithm also models the deployment of curtailments at market price trigger points. LMPs projections are made in user-defined market bubbles over long-term planning horizons. For the LTEMP EIS, it computes LMPS at each of the bubble shown in Figure K.1-1.

A recursive modeling process identifies the set of resources among existing and potential future resources with the highest and lowest market values to produce economically consistent capacity expansion and retirement schedules. Based on the NPV of hourly market prices, it chooses to build one or more technologies contained in a user-defined list of new resource candidates. AURORA compares those values to existing resources in an iterative process to create a capacity expansion path of new units over time. The end result is a coordinated forecast of capacity expansion schedules for multiple market areas that meet planning reserve margin targets. Information from both state renewable portfolio standards (RPSs) and utility-specific IRPs regarding renewable resource development goals were input into the AURORA model to estimate the future expansion of wind and solar resources in the system.

Capital investment decisions made in AURORA use levelized capital investment costs that spread the cost of building a new unit into payments that are made at set time intervals (i.e., weekly, monthly, annually) over the book life of the project, similar to home mortgage payments. In this study, these payments are made and accounted for from the time a new unit

comes online through the end of the LTEMP study period. This reduces modeling end-effects because new units contained in the AURORA expansion path will operate long beyond the end of the LTEMP period. For example, if a new unit is brought online during the last year in the study, only 1 year of capital payments are included in the economic cost calculations, not the entire cost of the project. This reduces issues associated with evaluating technologies that have disparate capital costs and operational characteristics on timelines that do not cover the entire life of the candidate resources.

This levelized cost methodology is equivalent to incurring all capital cost expenditures when the unit comes online and later receiving a salvage value payment at the end of the study period. The salvage value represents the economic value of the resource at the end the study. This approach is used in the Wien Automatic System Planning (WASP) Package. Developed in 1972 by the Tennessee Valley Authority and the Oak Ridge National Laboratory, it has long been in continuous use by many utilities around the world for power generation expansion planning. When using the WASP sinking fund depreciation accounting method, WASP mathematics are equivalent to NPV results used by Argonne in this study (IAEA 1980).

For the LTEMP EIS, AURORA is used in the order listed below for the following purposes:

1. Project Palo Verde market hub prices/LMPs (top tier),

2. Determine construction schedules for new units in the SLCA/IP market system (middle tier), and

3. Simulate unit commitments and perform SLCA/IP market system dispatch (middle tier).

Modeling for the top tier is performed once—the results are used across all LTEMP EIS alternatives. The middle tier of AURORA is run for each alternative.

AURORA is first used to project future hourly energy market prices throughout the Western Interconnection during the study period; that is, for top tier modeling. Without alteration, it uses a Western Interconnection topology and dataset that were provided by EPIS. It should be noted that EPIS derived model input data for load growth, utility fuel price projections, and the cost and performance for new candidate units for system capacity expansion based primarily on information contained in EIA's 2014 AEO (EIA 2014).

For the LTEMP EIS, LMPs at the Palo Verde marketing hub were selected as a representative hourly time series. These market prices are the primary economic driver that shape SLCA/IP hydropower operations in both versions of the GTMax-Lite model and the Small SLCA/IP Power Plant Spreadsheet. The same price set was used for all alternatives. As discussed in Attachment K.1, Argonne assumes that alternative operations at Glen Canyon Dam will have an effect of less than a few cents/kWh on Western Interconnection LMPs outside of the SLCA/IP market system.

The second purpose of the AURORA model was to project system capacity expansion paths and unit retirement schedules for utilities in the SLCA/IP market system based on the assumption that customers will engage in cooperative agreements that are mutually beneficial; that is, middle tier modeling. It uses detailed unit-level information about existing powerplant units owned and operated by WAPA and its LTF customers. The model also includes information about candidate units that could be built in the future. Projected power demands consist of WAPA project use loads (which are described later) and loads for SLCA/IP LTF customers as described above. Capacity is constructed such that the reserve margin of the aggregate eight large customers never drops below 15%.

The firm capacity credit assigned to SLCA/IP federal hydropower resources in AURORA is estimated by the WAPA Firm Capacity Spreadsheet. The firm capacity logic used in this tool is in part based on a risk level consistent with a dry (i.e., low) hydropower condition such that the CRSP Management Center and the EMMO will be able to meet its LTF contractual capacity obligations with SLCA/IP federal hydropower resources 90% of the time. This is consistent with the level of risk to which WAPA has been exposed in the past.

SLCA/IP utility system energy transactions with the rest of the Western Interconnection are assumed to be priced at levels projected by the AURORA Western Interconnection model run. For the purpose of determining capacity expansion paths, it was assumed that the SLCA/IP market system would only make power purchases. This assumption was made to ensure that the SLCA/IP market system would not construct capacity on a speculative basis for the purpose of selling energy to the Western Interconnection; that is, it constructs capacity primarily for internal purposes. Because the Western Interconnection prices tend to be more expensive than production costs in the SLCA/IP market system, purchases from the Western Interconnection tend to be small. However, the Western Interconnection energy was made available for purchase in situations where internal SLCA/IP production costs became expensive. In addition, reserve margin requirements were configured to exclude WAPA LTF purchases because Western's contracts are considered extremely reliable (i.e., non-contingent) from the buyer's perspective.

The third purpose of the AURORA model was to perform a detailed dispatch analysis of the SLCA/IP market system which consists of the SLCA/IP hydropower facilities and WAPA's SLCA/IP LTF customers. Resources available for hourly dispatch are based on a previous capacity expansion run made by AURORA.

K.1.5.10 LMP Calibration Spreadsheet (Top Tier)

Spot market prices were modeled for CY 2013 through CY 2033 by the Western Interconnection AURORA model. Prices from the first year of this run, 2013, were compared against actual day-ahead market (DAM) prices published by the Intercontinental Exchange (ICE) and the California Independent System Operator to determine model accuracy. The Palo Verde market hub was chosen for the LTEMP analysis to represent prices for the spot market in the AURORA network topology because it is a major hub relatively close to Glen Canyon Dam and is often used as the benchmark price for WAPA energy transactions.

In general, AURORA prices differed significantly from both ICE and California independent system operator day-ahead market (CAISO DAM) historical prices for 2013. Therefore, the LMP Calibration Spreadsheet was written to scale AURORA hourly LMPs to more closely match actual nominal values in terms of 2013 dollars. The ICE publishes day-ahead weighted average peak, off-peak, and Sunday off-peak electricity prices for each day. Sunday off-peak hours are the 16 daytime hours that have the highest loads; they correspond to the 16 hr classified as peak in the other 6 days of the week. Hourly prices generated by the AURORA model were subdivided into seven categories: holiday, Sunday daytime, Sunday nighttime, Saturday peak, Saturday off-peak, weekday peak, and weekday off-peak. AURORA 2013 monthly averages were computed for each category and compared against the monthly average ICE prices in these categories.

A scalar (ratio of the ICE to AURORA prices) was generated for each month and each category. Prices generated by the AURORA model were generally lower than the ICE prices. Prices in off-peak hours were lower by about 5 to 15%, and prices in peak hours were lower by as much as 20 to 50%. To adjust prices, both AURORA 2013 and projected LMPs for Palo Verde were multiplied by the aforementioned scalar.

LMPs at the Palo Verde hub were projected by applying AURORA model price growth rates to the calibrated 2013 price (Figure K.1-11). Future spot market prices are difficult to accurately forecast because they are dependent on many factors, each of which cannot be projected with certainty. Therefore, many future scenarios are possible. For the power systems analysis, the 2014 AEO (EIA 2014) reference case was used to supply AURORA with variable inputs that drive future prices. One of the most important of these is natural gas prices. Figure K.1-12 shows a very strong correlation between historical on and off-peak prices at the Palo Verde hub and natural gas prices. This correlation is due the fact that the resources that are on the margin (i.e., last ones dispatch and determine the LMP) frequently burn natural gas. This strong correlation is expected to continue in the future. AURORA model results support this expectation. Figure K.1-13 shows that the 2014 AEO (EIA 2014) forecasted annual average delivered natural gas price to increase in the future. By 2033, natural gas prices are expected to be about 83% more expensive than prices in 2013. Calibrated LMPs follow this same basic trend. By 2033, Palo Verde price projections, which are based on the aforementioned methodology, are expected to increase by 78%. Factors that lead to a slightly slower growth in LMPs include the emergence of more-efficient gas-fired electricity generating technologies that burn less fuel per MWh of fuel consumed and a projected increase in the penetration of variable energy resources (VERs).

K.1.5.11 Firm Capacity Spreadsheet (Bridges Bottom and Middle Tiers)

The Firm Capacity Spreadsheet uses maximum daily output levels from the Large and Small SLCA/IP Powerplant spreadsheets and an assumed risk preference to estimate the amount of firm capacity that is available to the SLCA/IP market system for credit toward the system reserve margin. It also applies outage results produced by the Hydropower Outage model the five large SLCA/IP federal hydropower plants. GTMax-Lite runs of Glen Canyon Dam incorporate outages into estimated daily peak powerplant operations under all 21 hydrological traces.

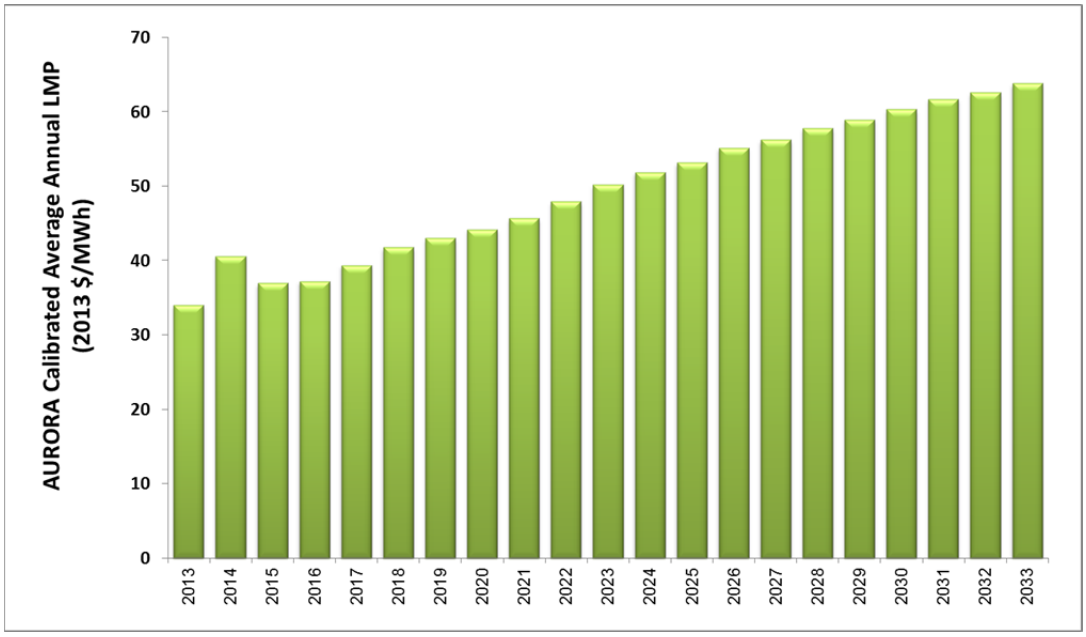


FIGURE K.1-11 Projected Annual Average Calibrated AURORA LMPs at the Palo Verde Market Hub

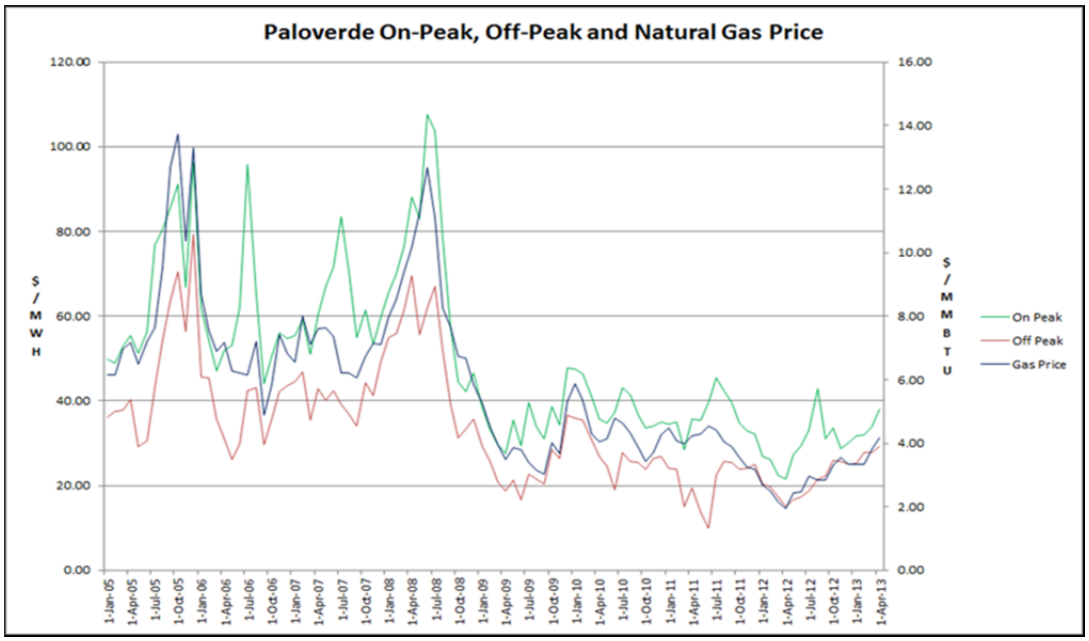


FIGURE K.1-12 Historical Palo Verde On- and Off-Peak Electricity Prices Compared to Natural Gas Prices

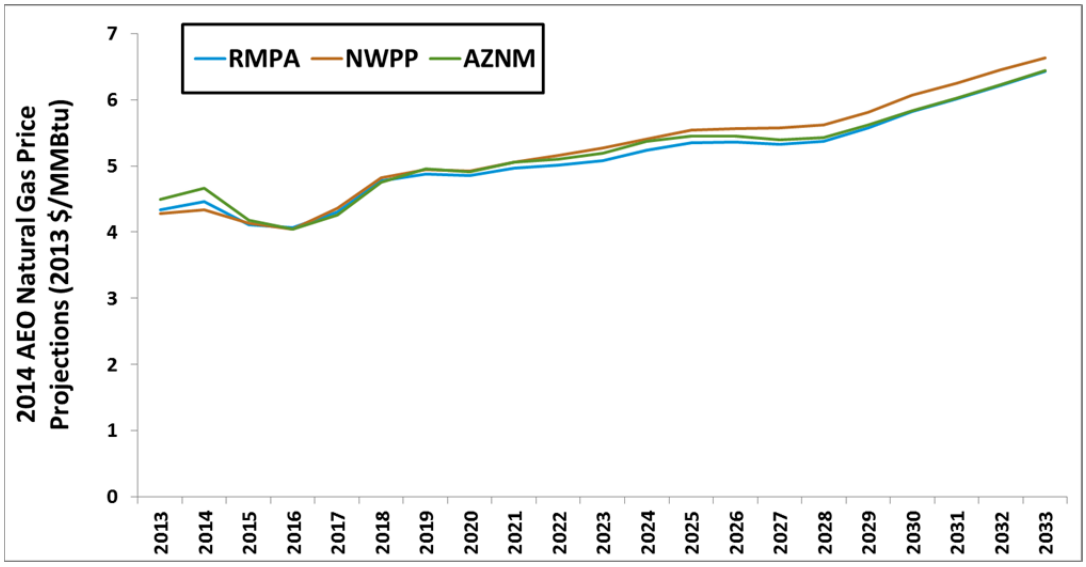


FIGURE K.1-13 2014 AEO (EIA 2014) Projected Delivered Utility Natural Gas Prices

In addition to outages, the spreadsheet incorporates a large number of factors in the determination of firm capacity. As explained in more detail in Section K.1.7, these factors include the following:

- The time of the year the system peak load is projected to occur;
- The probability distribution of the coincidental hydropower peak output potential from SLCA/IP hydropower facilities that consist of all SLCA/IP large and small federal hydropower plants as computed by Glen Canyon Dam GTMax-Lite and the Large SLCA/IP Powerplant Spreadsheet tools;
- Projected ancillary service obligations;
- Projected capacity levels that will be reserved to for project use obligations;
- Expected future system transmission losses; and
- The risk tolerance level associated with SLCA/IP federal hydropower having a lower production capability than the declared firm capacity level during the time of the system peak load.

Firm capacity results vary significantly by alternative and are sensitive to both assumptions regarding the selected risk tolerance level and the month in which the peak load is projected to occur in the future. For the LTEMP EIS, the capacity that is available to the SLCA/IP market system is a fixed amount over the entire study period. Spreadsheet firm

capacity results are input into the AURORA SLCA/IP market system runs that simulate capacity expansion.

K.1.6 SLCA/IP Market System, Data Sources, and Model

The power systems methodology assesses the economic impacts of changes in Glen Canyon Dam Powerplant operations at the systems level using the three-tiered approach briefly described in the Power Systems Geographic Scope section. The middle tier represents SLCA/IP federal hydropower resources marketed and scheduled the CRSP Management Center and all of the utility systems that receive LTF SLCA/IP energy and capacity.

Previous sections described federal hydropower resources and hourly prescribed energy injections into the SLCA/IP market system based on GTMax-Lite model results. This section provides additional information about modeling the loads and resources of CRSP Management Center LTF power customers. There are approximately 129 LTF SLCA/IP wholesale customer entities that are categorized as either large or small. Accounting for about 75% of WAPA's LTF energy and capacity sales, the eight largest customers are Deseret, NTUA, SRP, UAMPS, UMPA, PRPA, Tri-State, and CSU. Except for NTUA, all large LTF customers own and operate generating resources. There are about 130 remaining customers, which are aggregated into east and west "small customer" entities, accounting for the remaining 25% LTF sales. Energy received by a few customers under WAPA LTF contracts are used to serve project use loads such as pumping for irrigation. Figure K.1-3 shows a simplified topology for the SLCA/IP systems that was used by the AURORA model to simulate the capacity expansion pathways and dispatch under each alternative. The following sections describe key model input and modeling assumptions for the SLCA/IP system.

The AURORA model is used to simulate unit commitment scheduling, for resources dispatch, and for capacity expansion in the SLCA/IP market system. Details on model inputs for initial historical conditions and for simulating future operations are provided below.

K.1.6.1 Historical Data Sources

The first year simulated by AURORA is CY 2013. It set initial model conditions based on historical information and serves as a starting point for modeling the future. A considerable amount of data is needed for AURORA to model SLCA/IP market system operations including hourly load data, characteristics of existing powerplants, and firm hydropower contracts that WAPA's customers have with offices other than the CRSP Management Center. Primary data sources for this information include the following:

- EPIS—AURORA database containing general/default power systems data;
- EIA—existing powerplant ownership, capacity, technology type, primary mover, historical delivered fuel prices, plant fuel consumption, historical annual generation;

- ICE and CAISO Web sites—sources of historical day-ahead peak and off-peak electricity prices;

- NERC—power plant maintenance and forced outage characteristics from GADS;

- FERC—historical hourly load data for utilities and BAs;

- Large customer IRPs—a report filed by each of WAPA's customers and contains characteristics of existing power plants, utility system loads, and DSM programs; and

- WAPA—data and information on LTF contracts from the CRSP Management Center and other regional offices from which WAPA customers receive federal hydropower and detailed information on federal hydropower plant and WACM BA operations, including factors related to ancillary services and the transmission system.

The AURORA model uses a database constructed by EPIS that contains Western Interconnection-wide powerplant characteristics, fuel price projections, and hourly load profiles. These data were compared to the aforementioned data sources to verify their accuracy and consistency. Because the methodology calls for WAPA's eight large customers to be modeled in detail, Argonne staff constructed hourly load profiles for SLCA/IP system entities and carefully examined power plant characteristics data contained in the AURORA inventory and benchmark them against data on powerplant characteristics compiled by EIA.

Historical 2013 Loads

SLCA/IP market system loads were generated for three types of LTF customers: large, small, and project use. Project use loads are based on information provided by CRSP Management Center staff. These loads are aggregated into east and west groups and are assumed to be constant over each month. Project use loads are projected to increase over the study period, but are relatively small, ranging from a total project use monthly peak load of 4.15 to 51.42 MW. Project use loads are higher in the summer and lower in the winter.

The power systems modeling effort began at a time when historical FERC Form-714 load data for CY 2013 were not yet available. Argonne staff therefore constructed a time series of CY 2013 hourly loads for each of the eight large customers and for each of the two small customers groups classified as east and west.

Loads for 2013 were constructed by the Loads Shaping Algorithm. For the eight large customers, the algorithm scaled representative nominal hourly shapes to CY 2013 levels such that hourly loads were consistent with projected monthly peak and total load targets. As described previously, CY 2006 hourly load profiles were used as the basis for constructing these

nominalized shapes. CY 2013 load targets were based primarily on information contained in large customer IRPs.

Aggregate small customer loads in the west were based on the UAMPS load profile that was scaled to match 2013 small customer energy data used for retail rate analyses. UAMPS projected growth rates were also applied to the west small customer group. An identical method was used for the small customer group in the east, except in this case load profiles and growth rates for CSU were scaled to match small customer energy targets.

Although Western almost exclusively sells LTF capacity and energy to utilities in its service territory, special arrangements were made to enable Tribal entities to receive SLCA/IP federal hydropower capacity and energy. For 48 Tribes that do not operate their own electric utilities, WAPA made an administrative change to allow them to directly receive an allocation of power through a benefit crediting arrangement. In this benefit crediting arrangement, WAPA delivers the Tribe's allocation to its electric service supplier. Because the SLCA/IP rate is lower than the supplier's production cost, the supplier provides the Tribe with a payment that is equal to the Tribe's electric allocation from WAPA multiplied by the difference in rates. The payment received by the Tribe is the financial equivalent of a direct delivery of electricity. Through this arrangement, Tribes ultimately receive the same services, pay the same rates for both capacity and energy, and abide by the same terms as all other customers. For power systems economic modeling, these financial transactions are not explicitly simulated because the effects on overall system-level economics did not appreciably differ among alternatives.

2013 Powerplant Characteristics and Fuel Prices

Recent data (from 2012 and 2013) on thermal power plant characteristics were obtained from EIA Form-860. This information was coupled with monthly cost and quality fuel deliveries from EIA Form-923 to estimate delivered 2013 fuel prices for each of the thermal powerplants in the unit inventory of WAPA's large customers. Fuel prices for 2013 are typically used. However, when this information is not available, 2012 prices are used as a surrogate. AURORA model generating unit capacity levels vary by month, with generally higher capacities in the winter than in summer months.

In AURORA, delivered fuel prices are not directly assigned to each powerplant in its database. Instead, AURORA applies unit-specific fuel price multipliers to a common price. Henry Hub is used as a price reference point for natural gas, and state-level coal prices are used as coal reference points. The EPIS-supplied representation of the Western Interconnection uses actual and projected monthly natural gas prices at Henry Hub for the year 2010 in terms of nominal 2010 dollars. For power systems analysis, AURORA unit-level delivered natural gas prices are converted to 2013 dollars. Prices at points of delivery are typically higher than the Henry Hub price. Therefore, prices are adjusted to account for delivery costs by applying unit-specific price multipliers in the model. Natural gas prices for 2013 are based on plant delivery costs reported in FERC Form-923. Similarly, 2013 coal prices in 2013 nominal dollars are computed in AURORA by applying unit-level multipliers to state-level prices.

Natural gas prices in AURORA differ by month; generally, prices are higher in the winter as compared to the spring and autumn. These same seasonal trends were used for the LTEMP power systems study. No seasonal changes in coal or distillate fuel prices were assumed; that is, coal and distillate fuel prices are constant throughout 2013.

Only one small oil-fired unit is owned by WAPA's large customers. It is rarely dispatched. No adjustments were made to the EPIS default nuclear fuel price. Only one nuclear plant is partially owned by SRP. It is dispatched as a base load unit, and production levels do not vary significantly among alternatives. Therefore, production cost differences for this plant do not have a significant bearing on economic cost differences among alternatives.

O&M Costs for Existing and Committed Units

Real variable O&M costs for existing units and ones that are committed to be constructed are held static at 2013 levels throughout the study period. Note that real costs exclude inflation; therefore it is assumed that the economic cost of O&M for power production in the future will change at the same rate as inflation. Also, federal Principles and Guidelines (P&Gs) for economic and environmental evaluation of water-related resources precludes the use of speculative projections concerning capital and O&M cost.

Fixed O&M costs only factor into LTEMP EIS economic calculations for capacity expansion units because the retirement schedule of existing units and online dates for committed units do not change among alternatives; therefore the economic difference of these "fixed" costs between Alternative A, which serves as a reference point, and other alternatives is equal to zero. However O&M costs for newly constructed powerplants in the future differ by alternative and are therefore tracked and accounted for in the power systems analysis.

2013 Unit-Level Heat Rates

Documentation in the AURORA model acknowledges shortcomings in the default heat rate data in the EPIS-provided database. It recommends that EIA sources of historical generation data, like Form-923, be consulted to confirm plant-specific heat rates. This information was coupled with monthly powerplant generation and the cost and quality fuel deliveries from EIA Form-923 to generate heat rates and delivered fuel prices for each of the thermal powerplants in the unit inventory of WAPA's large customers. AURORA default heat rates differed by as much as 60% from levels calculated from current EIA data. Therefore, in this analysis heat rates calculated from EIA data replaced AURORA default values. However, EIA data was not reported for some thermal powerplants; in those cases, default AURORA values or surrogate values based on similar type plants were used. Some differences were also found when comparing AURORA default delivered fuel prices with those calculated from recent EIA data. When discrepancies were found, calculated fuel prices were used in this analysis. However, AURORA defaults were used for plants that either had no EIA data or where fuel prices were outside of a reasonable range.

2013 Firm Power Contracts

As described previously, contracts between the CRSP Management Center and its LTF customers are not directly modeled. Instead, power systems economic analyses assume that federal SLCA/IP hydropower plants are supply resources for meeting SLCA/IP system (i.e., large and small customer utility) loads. In addition to SLCA/IP capacity and energy, some customers also receive federal hydropower from other regional offices within the WAPA organization. Information on these non-SLCA/IP contracts was supplied by WAPA. These contracts are modeled in AURORA as virtual hydropower plants, the operation of which is constrained by contract monthly minimum and maximum hourly contract limits and total monthly energy bounds.

In addition to federal contracts, customers have contracts with entities that are either within the modeled SLCA/IP system and/or other Western Interconnection entities that are outside of the SLCA/IP market system. Information on these contracts was ascertained from customer IRPs. Details on these other contracts were typically not available. Therefore, Argonne power system modelers created simple representations of these contracts in AURORA using the information that was available in the IRPs. Contracts are modeled in AURORA as virtual thermal power plants with operating limits.

2013 Renewable Energy Resources (Water, Wind, and Solar)

The AURORA model also includes a representation of existing renewable energy resources. These resources include SLCA/IP system non-federal hydropower and wind and solar Variable Energy Resources (VERs) that produce power and serve system loads. Non-federal hydropower plant resources were modeled as AURORA hydropower plants based on the operating characteristics of the resource (i.e., run-of-river or peaking). For 2013 operations, monthly generation levels were benchmarked to actual levels recorded in EIA Form-923. Power production from VERS is represented as a fixed time series of hourly power injections into the grid using locational profiles provided by EPIS in the AURORA Western Interconnection database.

K.1.6.2 AURORA Model Dispatch Results for 2013

Initial model AURORA model runs of CY 2013 produced results that significantly differed from historical monthly generation levels. Model runs were mainly driven by EPIS input data that was supplied with the model. However, after system representation and input data refinements were made, the model results more closely mimicked historical production patterns. Figure K.1-14 shows that the 2013 AURORA generation profile by fuel type for WAPA's eight large LTF customers is similar to actual 2013 levels as found in EIA Form-923. Generation for hydropower plants by LTF customer utilities exactly match prescribed historical levels.

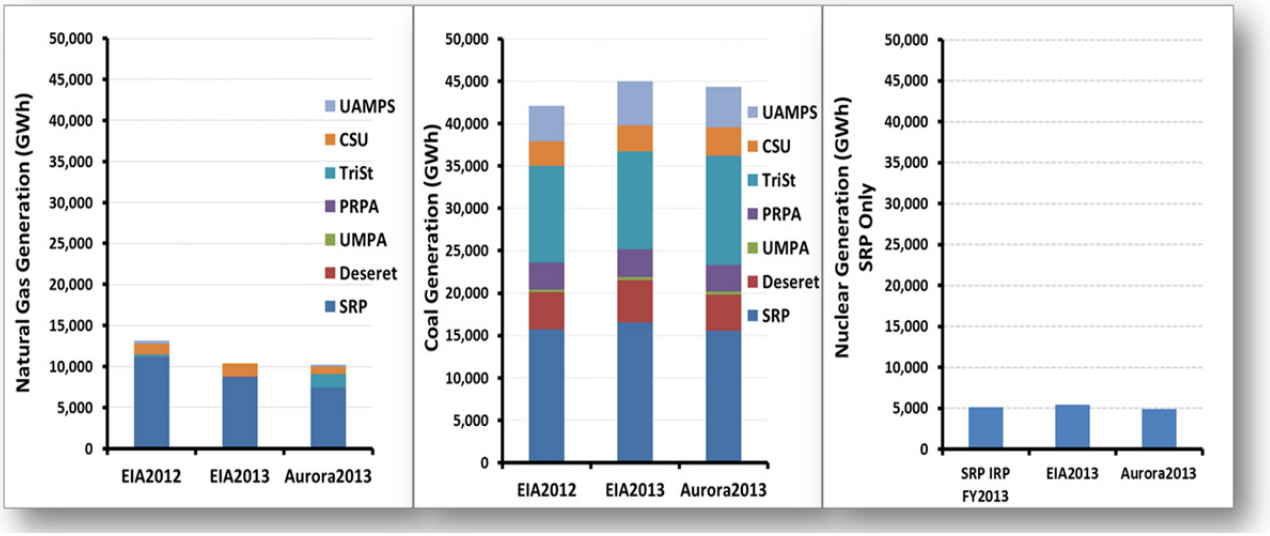


FIGURE K.1-14 Comparison of Modeled and Actual Annual Aggregated Generation Levels (from the EIA) for Natural Gas, Coal, and Nuclear Powerplants under the No Action Alternative

K.1.6.3 SLCA/IP Market System Projections

SLCA/IP market system supply and demand attributes, time value of money assumptions, and projections driving variables such as load growth, delivered utility fuel prices, and new unit technology characteristics play a major role in the development of the system and LTEMP EIS power system results. Projected future developments in the SLCA/IP market system rely on several information sources that include the following:

- Large customer IRPs—future fossil-fuel powerplant additions, VER powerplant planned additions and future expansion goals, and DSM initiatives;

- EIA announced (or committed) new unit additions, 2014 AEO (EIA 2014) candidate technology characteristics, utility fuel price, and load projections as driven by broader forces such as overall U.S. and global macroeconomic developments; and

- WAPA—changes in project use loads and outlooks for future ancillary service requirements.

WAPA LTF customers are required to submit IRPs in order to receive federal hydropower capacity and energy. Information contained in these IRPs was used as a principal source of model inputs for future developments in terms of load growth and resource capacity expansion. However, not all IRPs cover the entire timeframe of the LTEMP EIS study period. Therefore, projections found in the 2014 AEO (EIA 2014) were used to supplement LTF customer IRPs and provide projections that were based on a common and consistent basis.

Load Growth Projections

This section will describe in detail how the hourly loads for the eight large customers and the two groups of aggregate small customers were developed for the years in the LTEMP study period. As noted earlier, small customers were aggregated into an east group or bubble and a west group or bubble.

Developing hourly loads was a three-step process. First, historical hourly load data was gathered for each utility to be modeled. Second, a historical year was selected that best represented the load profiles of all years for which data was collected. The year selected had the best matches to both the average weekly load factor and the average annual load factor across all years. Third, the Hourly Load Forecast Algorithm was used to generate hourly load profiles for all future years for each utility. The model scaled hourly loads so they followed the profile of the representative year and at the same time also match forecasted monthly peak and total monthly energy for each utility modeled.

To find the representative historical year, hourly loads were collected from each large customer for the years 2006 to 2009. The data were compiled by FERC in Form-714 and are publicly available via software downloaded from the FERC Web site (available at http://www.ferc.gov/docs-filing/forms/form-714/view-soft.asp). These years were chosen because they were the only recent set of years for which complete annual datasets were available for all eight customers. For more details on load data collection, see Attachment K.7.

Small Customer Loads. As noted earlier, small customers were aggregated into an east bubble and a west bubble. Staff from WAPA assisted Argonne in classifying whether small customers should be placed into the east or west bubble. In general, small customers in Colorado, New Mexico, and Wyoming were put into the east bubble, while small customers in Arizona, Nevada, and Utah were put into the west bubble. Small customer load shapes were based on the representative year from one of the eight large customers. For small customers in the east bubble, the profile from CSU was used; for small customers in the west bubble, UAMPS was used. UAMPS is in the western part of the CRSP Management Center customer territory and is comprised of many cooperating small customers. Therefore, it was judged that UAMPS load shape was representative of small customers in the west bubble. CSU is a municipal utility in the eastern part of WAPA's service territory; therefore, its load shape was used to represent small customers in the east bubble. These load shapes were scaled to match their estimated historical total load based on information that was collected for the retail rate payer analysis described in Section K.3.

Representative Load Shape. After collecting the historical data, total hourly coincidental loads were computed for the eight large utilities for the 2006 through 2009 time period. A weekly load factor (WLF) was calculated for each week in each year for which FERC Form-714 data were available. An average weekly load factor (AWLF) across all years was also calculated. Then the sum of the squared differences (SSD) between the WLF and the AWLF was calculated using the equation SSD (WLF) = $\sum$ (WLF-AWLF).^{2} A similar calculation was

performed to find the SSD between the annual load factor (ALF) for each year and average annual load factor (AALF) across all years or SSD (ALF) = $\sum$ (ALF-AALF)^2. The sum of the squared differences (squared errors) for both the WLF and ALF were then summed. CY 2006 had the smallest errors and therefore was selected as the representative year for all customer loads because it had the smallest sum, which indicated that, among all years, its relative shape was the closest to the average. Using a common year for all utilities correctly captures load diversity among the utilities, including those resulting from large-scale weather patterns.

After selecting the representative year, the Hourly Load Forecast Algorithm was used to generate hourly load profiles for future years for each of the eight large LTF utilities and for each small customer bubble. Inputs into the algorithm were the utility's hourly load profile for the representative year and the forecasted monthly peak load and energy for each future year. Based on the data that were available, a load forecast was generated using a customized method for each utility. The following describes the method used to generate each load forecast.

Salt River Project

1. Historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Total annual energy for 2012 was specified in the 2013 IRP (SRP et al. 2012). From 2013 to 2033, the annual energy was assumed to grow at the same annual rate as the total electricity sales forecast for the Southwest region of the Western Electricity Coordinating Council in the 2014 AEO (namely, Table 91 in EIA 2014)).

3. Annual peak loads for 2012 to 2016 were specified in the 2013 IRP (SRP et al. 2012). From 2017 to 2033, the peak load was assumed to grow at the same annual rate as used for the total annual energy shown above (namely, the data from Table 91 of the early release of EIA 2014).

Navajo Tribal Utility Authority

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2030 were obtained from the October 2012 IRP (NTUA 2012).

3. Annual peak loads and energy for 2031 to 2033 were calculated using the same growth rate as 2030.

UMPA

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2033 were obtained from the IRP 5-year plan (UMPA 2013).

UAMPS

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. UAMPS staff provided historical monthly energy and peak demand data for 2011 to 2013 (Anderson 2014).

3. There were no growth forecasts in the UAMPS IRP (UAMPS 2013), so the same growth rates were assumed for annual peak and energy as those provided in the UMPA IRP for 2014 to 2033. Members of UAMPS were assumed to have similar energy demand profiles as members of UMPA.

Deseret

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2018 were obtained from the IRP update (Deseret 2012).

3. From 2019 to 2033, the annual peak load and energy were assumed to grow at the same rate as the total electricity sales forecast for the Rocky Mountain region of the Western Electricity Coordinating Council in the 2014 AEO (namely, Table 94, in EIA 2014).

Tri-State Generation and Transmission Association

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2029 were obtained from the IRP (Tri-State 2010).

3. Annual peak loads and energy for 2030 to 2033 were assumed to grow at the same rate as 2029.

Colorado Springs Utility

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2031 were obtained from the IRP (CSU 2012).

3. Annual peak loads and energy for 2032 to 2033 were assumed to grow at the same rate as 2031.

Platte River Power Authority

1. The historical hourly load profile for 2006 was used. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from 2006.

2. Annual peak loads and energy for 2012 to 2020 were obtained from the IRP (PRPA undated).

3. Annual peak loads and energy for 2021 to 2033 were assumed to grow at the 5-year average growth rate from 2016 to 2020.

Small Customer—West

1. The historical 2006 hourly load profile for UAMPS selected as representing small customers in this bubble.

2. Data was collected for 2012 on retail energy sales from EIA Form-861 and summed for all small customers in this bubble.

3. The annual load factor for UAMPS was assumed to be representative of this small customer group. The annual peak load for 2012 was computed from the retail energy sales in 2012 and the UAMPS load factor.

4. Annual peak loads and energy for 2013 to 2033 were assumed to grow at the same rate as for UAMPS.

5. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from the 2006 UAMPS load profile.

Small Customer—East

1. The historical 2006 hourly load profile for CSU selected as representing small customers in this bubble.

2. Data for 2012 was collected on retail energy sales from EIA Form-861 and summed for all small customers in this bubble.

3. The annual load factor for CSU was assumed to be representative of this small customer group. The annual peak load for 2012 was computed from the retail energy sales in 2012 and the CSU load factor.

4. Annual peak loads and energy for 2013 to 2033 were assumed to grow at the same rate as for CSU.

5. The monthly peak loads and energy were based on the ratios of monthly peak to annual peak and monthly energy to total annual energy from the 2006 CSU load profile.

Peak and total load growth rates may be different, resulting in future load profiles that are either more or less "peaky" in the future relative to historical levels. Also, both peak and total load growth rates differ among individual large utilities and for small customer aggregates. Using this method allows the model to grow loads and transform load shapes uniquely for each profile as reflected in IRPs' long-term trends.

Figures K.1-15 and K.1-16 show stacked bar charts of customer non-coincidental monthly peak load and total monthly load projections, respectively. As described in sections that follow, projections of the eight large customer system summer peak load is particularly significant. Any reduction in Glen Canyon Dam Powerplant capacity as a result of more stringent operating criteria does not incur an economic cost until all of the excess capacity in the system is fully depleted. The year in which this occurs is heavily dependent on large customer utility system load growth. Attachment K.6 contains more detailed results for individual large customers and for the two aggregate small customer bubbles.

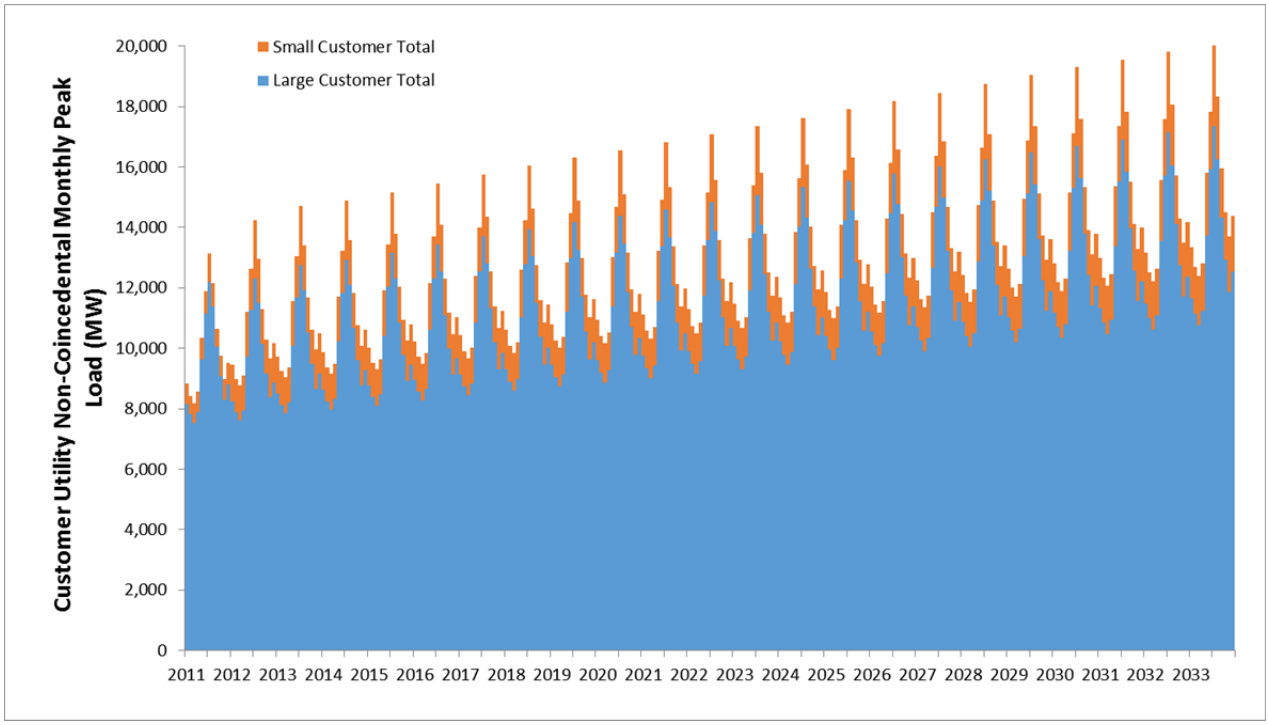


FIGURE K.1-15 Total Non-coincidental Peak Loads for the SLCA/IP Market System

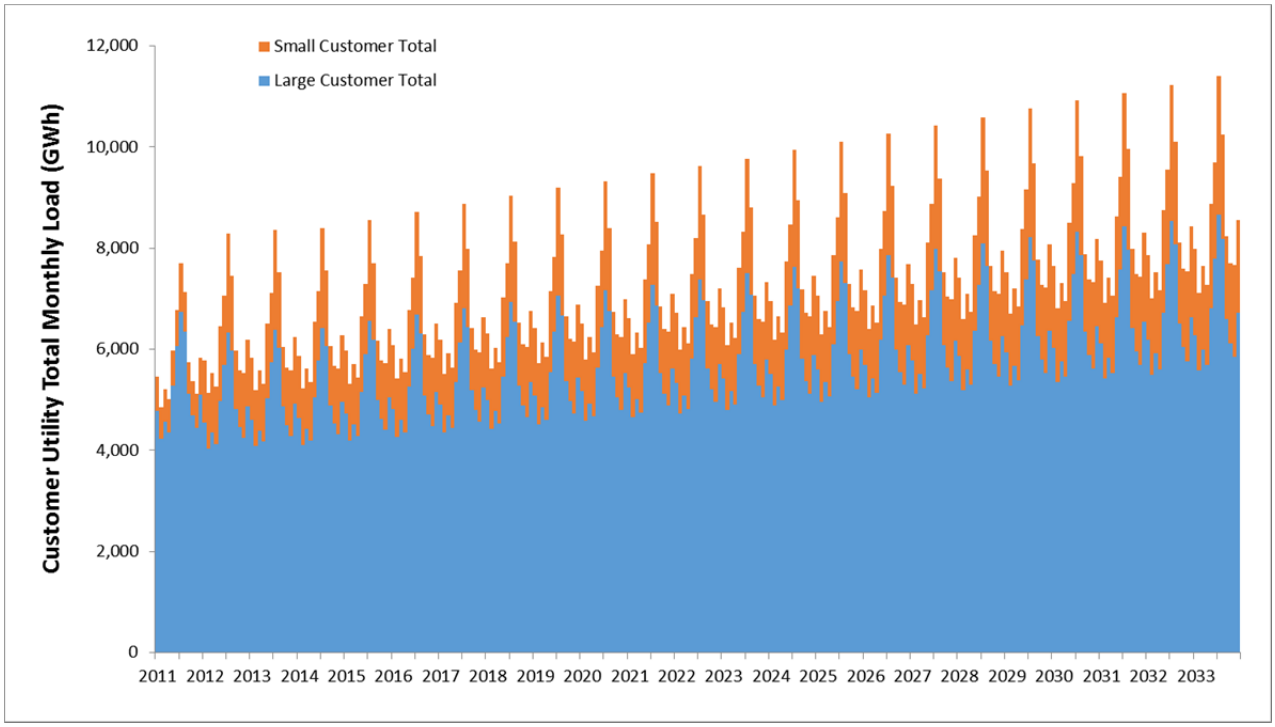


FIGURE K.1-16 Total Monthly Loads for the SLCA/IP Market System

Capacity Expansion Candidate Unit Characteristics

To reliably meet the forecasted increases in electricity demand and to replace powerplants that will be retired during the study period, new powerplants will be constructed in the SLCA/IP market system.

Argonne staff used the AURORA model to create system capacity expansion paths and unit retirement schedules for utilities in the SLCA/IP system for each of the EIS alternatives. As described previously, AURORA uses detailed unit-level information about existing and committed generating units owned and operated by WAPA's LTF customers. The model also includes information about candidate units that could be built in the future. The type and number of new technologies added over time was determined by Argonne staff by tunneling AURORA model capacity expansion runs. In this context, "tunneling" refers to restricting the number of possible model solutions to a smaller set of capacity expansion possibilities (e.g., restricting the number of possible new gas-turbines built in a specific year and location [i.e., bubble], to one to three units instead of the model default of zero to unlimited new units). This technique is often used in capacity expansion planning when the number of combination of expansion technologies is otherwise enormous. It often requires multiple iterative model runs as the user explores different tunnel boundaries such that the solution is not bounded by the user-defined limits. Capacity is constructed such that the capacity reserve margin of the aggregate eight large customers never drops below 15%. Table K.1-1 shows the cost, in terms of 2013 dollars, and performance characteristics of a suite of candidate plants from which the AURORA model could choose to expand capacity of the power system.

Note that the list of candidate technologies input into the AURORA model includes a range of types and sizes. The model "builds" units taking into account load growth, costs, and technology attributes, including the size of each candidate. AURORA makes a trade-off between building large units with economies of scale (lower $/MW cost for large units) that often leads to excess capacity that may persist for a few years, versus building several small ones that better follow capacity needs (smaller excesses) but are more expensive to build in terms of $/MW.

Expanding capacity for the aggregate customer group leads to a lower cost as opposed to building capacity for each individual utility. By doing so, customers take advantage of economies of scale and lower amounts of new capacity. The sharing of new capacity can be accomplished via joint unit ownerships and long-term firm capacity agreements among customer utilities.

Expansion candidates were selected from the suite of new central station electricity generating technologies in the 2014 AEO (EIA 2014). The suite includes conventional and advanced thermal units and renewables. Performance characteristics in the table include unit capacity, heat rate, and fuel type, and cost characteristics include capital costs, fixed and variable O&M costs, book life of the unit, and number of years it takes to construct. Costs are shown as a range because WAPA's customers are located in three different geographic regions identified by the EIA 2014 AEO (EIA 2014) electricity market module; each has powerplant-specific labor multipliers. Different labor multipliers were factored into the powerplant costs from EIA depending upon where the plant would be located. Labor costs vary by region where the plant is

TABLE K.1-1 Cost and Performance Characteristics of Capacity Expansion Candidates

Expansion Candidate Technology	Capacity (MW)	Heat Rate (Btu/kWh)	Fuel Type	Unit Book Life (yr)	Construction Lead Time (yr)	AFUDC (% of overnight cost)	Levelized Capital Cost (2013$/MW/yr)		Fixed O&M Cost (2013$/MW/yr)		Variable O&M Cost (2013$/MWh)	
							Min	Max	Min	Max	Min	Max
Scrubbed Pulverized Coal	600	8,800	Coal	30	4	9.83	194,080	197,146	31,491	31,982	4.51	4.59
Integrated Gasification Combined Cycle	550	8,700	Coal	30	4	9.83	250,755	253,980	52,015	52,684	7.31	7.40
Conventional Combined Cycle	300	7,050	Natural Gas	30	3	7.26	59,953	60,429	13,456	13,563	3.68	3.71
Advanced Combined Cycle	400	6,430	Natural Gas	30	3	7.26	66,931	67,407	15,708	15,825	3.34	3.37
Conventional Combustion Turbine	120	10,850	Natural Gas	30	2	4.76	62,438	62,755	7,544	7,578	15.87	15.95
Advanced Combustion Turbine	230	9,750	Natural Gas	30	2	4.76	43,722	44,304	7,297	7,392	10.75	10.89
Advanced Nuclear	2,236	10,452	Uranium	30	6	15.19	385,516	386,997	94,873	95,243	2.18	2.19
Wind	50	0	Wind	30	3	7.26	105,631	106,900	40,996	41,350	0.00	0.00
Solar Thermal	50	0	Solar	30	3	7.26	240,921	253,715	65,452	68,112	0.00	0.00
Photovoltaic	50	0	Solar	30	2	4.76	217,553	225,801	24,055	24,966	0.00	0.00

Source: EIA (2014).

constructed; a regional multipliers table is located on the EIA Website (http://www.eia.gov/forecasts/capitalcost).

Overnight capital expenses and fixed O&M costs are based on 2014 AEO (EIA 2014) data and expressed in 2012 dollars. AEO documentation indicates that these costs are applicable to new units built in 2014 and later. It is assumed that these costs will not change in real terms; therefore, capital costs for a specific technology in real terms do not change as a function of online date. The AEO costs do not include expenses paid by plant owners that are plant specific and can vary significantly between two virtually identical plants in the same geographic region. Therefore, financing-related costs are excluded from AEO capital costs, and items like insurance, property taxes, asset management fees, and energy marketing fees are excluded from AEO fixed O&M costs (EIA 2013). The AEO cost values were converted to 2013 dollars using the "Powerplants" index contained in the "Bureau of Reclamation Construction Cost Trends" table (Reclamation undated). The values for January were used because it was assumed that new plants came online at the beginning of the year. Fixed O&M costs were converted to 2013 nominal dollars using this same table, except in this case the "Powerplant Accessory elect. & misc. equip" index was used. Variable O&M costs for new construction are converted to 2013 nominal dollars based on the producer price index (PPI) for "Electric power transmission, control, and distribution energy production" (series ID code pcu22112-22112-) (BLS undated).

In the AEO, capital costs are shown as an "overnight" cost, which is an estimate of the cost at which a powerplant could be constructed assuming that the entire process from planning through completion could be accomplished in a single day. However, in reality a plant takes several years to construct. Money borrowed or committed to a project during its construction must be repaid with interest. The term for this expenditure is allowance for funds during construction (AFUDC). Because capital costs from the 2014 AEO (EIA 2014) for expansion candidates were overnight costs, they did not include AFUDC. Therefore, these additional expenditures were added to the overnight capital cost before the capital costs are levelized. Calculation of AFUDC assumes that a certain percent of the total overnight cost is borrowed at regular intervals during construction. The time series of expenditures is often referred to as an "S curve" of capital spending. The time series of expenditures from the S curve coupled with the interest rate of the borrowed money and the time period over which it is borrowed yields the amount of interest paid per dollar or as the amount of AFUDC as a percent of the overnight cost.

AFUDC is estimated for each technology using a spreadsheet model. For this study, a Weibull distribution was used to represent the S curve of capital spending and the interest rate assumed was 4.28%. Table K.1-1 shows the amount of AFUDC as a percent of the overnight cost. It estimates interest payments monthly using a blended average of long-term taxable and municipal bond rates, which are estimated using information from several sources including the following:

1. WM Financial Strategies (undated)

2. Bloomberg Business (undated)

3. BondsOnline (undated)

Assumed construction times used for the study period were also obtained from the 2014 AEO (EIA 2014). The average projected bond rate in real terms (i.e., actual quoted levels less projected inflation) is expected to vary slightly over time. As a simplification, an annual average bond rate of 4.28% was used regardless of when construction begins. This is the average rate over the 2017 through 2033 time period. It should be noted that during this time period the weighted average annual bond rate fluctuates between 4.16% in 2033 and 4.39% in 2019; that is, a range of only 0.23%.

It should be noted that in order for the power systems analysis to be consistent with other LTEMP resource study areas, the analysis period and assumed implementation date of all alternatives is assumed to occur retroactively. Therefore, in order to best capture the economic impacts of an alternative, capacity replacement for lost Glen Canyon Dam Powerplant capacity may be brought online in the model sooner than what may be physically possible.

Capital costs used for this analysis are similar to those recommended by Energy and Environmental Economics, Inc. (E3), for WECC 10- and 20-year planning studies (E3 2014). Similar to this study, E3 used AEO new powerplant construction cost information as the basis for its recommendations to WECC. However, E3 used data from the 2013 AEO, while this analysis used more recent data contained in the 2014 AEO (EIA 2014). The costs between the two sources were slightly different. Overnight capital costs for the two key technologies selected by AURORA for SLCA/IP market system expansion are somewhat lower in the 2014 AEO (EIA 2014) compared to the 2013 AEO; costs are 5.2% less for advanced combustion turbines and 7.6% less for advanced natural gas combined cycle plants.

E3 also used a method similar to that used in this study by adjusting overnight capital costs to account for additional expenditures like AFUDC. The AFUDC multipliers applied by Argonne are slightly greater than those used by E3. For example, Argonne used an IDC multiplier of 1.0476 for advanced combustion turbines, while E3 used a multiplier of 1.035. For advanced natural gas combined cycle technologies, Argonne used a multiplier of 1.0983 while E3 used a multiplier of 1.068.

Finally, the levelized cost of capital plus fixed O&M cost used in Reclamation's (2007a) *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Interim Guidelines EIS) is consistent with levels used in this study. For a natural gas combined cycle plant, the total cost presented in that EIS was $75,800/MW-yr (in 2007$; i.e., approximately $83,400/MW-yr in 2013$). In comparison, this study uses a levelized capital cost of capital plus fixed O&M that, depending on location, ranges between $82,639/MW-yr and $83,232/MW-yr. No other technologies were considered in the Interim Guidelines EIS; therefore, a comparison cannot be made for the combustion turbine technology.

In an email response (James 2014) sent to LTEMP co-lead agencies following the March/April 2014 Stakeholder Workshop, the Colorado River Energy Distributors Association (CREDA) suggested using capital cost data from a document published by the Electric Power Research Institute (EPRI 2013). In this document, the overnight capital cost of a natural gas–fired combined cycle plant was shown to have a range of 900 to 1,150 $/kW (in 2011$); the lower cost unit used wet cooling and the higher cost dry cooling. The wet cooling value was

similar to the value from the 2014 AEO (EIA 2014), which also assumed wet cooling. When AFUDC was added, the cost range became 1,025 to 1,325 $/kW, which equates to an AFUDC multiplier of about 15% above the overnight cost. This multiplier is substantially more than AFUDC multipliers used by either Argonne or the E3 report. The EPRI report did not provide a rationale for using such a high multiplier. The discount rate assumed by the EPRI study was also greater than the one used by Argonne (i.e., 5% vs. 4.28%, respectively).

CREDA supplied its own capital cost estimate for a natural gas–fired combined cycle plant because it believed that the EPRI data did not fully account for higher elevations and harsher ambient conditions that exist in CREDA member service regions. The capital cost given by CREDA ranged from 1,130 to 1,426 $/kW. It was assumed that AFUDC was included in these capital costs, but assumptions about calculating the AFUDC were not given. Therefore, we were unable to compare Argonne's and E3's assumptions to CREDA's.

CREDA also supplied an estimate of levelized cost for the natural gas–fired combined cycle plant; the cost range was 108,000 to 132,000 $/MW-yr. This cost was based on actual Southwest utility experience. Although CREDA did not state the exact discount rate used to determine the levelized cost, it did acknowledge it was greater than 5%. However, based on the capital cost range in units of $/kW that CREDA supplied, its discount rate would be approximately 6.25%, which is substantially higher than the discount rate used by Argonne.

The economic cost to build a new generating unit and the financial outlays that a utility incurs to build a new generating unit are fundamentally different. For example, utility outlays for taxes and insurance are excluded from an economic analysis because these are transfer payments that are not part of the cost of construction. These costs, however, are important for a utility and therefore are key financial elements in utilities' cost calculation. Also, the EIA costs used in this study are typical values that are adjusted for broad regional construction costs such as material and labor. These data are not utility- or site-specific, which would take into account other factors such as the availability of cooling water. Although these considerations are important for a specific site, more generic/typical values are applied for this analysis. For example, it is assumed that a natural gas combined-cycle (NGCC) unit would be constructed at a site where there is sufficient cooling water to operate the facility, thereby eliminating the need to build expensive dry cooling technologies.

Generating Unit Operating Cost and Fuel Price Projections

This section will describe how fixed O&M costs of expansion candidates generating plants were projected into the future and will also describe how fuel prices for both existing and new generating plants were projected.

Variable O&M Costs for Existing and Committed Units. The AURORA model default database currently contains unit-level estimates of variable O&M costs for the year 2010 in terms of nominal 2010 dollars. These costs are converted to 2013 nominal dollars based on the PPI for "Electric power transmission, control, and distribution energy production" (series ID code pcu22112-22112-) (BLS undated). This equates to an increase in nominal cost of approximately 6.9%, which is reflected in AURORA inputs, thereby affecting unit-level total power production cost.

Future Natural Gas Prices for Existing Units. Unit delivery multipliers are adjusted for future time periods to be consistent with anticipated real price projection changes forecasted regionally by the 2014 AEO (EIA 2014). The cumulative percent increase in natural gas prices are provided in Table K.1-2. Note that all multipliers in the table are relative to the 2013 price.

TABLE K.1-2 Cumulative Annual Percentage Increase in Natural Gas Prices at the Henry Hub[a]

Year	Percentage Increase
2014	3.7
2015	3.9
2016	14.9
2017	22.2
2018	33.2
2019	29.3
2020	21.5
2021	29.5
2022	33.9
2023	37.6
2024	42.1
2025	45.3
2026	48.8
2027	52.3
2028	55.3
2029	60.4
2030	67.5
2031	71.3
2032	76.5
2033	82.8

[a] Natural gas prices are highly volatile, and prices may have changed by the time the EIS was published.

Future Natural Gas Prices for New Expansion Units. Future natural gas prices for new units constructed by AURORA model expansion plans are specified by bubble and duty cycle. These prices are linked to the absolute real 2013 price levels and price changes over time that are consistent with the 2014 AEO (EIA 2014) prices shown in Figure K.1-17. Prices can also vary by technology type. The 2014 AEO (EIA 2014) price projections are specified in terms of 2012 dollars. These were converted to 2013 dollars using the GNP IPD based on the GNP IPD for January 2013 relative to January 2012 GNP IPD (see http://research.stlouisfed.org/fred2/data/GDPDEF.txt).

Natural gas prices in AURORA differ by month; generally, prices are higher in the winter as compared to the summer. In the AURORA EPIS default database, this monthly price pattern is most distinct (i.e., relatively large price range during the year) in early forecast years and gradually diminishes over time. These same seasonal trends were used for the LTEMP power systems study.

Future Coal Prices for Existing Units. AURORA base coal prices are entered at the state level and change annually. Unit delivery coal price multipliers are adjusted for future time

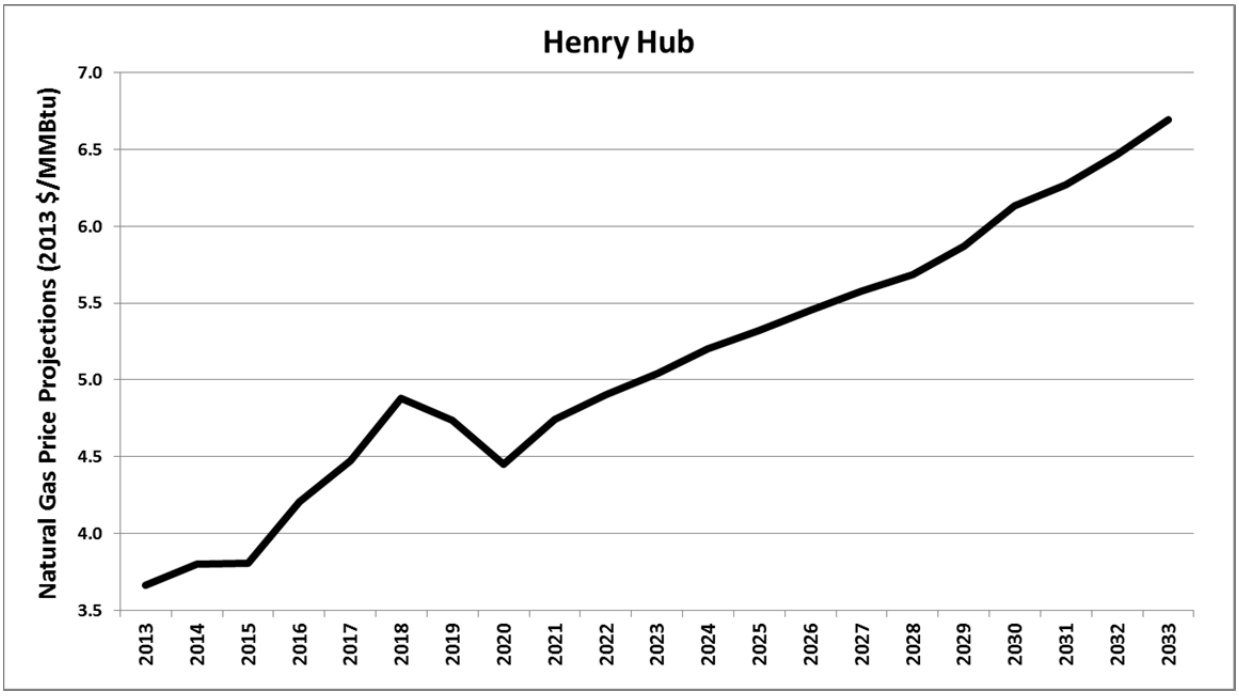


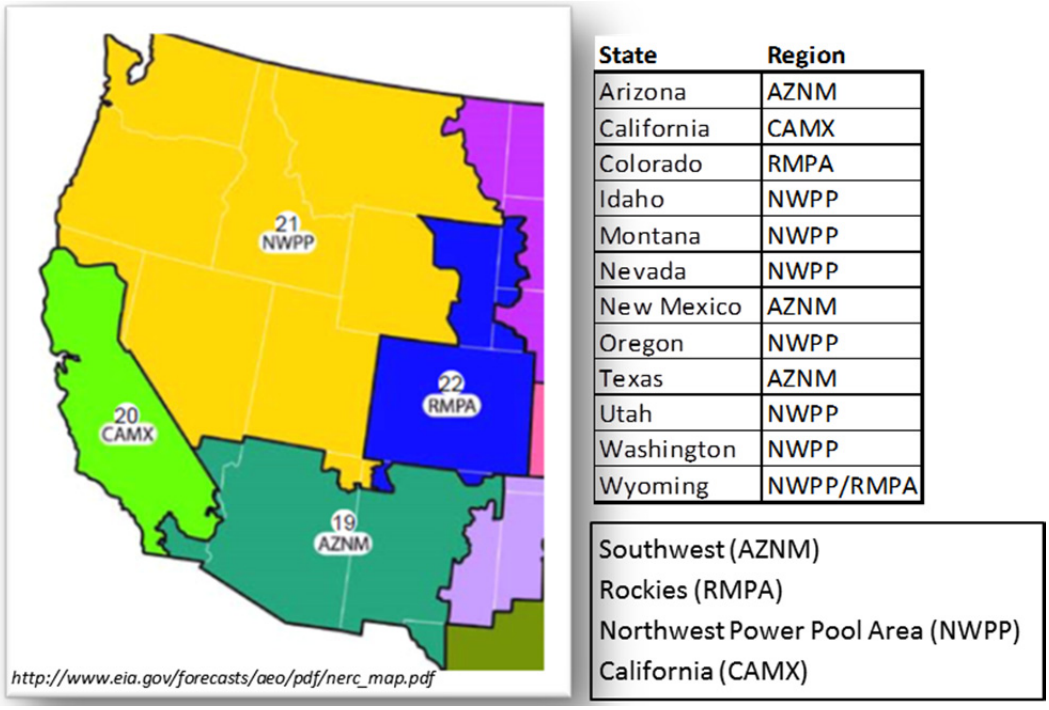
FIGURE K.1-17 Projected 2014 AEO (EIA 2014) Natural Gas Prices at the Henry Hub (Note that natural gas prices are highly volatile, and prices may have changed by the time the EIS was published)

periods to be consistent with anticipated real price projection changes forecasted regionally by the 2014 AEO (EIA 2014) electricity market module shown in Figure K.1-18. Regional multipliers are shown in Table K.1-3.

Multipliers are applied at the unit level, depending on the state in which it resides. Therefore, as shown in Figure K.1-18, states were paired with the AEO regions. Because Wyoming is split between two regions, an average of the two was used.

Future Coal Prices for New Expansion Units. Future coal prices for new units constructed by the AURORA model expansion plan are specified by bubble (i.e., large customer) and duty cycle. These are consistent with absolute real-price levels and changes over time projected by 2014 AEO (EIA 2014), as shown in Figure K.1-19. The 2014 AEO (EIA 2014) price projections are specified in terms of 2012 dollars which are converted to 2013 dollars using the GNP IPD.

Future Distillate Fuel Oil for Existing Units. Future delivered price multipliers are adjusted for future time periods to be consistent with anticipated real price projection changes forecasted regionally by the 2014 AEO (EIA 2014). Regional multipliers are shown in Table K.1-4.



State	Region
Arizona	AZNM
California	CAMX
Colorado	RMPA
Idaho	NWPP
Montana	NWPP
Nevada	NWPP
New Mexico	AZNM
Oregon	NWPP
Texas	AZNM
Utah	NWPP
Washington	NWPP
Wyoming	NWPP/RMPA

FIGURE K.1-18 2014 AEO (EIA 2014) Electricity Market Module Regions and the Mapping of States to Regions

Future Nuclear Fuel Price for Existing Units. EPIS-supplied nuclear fuel prices and projections were used for power systems modeling. As previously noted, there is only one nuclear plant in the SLCA/IP market system whose production levels do not vary significantly among alternatives.

Renewable Resource Projections

Future renewable resource additions are built by the model such that each utility complies with information included in its IRP. One simplification is that a utility employs a single type of renewable generation to serve future load in each state (namely, solar for Arizona and New Mexico and wind for Utah and Colorado).

TABLE K.1-3 Cumulative Annual Percent Increase in Regional Coal Prices

	Year																			
Region	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
RMPA	–1.6	2.7	6.5	8.8	11.6	13.7	15.8	17.7	20.0	22.1	24.4	26.8	28.7	30.3	29.3	30.0	30.1	30.9	31.7	33.8
NWPP	0.6	4.5	10.0	11.9	14.7	17.1	19.4	20.5	23.0	26.4	28.7	31.2	33.2	35.1	32.6	32.3	31.2	31.5	30.6	34.4
AZNM	–1.7	5.1	8.6	11.6	8.9	9.2	9.6	10.8	12.2	13.7	14.7	15.9	16.8	17.6	18.1	19.2	20.2	21.3	22.3	23.3
CAMX	–4.0	2.7	4.3	5.8	7.8	9.6	11.6	13.1	15.1	17.0	19.1	21.2	22.7	23.9	24.9	26.9	28.7	30.5	31.8	33.1

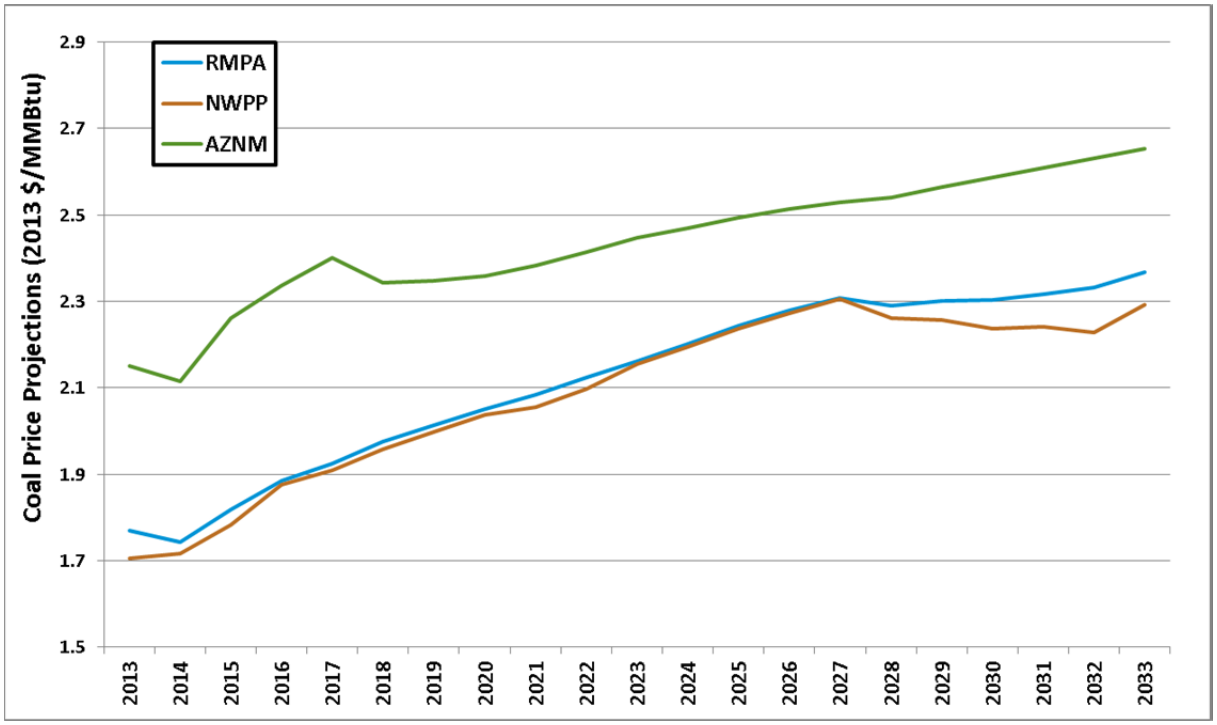


FIGURE K.1-19 Projected AEO 2014 (EIA 2014) Coal Prices by Electricity Market Module Region

K.1.7 Glen Canyon Dam Powerplant Capacity Cost and Benefit Methodology

The difference between the firm capacity level of Alternative A and the firm capacity level under a specific alternative is the amount of additional capacity that will eventually need to be built. It is referred to as lost Glen Canyon Dam capacity and will be replaced at some point in the future by one or more entities in the SLCA/IP market system, which consists of WAPA and its LTF customers. The economic costs of this lost firm capacity is based on the capital and fixed O&M costs that would be expended to construct and operate new units that replace it. The amount of replacement capacity that would need to be built is dependent on several factors, including the level of current and committed system resources, future annual system peak loads, and system reliability criteria. Economic impacts are measured for the system as a whole, where system-wide capacity expansion pathways are simulated and associated costs are computed for each alternative. A time series of costs differences relative to Alternative A is then computed and expressed as a single NPV for each alternative. Capacity replacement costs include capital investment for new capacity plus fixed O&M costs for operating the newly constructed units.

TABLE K.1-4 Cumulative Annual Percentage Increase in Regional Distillate Fuel Prices

	Year																			
Region	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
RMPA	–5.6	–10.2	–13.0	–13.9	–13.0	–11.1	–9.3	–7.3	–5.2	–3.3	–1.5	0.3	1.7	3.5	4.9	6.4	7.6	9.0	10.6	12.2
NWPP	–5.6	–10.4	–13.3	–14.2	–13.2	–11.3	–9.5	–7.5	–5.3	–3.5	–1.5	0.3	1.8	3.4	4.8	6.4	7.6	9.0	10.6	12.2
AZNM	–5.6	–10.2	–13.0	–13.9	–13.0	–11.1	–9.3	–7.3	–5.2	–3.3	–1.5	0.3	1.7	3.5	4.9	6.4	7.6	9.0	10.6	12.2
CAMX	–5.6	–10.4	–13.1	–14.0	–13.1	–11.2	–9.4	–7.4	–5.3	–3.4	–1.5	0.3	1.8	3.5	4.8	6.4	7.6	9.0	10.6	12.2
NWPP/RM	–5.6	–10.3	–13.1	–14.0	–13.1	–11.2	–9.4	–7.4	–5.3	–3.4	–1.5	0.3	1.7	3.4	4.8	6.4	7.6	9.0	10.6	12.2

K.1.7.1 Treatment of Glen Canyon Dam Capital and Fixed O&M Costs

The Glen Canyon Dam and Powerplant were constructed between June 1960 and September 1966. Preceding the construction of the dam, diversion tunnels were dug and a coffer dam was built upstream to divert water from the main dam construction site (see http://www.usbr.gov/uc/rm/crsp/gc/history.html). All of the capital costs to build the dam and powerplant were incurred in past. Therefore, the economic costs of these past expenditures are treated as sunk investments under all alternatives; that is, economic costs for building the dam and powerplant are set equal to zero because past expenditures cannot be altered. Furthermore, it is assumed that any additional capital investment in the dam and powerplant that will be incurred in the future is unaffected by an alternative. It therefore follows that capital investment differences among alternatives is also zero. Similarly, Glen Canyon Dam fixed O&M costs are assumed to be unaffected by all of the alternatives. It is also assumed that the total physical 1,320 MW of nameplate capacity at Glen Canyon Dam is identical under all LTEMP EIS alternatives and that the capacity of all powerplant units will not change over the study period.

Past Glen Canyon Dam construction costs and interest expenses are paid by WAPA SLCA/IP LTF customers through WAPA's firm energy and capacity rates. Revenues from the sale of CRSP power are deposited in the U.S. Treasury. These power revenues also pay for irrigation assistance, O&M costs, salinity control, and environmental programs. CRSP power revenues have funded more than $287 million of costs associated with environmental programs in the Grand Canyon. Of this amount, Glen Canyon Dam environmental experiments recommended through the Glen Canyon Dam Adaptive Management Program have cost $63.3 million since 1992.

K.1.7.2 WAPA's SLCA/IP LTF Obligations and Glen Canyon Dam Replacement Capacity

Currently, Glen Canyon Dam capacity primarily benefits SLCA/IP LTF customers. Through its marketing program, WAPA currently sells customers bundled SLCA/IP federal hydopower resources, not individual plants. For power systems analysis, firm capacity is therefore determined for the entire system, based on the coincidental sum of maximum daily energy outputs from all SLCA/IP federal hydropower facilities and other factors such as those described in the Firm Capacity Spreadsheet section (Section K.1.5.11). For the LTEMP EIS, Argonne conducted a study of WAPA's SHP commitment levels over the last 10 years; the study is described later in this appendix, in the Firm Capacity Risk Level section. The study found that capacity has historically been marketed such that 90% of the time WAPA's 11 SLCA/IP federal hydropower plants had sufficient maximum operating capabilities to meet customers' total peak requests for energy within the bounds specified by SLCA/IP LTF contracts. This same 90% level is used to determine the firm capacity under all of the alternatives. However, in the future WAPA may choose to market capacity at either a higher or a lower risk level.

Operating criteria differ by alternative in terms of the distribution of monthly water release volumes during a WY and the level of operating flexibility that is allowed at Glen Canyon Dam. Both affect the maximum output level that the Glen Canyon Dam Powerplant is

allowed to deliver during times of SLCA/IP market system peak load. The difference between the Alternative A capacity and the capacity under another specific alternative is the amount of additional capacity that will eventually need to be built above the Alternative A capacity expansion plan. This lost capacity will be replaced at some point in the future by one or more large SLCA/IP LTF customer utilities. For the purposes of economic impacts, it is assumed that the identification of the entities that replaces this lost capacity is inconsequential. As stated previously, this is an economic analysis that measures the net cost difference for the system as a whole, not a financial analysis of individual entities (e.g., a utility company) that operate within the system.

The wholesale rate and retail rate studies that are presented in Sections K.2 and K.3, respectively, discuss potential impacts on individual entities within the SLCA/IP market system. The wholesale rate study also discusses rates under a scenario in which WAPA replaces lost capacity, as well as another scenario in which WAPA makes capacity and energy obligations based on the chronological capabilities of SLCA/IP federal hydropower resources. The latter scenario requires that SLCA/IP LTF customers replace the lost capacity.

K.1.7.3 WAPA SLCA/IP Firm Hydropower Capacity

Argonne used several tools and models of varying levels of detail and complexity to estimate SLCA/IP federal hydropower plant firm capacity levels; that is, the maximum power output that system operators can usually, but not always, rely upon to meet peak loads. Argonne also developed capacity expansion paths for each alternative and associated costs for the SLCA/IP market system. An expansion path describes the timing and type of new units that will be built in the future. It is based on a host of factors such as SLCA/IP firm capacity, the system capacity reserve margin goal, projected fuel prices, the characteristics of existing powerplants, and peak load growth.

Firm capacity is based on the coincidental sum of maximum daily energy outputs for all SLCA/IP federal hydropower facilities. The method used varies by powerplant size and operating criteria. Figure K.1-20 lists SLCA/IP federal hydropower facilities grouped by size. The figure also provides information on the models, parameters, and data used for estimating firm capacity.

The entire physical capacity of SLCA/IP federal hydropower resources is not available to meet LTF customer loads. Instead capacity is reserved for other purposes. As shown in Figure K.1-21, some of these purposes include capacity set aside to serve project use loads such as pumping for irrigation, replacing transmission losses, providing spinning reserves, and performing regulation services. A more detailed description of these components is provided next.

From an operational standpoint, the capacity that is reserved for these purposes is known with a relatively high degree of certainity. However, at any single point in the future, the impacts of unit outages, reservoir elevation, and enviromental operating critera on hydropower resource capacity are highly variable and cannot be predicted without forecast error. Therefore, SLCA/IP

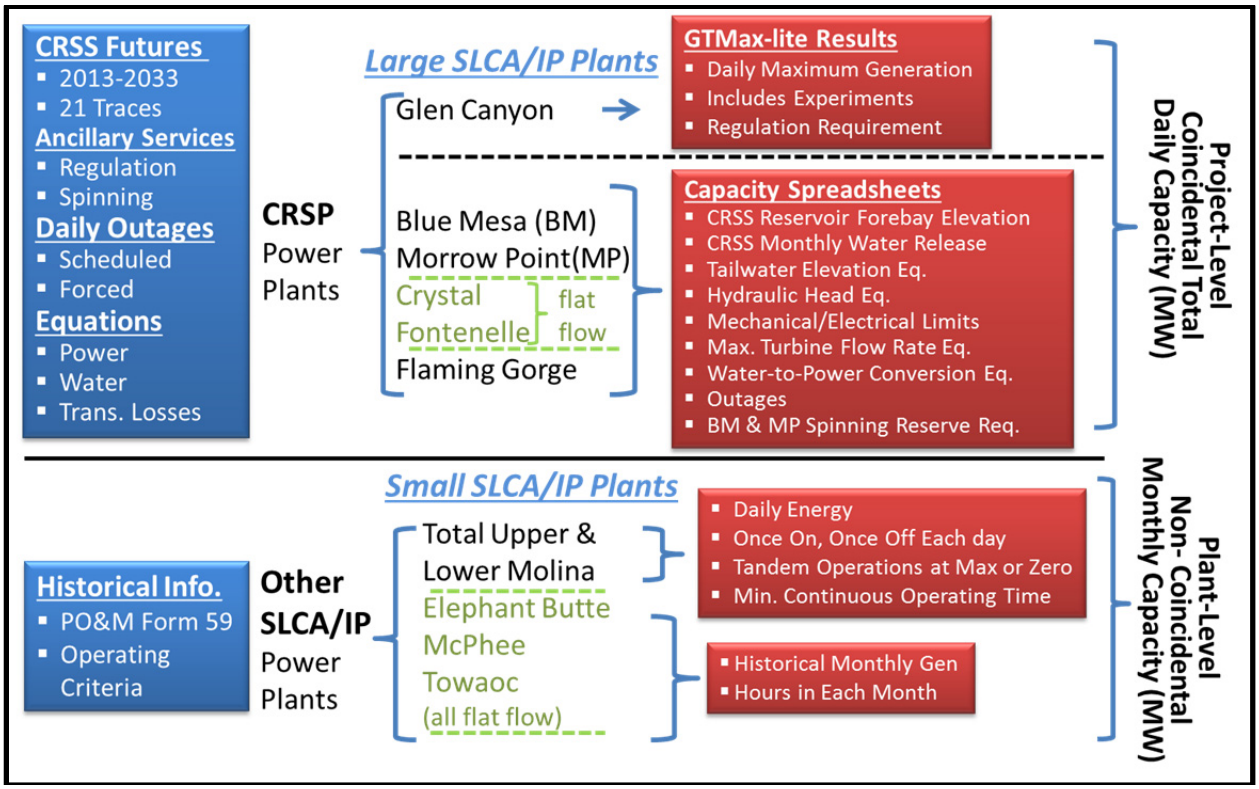


FIGURE K.1-20 WAPA SLCA/IP Hydropower Powerplants

federal hydropower resources are exposed to risks because the future of both reservoir conditions and the operating state of generating units are not known with certainty. This risk level is directly related the amount of firm capacity that is assumed (that is, the lower the amount of firm capacity, the lower the risk). The power systems methodology uses a probabilistic approach to quantify this risk.

Project Use Loads

WAPA has an obligation to serve project use loads such as pumping for irrigation. These loads are also given a high priority in LTEMP power system models; that is, these loads must be satisfied before other SLCA/IP market system loads are served. Summary data that describes project use obligations was obtained from the CRSP Management Center. These obligations were transformed into hourly "flat" load vectors. During the study period, one new project use load will come online: the Navajo-Gallup Water Supply Project. From discussions with CRSP Management Center staff, it was determined that there would be additional project use loads from this project of 5 MW load in 2018, 2023, 2024, and 2029, for a total increase of 20 MW. Loads are assumed to be identical for both capacity and energy economic analyses. In addition, these loads are assumed to be unaffected by alternative.

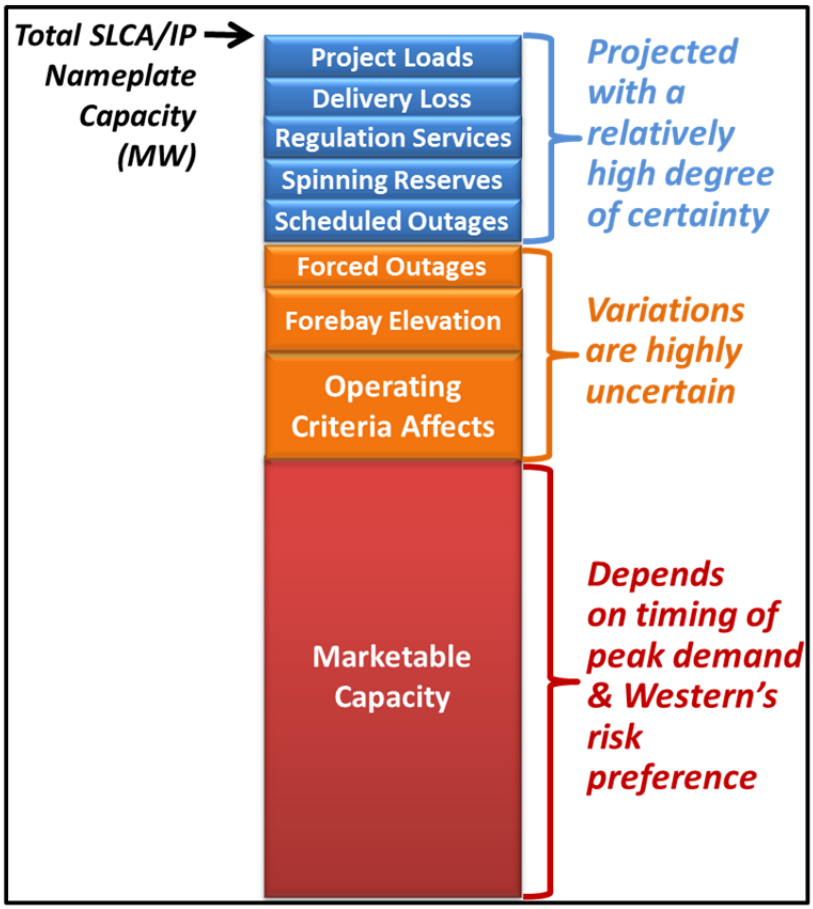


FIGURE K.1-21 SLCA/IP Federal Hydropower Capacity Uses and Variability Factors

Delivery Losses

Energy is lost in the process of transporting energy from SLCA/IP federal hydropower generation points to points of energy delivery. Under current accounting practices, which were established after system consolidation measures were implemented, transmission system losses are set to 5% (Scheid 2015). Therefore, it is assumed that marketable capacity that is delivered to customers is reduced by this same percentage. For example, when the Fontenelle Powerplant produces its maximum output of 10 MW, it is assumed that only 9.5 MW is delivered to demand points; that is, for accounting purposes, 0.5 MW is lost during the transmission process. As described in section K.1.3.2, 5% losses for SLCA/IP energy deliveries are also accounted for in AURORA model capacity expansion and dispatch simulations.

Ancillary Services

As part of its power pool agreements, WAPA has an obligation to provide ancillary services. SLCA/IP resources provide regulation reserves and fast spinning reserves. As shown in

Table K.1-5, both of these ancillary services are projected to increase by up to 80 MW. The maximum requirement is reached in 2025 for regulation reserves and in 2030 for fast spinning reserves. A total of 160 MW of ancillary will then be maintained from 2030 into the foreseeable future. Estimates of future ancillary service levels were provided by Reclamation based on a discussion with WAPA staff in May 2013.

TABLE K.1-5 Assumed Ancillary Services Provided by SLCA/IP Hydropower Facilities from 2013 to 2030

	Ancillary Services (MW)		
Year	Fast Spinning Reserves	Regulation Reserves	Total
2013	43	60	103
2014	45	62	107
2015	47	63	111
2016	50	65	115
2017	52	67	118
2018	54	68	122
2019	56	70	126
2020	58	72	130
2021	60	73	134
2022	63	75	138
2023	65	77	141
2024	67	78	145
2025	69	80	149
2026	71	80	151
2027	73	80	153
2028	76	80	156
2029	78	80	158
2030+	80	80	160

Figure K.1-22 shows how the methodology used for this study explicitly reduces the operating range of plants that provide one or more ancillary services. A plant's hourly maximum output is reduced by the level of regulation service and spinning reserve provided. In addition, when providing regulation services, the minimum generation level is also increased by the level of regulation service provided. Note that under current power pooling agreements, a powerplant simultaneously provides identical levels of up and down regulation. Based on discussions with power system operators, the priority for ancillary services provided by SLCA/IP federal hydropower resources is as follows. The first priority is to serve both regulation services and spinning reserves at Glen Canyon Dam. However, if the Glen Canyon Dam Powerplant has insufficient capacity to serve both or doing so would increase Glen Canyon Dam non-power water releases, spinning reserves will be off-loaded to powerplants located in the Aspinall Cascade and, if absolutely necessary, followed by regulation services.

When Glen Canyon Dam serves regulation services, it instantaneously fluctuates above and below a fixed generation set point. For example, when the hourly set point is 500 MW and regulation services is 60 MW, generation will go to a minimum of 440 MW when regulating down and go up to a maximum of 560 MW when regulating up. Based on conversations with EMMO staff, the net energy generated to provide regulation over a 1-hour time period is very close to zero; that is, instantaneous fluctuations in generation above and below the generation set point sum to zero. In the example above, 500 MWh of generation would be generated during the hour.

Because water release restrictions at Glen Canyon Dam are specified in terms of average hourly flow rates, and not instantaneous limits, regulation services can continue to be provided when releases are at an environmental flow rate limit. For example, a powerplant's generation can be set for an hour to a level that exactly releases the minimum water flow rate requirement. When providing regulation services during this hour, instantaneous flow rate will sometimes be lower than the environmental "hourly rate" minimum (regulating down), but these low flows will be offset by instances when it is higher than the minimum flow (regulating up).

Regulation services will affect the operating range at Glen Canyon Dam. The sum of the regulation service plus the operational set point cannot exceed the physical maximum MW output of the *entire* powerplant. The maximum physical output of the plant is dependent on the number of units that are operational and Lake Powell's water elevation. At the other extreme, the set point operation minus regulation service cannot be less the minimum operating limit of a *single* Glen Canyon Dam unit.

Spinning reserves only affect the maximum set point at Glen Canyon Dam. Under normal operating conditions, this spare or reserved capacity is not utilized. However, events such as a unit forced outage or downed power lines may result in a sudden grid energy imbalance; that is, there is not enough energy production to serve load. To overcome this deficiency, spinning reserves are deployed and one or more powerplants increase output to return the system to a balanced state as quickly as possible.

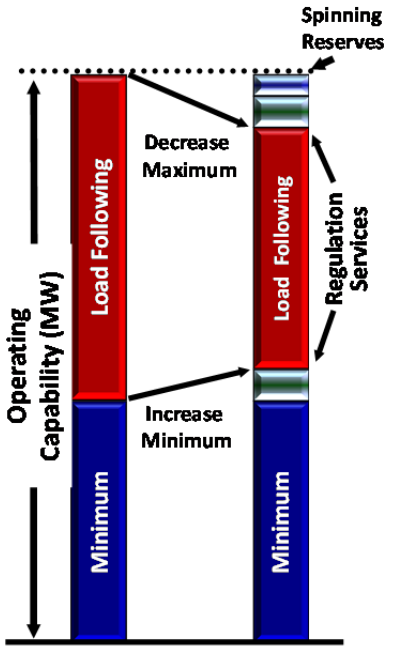


FIGURE K.1-22 Reductions in Operating Range when Providing Ancillary Services

When spinning reserves are deployed at Glen Canyon Dam, the powerplant very quickly ramps up production by a maximum of 60 MW. Under these conditions, the water release up-ramp is allowed to exceed environmental operating limits. Glen Canyon Dam "emergency exception criteria," which are stipulated under all alternatives, allows Glen Canyon Dam to operate outside of minimum and maximum flow limits, daily changes constraints, and both maximum hourly up- and down-ramp rates in the event of a power system emergency (e.g., grid energy imbalance events). However, similar to regulation services, the set point generation level plus the spinning reserve service cannot exceed the physical maximum MW output of the *entire* plant. As shown in Figure K.1-22, when both ancillary services are being served, the sum of set point, regulation, and spinning reserves cannot exceed then maximum output capability of the plant.

The economic cost of providing ancillary services at Glen Canyon Dam varies by alternative, such that the greater the operational flexibility is, the higher the cost of serving regulation and spinning reserves will be. Under flat flow alternatives, ancillary services do not typically affect the operating range because there is no flexibility in the system. On the other hand, ancillary services at times bind (i.e., lower) the maximum output level at Glen Canyon Dam. These binding events occur when the monthly water release volume allows for a relatively large daily operating range and a higher base flow. Glen Canyon Dam unit outages and lower reservoir elevations exacerbate the economic impacts of this constraint by essentially lowering the maximum physical output of the plant.

The time series of ancillary service projections shown in Table K.1-5 was used in GTMax-Lite model runs that determine differences in capacity and energy value among LTEMP EIS alternatives. Glen Canyon Dam currently supplies a total of 67 MW of ancillary services,

and this is not expected to increase during the LTEMP study period. Therefore, a sensitivity study was performed to determine how firm capacity levels will change if a different ancillary services schedule is used. The sensitivity study and results are reported in Section K.1.10.8.

Outage

All of the SLCA/IP hydropower resources undergo both scheduled and forced unit outages, during which times a unit either produces no output or produces at a level that is lower than its full capability; that is, the capacity is temporarily de-rated. Maintenance is normally performed during a scheduled outage, while forced outages typically occur at random, and are precipitated by the failure of one or more unit/plant components.

For the LTEMP study, the Reclamation provided Argonne with unit-level maintenance schedules for the six largest SLCA/IP facilities over the study period. When a unit is taken out of service for maintenance, the maximum output of that unit is set to zero in all pertinent modeling processes, including both versions of GTMax-Lite and spreadsheet tools that estimate maximum physical output levels at large SLCA/IP hydropower resources other than Glen Canyon Dam.

To represent unit forced outages at large SLCA/IP powerplants, a methodology was developed to incorporate the number, cause, and duration of forced outages that may potentially occur during the study period. Data on forced outages for hydroelectric turbines were obtained from the GADS. This database is maintained by NERC and contains operating information on electric generating equipment. GADS data were input into an algorithm that produces a plausible series of random outages for units at the Glen Canyon Dam Powerplant. Using a different set of random draws for each run, the forced outage model performed numerous simulations. The run that produced the most representative time series of outages in terms of matching overall GADS statistical averages was selected. It should be noted that the forced outage model only represents full unit outages. It therefore does not directly represent partial outages. However, the model uses equivalent outage statistics that implicitly account for these types of outages. For example, if a unit is de-rated by 25% over a 6-month time period, the equivalent outage rate would be 12.5%. Details of the forced outage algorithm and methodology are described in Attachment K.5.

Scheduled and forced outages are not explicitly modeled for small SLCA/IP federal hydropower resources. However, outages are reflected in the model to the extent that unit down time is reflected in Form PO&M-59 data, which is ultimately used to model small federal hydropower facilities. For example, if the McPhee unit was down for an entire month, a zero generation level would be reported by Form PO&M-59 for that month, which would affect the results produced by the Small SLCA/IP Powerplant Spreadsheet model. Although this methodology is not the most accurate modeling approach, it should be noted that the total small facilities capacity is less than 3% of the entire SLCA/IP federal hydropower capacity. Therefore, modeling errors were judged by Argonne staff to be negligible.

Maximum Power Plant Output, Forebay Elevations, and Monthly Releases

The surface water elevation in a reservoir affects both hydropower maximum possible output level and the amount of water that needs to be released through a turbine to produce a unit (MWh) of energy. For the large SLCA/IP hydropower resources, end of the month reservoir elevations, also referred to as forebay elevations, were projected using Reclamation's CRSS and the SBM models.

Because EIS alternative operating criteria affect monthly Glen Canyon Dam water releases, and therefore Lake Powell water elevations, CRSS and SBM make separate projections for each alternative. Future hydrology conditions are not known with certainty; therefore, the CRSS model projected 105 possible outcomes at the end of each month throughout a 2013 through 2060 time period, inclusive. Although 48 years of monthly outcomes were projected, only the first 21 calendar years (20 water years) were used for analysis in the EIS. Each outcome, also known as a "trace," is based on a unique historical series of hydrological conditions. Therefore, hydrological conditions are deterministic and it is extremely unlikely that any one trace will ever be repeated. Of these 105 traces, a common set of 21 was used by all EIS research areas.

Using this information, the GTMax-Lite model is used to optimize the hourly operations of the Glen Canyon Dam such that is maximizes the economic value of energy. As described previously, GDC GTMax-Lite runs were performed twice. The first provides input to the SBM and the second run accommodates experimental releases using altered SBM monthly water release volumes and reservoir elevations. Hourly operations are projected over the entire time period for all 21 traces for each alternative. Daily maximum daily generation levels from Glen Canyon Dam GTMax-Lite output for all alternatives and traces are stored for use by the Firm Capacity Spreadsheet.

The maximum monthly physical output levels for the other five large SLCA/IP hydropower resources were computed over the entire study period for all 21 CRSS traces. Each powerplant's maximum possible output level is based on the following set of conditions, limits, and equations;

1. Mechanical/electrical turbine capacity limit;

2. Unit operating status (either operating or out of service);

3. Reservoir elevation as a function of water storage;

4. Maximum turbine water release as a function of head (forebay minus tailwater elevations);

5. Tail-water elevation as a function of maximum flow rate; and

6. The water-to-power conversion factor that is a function of reservoir forebay elevation.

In order to solve for the above set of relationships, an iterative process is used to converge all interdependent relationships to a consistent set of values. Interdependencies occur because the tailwater elevation is a function of the turbine flow and the turbine flow is a function of the system head, which is the difference between the tailwater and reservoir forebay elevations. In addition, the total turbine flow rate, and therefore tailwater and head, depend on the number of units that are operating. End-of-month reservoir forebay elevation levels that are used in the dispatch process for the other five large SLCA/IP hydropower plants are obtained from the CRSS model.

The physical maximum output level for the small SLCA/IP federal hydropower plants was set to the nameplate capacity. However, for small run-of-river hydropower plants, historical maximum output levels are based on the MWh of energy that a plant produced during a month divided by the number of hours that occurred during the month. The maximum output is typically achieved only at the Molina units.

Operating Criteria Effects on the Maximum Output Level

In addition to physical limitations, operations at all SLCA/IP hydropower plants are required to remain within a set of institutional and environmental limitations. For power systems analysis, SLCA/IP modeled operations are restricted by three types of limitations. These include (1) reservoir operating restrictions, (2) reservoir water release constraints, and (3) downstream gage stage and water flow limitations. Each of these affects the maximum daily output level. Depending on the situation, operating criteria do not allow a powerplant to reach its maximum physical output potential.

Glen Canyon Dam. The impact of operating criteria on Glen Canyon Dam maximum output levels is both complex and situational, involving not only the criteria, but also other factors such as the ancillary service requirements, monthly water release volumes, Lake Powell Reservoir elevation, and the number of operational units. End-of-month Lake Powell Reservoirs were obtained from the SBM.

To provide accurate estimates of the operating criteria on Glen Canyon Dam maximum output levels, Argonne optimized its hourly dispatch using a configuration of the GTMax-Lite model that only models Glen Canyon Dam. The GTMax-Lite model incorporates all environmental constraints imposed on Glen Canyon Dam from the current operating regime, such as restrictions on reservoir water release up/down ramp rates, minimum and maximum hourly release rates, and flow rate changes over a rolling 24-hour period. It also includes a projected maintenance schedule provided by Reclamation and a set of random unit forced outages. When physically possible and economically advantageous, the Glen Canyon Dam Powerplant also has ancillary service requirements, which, as discussed above, can impact Glen Canyon Dam's operational range.

For Glen Canyon Dam, the daily capacity level is set to the maximum output level that was modeled each day by GTMax-Lite. Although all operating criteria at Glen Canyon Dam

potentially affect the maximum output potential, the daily change constraints in combination with water availability typically are the most binding. In addition to the aforementioned operating criteria, HFEs also affect capacity.

Aspinall Cascade: Blue Mesa, Morrow Point, and Crystal Dams. The Aspinall Cascade is operated as a tightly coupled, multipurpose system with a total nameplate capacity of approximately 283.4 MW. Plants in the cascade include Blue Mesa, Morrow Point, and Crystal. At the top of the cascade (i.e., highest elevation), the Blue Mesa Powerplant operates in a peaking mode. Located 12 mi downstream from Blue Mesa, the Morrow Point Power Dam is in the middle of the cascade. When tour boats operate in the Morrow Point Reservoir, there is a minimum reservoir elevation requirement of 7,151 ft. In addition, the Morrow Point Reservoir cannot be drawn down by more than 3 ft per rolling 24-hour period if the surface elevation is below an elevation of 7,144 ft. When tour boats are not operating, the minimum reservoir elevation is 7,125 ft.

The Crystal Powerplant is at the bottom of the cascade. In addition to functioning as a power generation unit, its operations stabilize the flow of water through Gunnison National Park. The flat flow requirement precludes it from rapidly changing its power output from one hour to the next. Operating criteria for the Crystal Reservoir are season specific. During the wet season (March 1 to June 30), the operating criteria limit reservoir drawdown to no more than 4 ft in a 24-hour rolling period, 5 ft over a 48-hour rolling period, or 6 ft over a 72-hour rolling period, and so on. In addition, once an elevation of 6,748 ft is reached, the reservoir level may not drop by more than 0.5 ft per 24-hour rolling period. During the remainder of the year, there is a 10-ft-per-24-hr-period fluctuation limit, with a maximum 3-day drawdown of 15 ft. If the reservoir elevation is below 6,733 ft, there is a 5-ft-per-24-hr-period drawdown limit, with a maximum drawdown of 20 ft per 7-day period.

Cascade reservoir restrictions can at times affect the hourly dispatch of powerplant units. However, for the LTEMP EIS, it is assumed that these operating criteria do not affect the maximum output level that can be achieved at the Blue Mesa and Morrow Point. Generation at both of these powerplants can be ramped up or down from a zero output level to maximum capability in a matter of minutes without adverse effects on the power equipment. In addition, the plants are scheduled in advance, so reservoirs can usually accommodate water releases associated peak powerplant output levels without violating reservoir operating criteria. Therefore, it is assumed that Blue Mesa and Morrow Point maximum output levels are limited only by the reservoir level and the number of units that are in service as described in the Forebay Elevation section above.

The Crystal Dam however has a flat flow requirement that precludes it from rapidly changing its power output from one hour to the next. Therefore, the maximum output level from this plant is assumed to equal the monthly generation at the plant divided by the number of hours in the month.

Green River: Fontenelle Dam and Flaming Gorge Dam. The Fontenelle Powerplant also releases water at a constant rate (or flat flow), and output levels are nearly constant during daily operations. Therefore, maximum output level from this plant is assumed to equal the monthly generation at the plant divided by the number of hours in the month.

Operations at Flaming Gorge Dam are subject to set of complex limitations that affect maximum daily capacities. These include a minimum flow rate of 800 cfs, a maximum up-ramp rate of 800 cfs/hr, and a down-ramp rate limit of 1,000 cfs/hr. Water releases are further constrained to a constant rate (i.e., flat flow) in the summertime during the hours of the day when people are likely to be fishing below the dam. In keeping with current practices, the computation of Flaming Gorge capacity assumes the following:

1. The daily water release volume is the same for all days of a month;

2. The hourly water release pattern is identical each day of the week;

3. There is a one-hump release pattern during the summer; and

4. There is flat flow in summer between the hours of 6:00 AM and 7:00 PM (i.e., a duration of 13 hr every day).

The trapezoidal methodology utilized in the Large Plant Capacity Spreadsheet is illustrated in Figure K.1-23. It applies simple geometric equations to estimate Flaming Gorge base and peaking capacities using daily water release volumes and reservoir elevations derived from CRSS model results. The base capacity is computed by multiplying the 800 cfs minimum flow requirement by a water-to-power conversion factor that is a function of hydraulic head. It requires a significant volume of base load water to be released each day (i.e., constant 800 cfs release over a 24-hour period).

The water volume that remains after sustaining the daily base release is used to estimate peaking capacity as the height of a trapezoid. The length of the top of the trapezoid is 13 hr (i.e., fishing duration) and length of its bottom/base is equal to 13 hr plus the up and down ramping times. As shown in Figure K.1-24, these ramping times increase as a function of peaking water volume and subjected to a total time limit of 11 hr (i.e., 24 hr less the 13 hr flat flow period).

Furthermore, the sum of the base load and peaking capacities cannot exceed the total physical turbine flow limit multiplied by the water-to-power conversion factor, as described in more detail in the Forebay Elevation section; both the maximum turbine flow limit and the power conversion factor are a function of the hydraulic head. The total turbine water release, and therefore the maximum output level, is reduced when turbines are taken offline due to a scheduled or forced unit outage at Flaming Gorge. The results of performing trapezoidal computations over a large range of daily water volumes are shown in Figure K.1-25. This relationship between daily water volume and maximum turbine flow rate is fairly accurately described by a sixth order polynomial. Multiplying the maximum flow rate by the water to power conversion factor yields a capacity estimate.

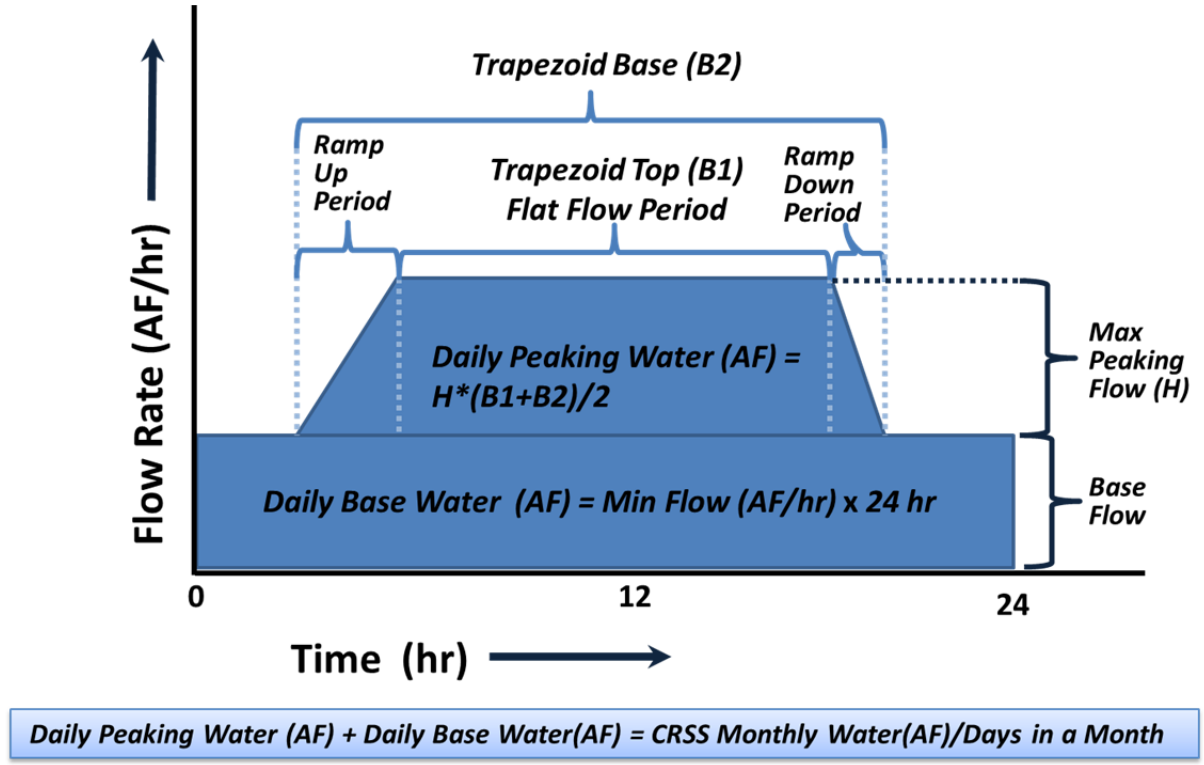


FIGURE K.1-23 Illustration of the Trapezoidal Method Used to Compute Capacity at Flaming Gorge Dam

To protect endangered native fish in the Green River basin, the U.S. Fish and Wildlife Service released a biological opinion (FWS 1992) designed to protect the Colorado Squawfish and Razorback Sucker. The overall intent of the opinion was to structure releases from the Flaming Gorge reservoir so that they resemble natural hydrograph and water temperature conditions. A final set of restrictions was implemented in WY 2006 following completion of a final EIS on the operation of Flaming Gorge Dam (Reclamation 2005) and issuance of its ROD (Reclamation 2006) in February 2006.

High spring release volumes are being structured to enhance river flows during spring spawning periods. Flow volumes include full powerplant output (approximately 4,500 cfs or 141 MW) to full plant output plus bypass tubes and spillways combined. The high release period could be held for as long as 4 weeks. The actual volume and duration of release from Flaming Gorge is determined by the river volume desired on the Green River below the Jensen measurement gage at Jensen (or Jensen Gage) and inflow support from the Yampa River. The high spring release is patterned around the peak runoff period, which varies each year based on weather conditions and endangered fish spawning activities. High peak spring releases transfer water that historically was released during summer and winter peak months to spring months. This shifting of water among months of the year is factored into CRSS model runs that provide input data into the Large Plant Capacity Spreadsheet.

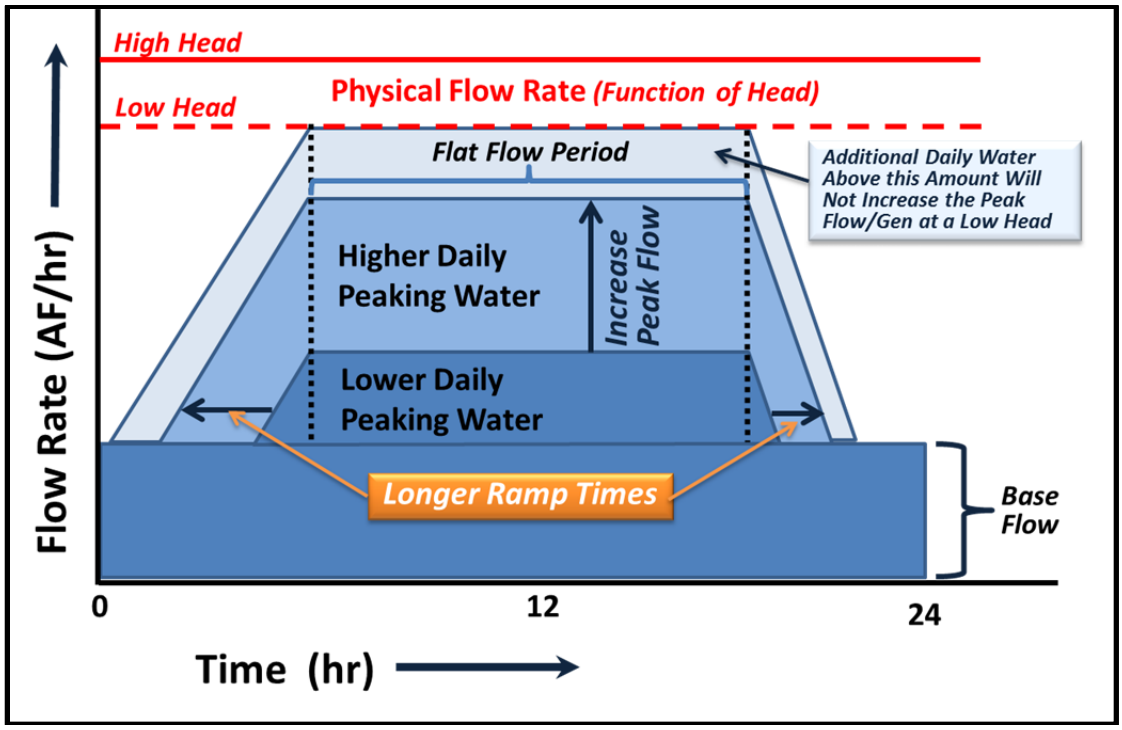


FIGURE K.1-24 Illustration of Ramping Time Increase as a Function of Increasing Water Volumes at Flaming Gorge Dam

After the high spring release is completed, flows on the Green River below the Jensen Gage are held to an average of 1,600 cfs, if possible. The gage is about 94 mi downstream of the reservoir, receiving water not only from Flaming Gorge but also from the uncontrolled Yampa River, which joins the Green River approximately 65 mi downstream of the dam. This means that releases from the Flaming Gorge power plant are held to a minimum of 800 cfs (25 MW) until a time when the combined average flows on the Green and Yampa rivers below Jensen fall below the desired level of 1,600 cfs average. This powerplant restriction can last from 3 to 8 weeks, depending on snowpack conditions.

Flaming Gorge operations must also be patterned such that daily stage readings at the Jensen Gage do not fluctuate by more than 0.1 m. These stage readings are a function of hourly water releases from Flaming Gorge, inflows into the Green River from the Yampa River (105 km [65 mi] downstream of the dam), downstream flow rate attenuations, and water travel times. Although the influence of Jensen Gage constraints are not factored into the capacity estimate, at low daily water release volumes the daily range of Jensen Gage flow rates are also low.

Small SLCA/IP Resources. Relatively small SLCA/IP hydropower plants including Towaoc, McPhee, Elephant Butte, Upper Molina, and Lower Molina power plants. In total, these facilities contribute a relatively small amount of capacity and all but the Molina power plants are flat flow facilities. Powerplant capacities for small powerplants are computed in a spreadsheet based on historical monthly generation data as archived in Form PO&M-59. For the small

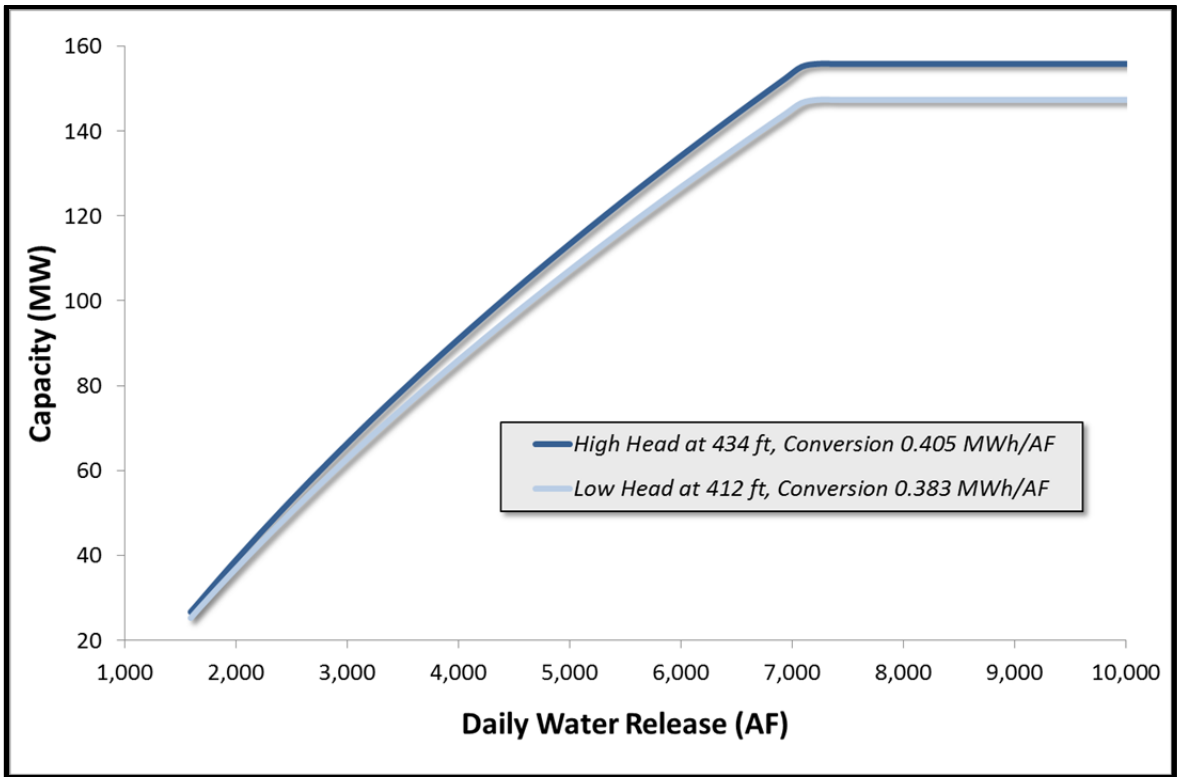


FIGURE K.1-25 Capacity Values at Flaming Gorge Dam Calculated over a Wide Range of Daily Water Releases Using the Trapezoidal Method

powerplants that are run at flat flow, the firm capacity credit is primarily a function of monthly estimates of total energy production divided by the number of hours in a month.

However, Molina powerplants are dispatchable and operated in unison. The spreadsheet algorithm evenly divides Form PO&M-59 monthly generation among all days in the month. The spreadsheet then operates Molina at maximum output continuously until the entire daily generation is exhausted; that is, the units start and stops once per day and no power is produced in any other hours. The block of operating hours is based on market prices such that the economic value of Molina resources is maximized.

Risk-Based Firm Capacity Operating Criteria

As discussed previously, numerous factors influence the amount of firm capacity that is credited toward reserve margin computations for SLCA/IP system. Two of these factors are discussed in this section. These include (1) the month when system peak load occurs and (2) the percentage of time that the entire firm capacity or more will be available to meet the system peak load.

System Peak Load Month. The month in which the system peak load occurs and upon which firm capacity calculations would be based was debated and ultimately jointly decided upon by staff from Reclamation, WAPA, National Park Service (NPS), and Argonne. August was chosen as the month when the system peak load occurs. This decision was made after examining historical FERC Form-714 data for CY 2006 through CY 2012, inclusive. Hourly load data were available for all eight large customer utilities. However, NTUA and Deseret data was only available for the first 4 of the 7 years. No hourly load data were available for any of the small LTF customers.

An examination of large LTF customer historical peak loads over this time period showed that individual customer peaks almost always occurred during the summer. A few exceptions occurred. CSU experienced one annual peak load in April 2006 and another peak in December 2009. In addition, NTUA, which has the lowest peak load of the eight large customers, experiences its peak load in either December or January. Figure K.1-26 shows that the NTUA peak load is about 1% of the non-coincidental sum of the eight large customer average annual historical peak loads. The sum of these annual non-coincidental peaks changed very little during the 2006 to 2012 time period, and averaged approximately 11,800 to 11,900 MW.

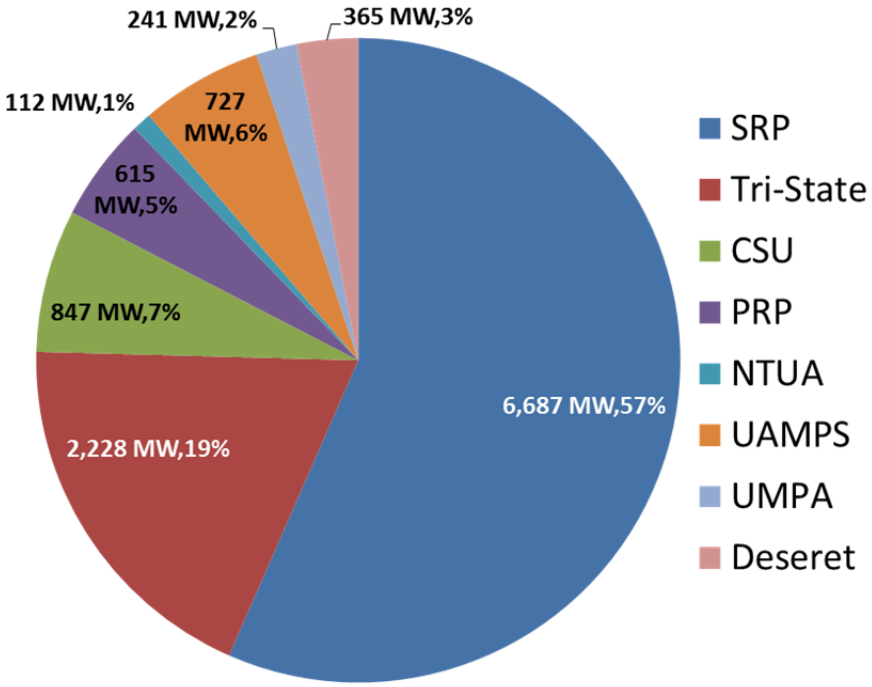


FIGURE K.1-26 Average Historical Non-coincidental Annual Peak Loads (in MW) for the Eight Large Customers and Percentages Relative to the Total

When the peak occurs in the summertime, it almost always occurs in either July or August. Only CSU experienced a different summer peak; it occurred in June of 2012 and was 2 MW greater than the highest load in July. A close examination of when the peak occurred also revealed that, for several utilities, there was no clear pattern of which month the peak occurs in. For example, SRP, which accounts for a majority of the non-coincidental total, experienced 3 years during which the annual peak occurred in July and 3 years during which the peak occurred in August. In 2007, the maximum load in July equaled the maximum in August. In addition, July and August maximum loads tend to be very similar across all systems.

Coincidental annual peak loads were also examined. The coincidental peak was determined by first summing up the available loads for the eight large customers on an hourly basis and then identifying the month in which the maximum total hourly load occurred. Results of this exercise also showed that, historically, July and August both had very similar maximum loads. Figure K.1-27 shows annual coincidental monthly maximum loads for 4 years (CY 2006 through CY 2009), based on data for all eight large SLCA/IP customers. In chronological order, the bars show annual peaks and the line shows the average. Figure K.1-28 shows the same information, except it is for an additional 3 years (CY 2010 through CY 2012) and is based on only six utilities. Information is presented in two separate figures because all load data were not available for all 7 years. As mentioned previously, FERC hourly data were not available for NTUA and Deseret during this time period. It should be noted that, for CY 2011 and CY 2012, the August peaks were markedly higher than those in July. The representative lead profile for the large customers has a coincidental peak load of about 12,370 MW.

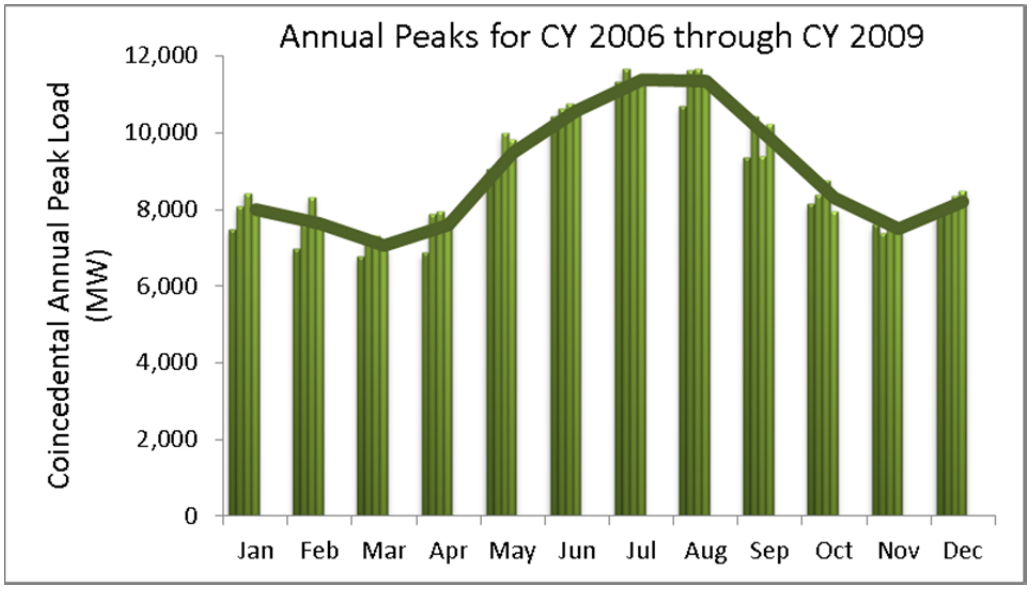


FIGURE K.1-27 Historical Coincidental Annual and Average Peak Loads for the Eight Large Customers during the CY 2006 through CY 2009 Time Period

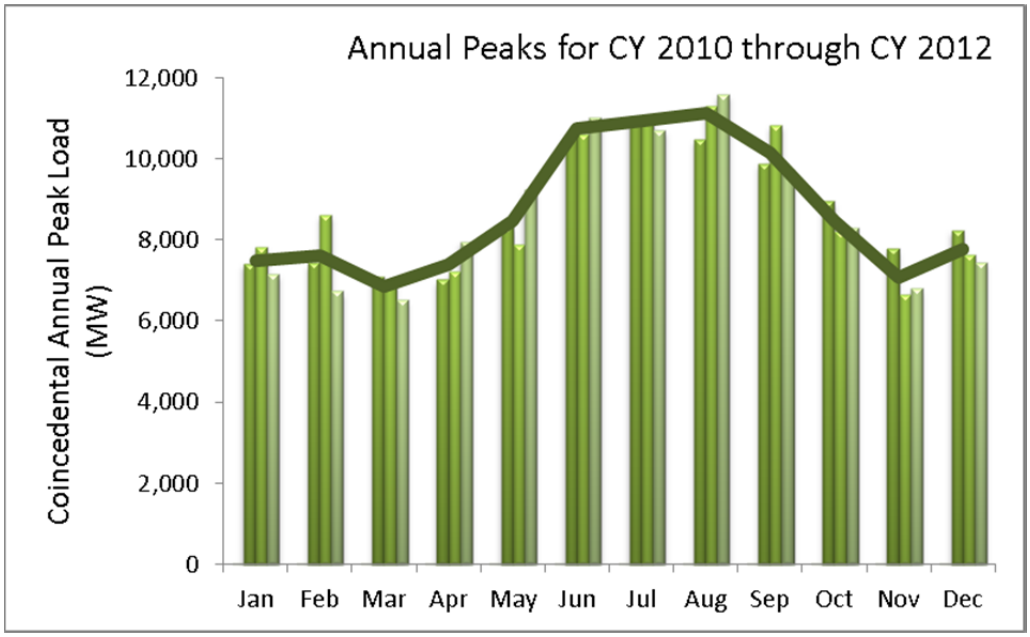


FIGURE K.1-28 Historical Coincidental Annual and Average Peak Loads for Six Large Customers during the CY 2010 through CY 2012 Time Period

Firm Capacity Risk Level. Assumptions regarding the level of risk that would be used in the LTEMP power systems analyses to determine firm capacity levels under each alternative were debated and jointly decided upon by staff from Reclamation, WAPA, NPS, and Argonne. Again, historical information was used to help in the decision-making process. However, unlike the process that was used to determine the timing of the peak load, which primarily relied on historical data, these methods also required the use of modeling tools—most of which were previously described in the Modeling Tools section.

Under terms of the SLCA/IP 2004 LTF contracts, WAPA's CRSP Management Center Office is obligated to provide its LTF customers with a minimum capacity level (SHP). The SHP level must be supplied regardless of the state or condition of SLCA/IP hydropower resources. These LTF contracts became effective on October 1, 2004, and will continue until September 30, 2024. When SLCA/IP resources are incapable of fulfilling WAPA's entire obligation, WAPA must make power purchases to cover any shortfalls. Therefore, WAPA and its LTF customers are exposed to market risks because the future of both reservoir conditions and the operating state of generating units are not known with certainty. Argonne conducted an analysis to roughly approximate risk levels to which WAPA is exposed under its current SHP obligation. For this analysis, risk exposure is measured as the probability that WAPA will not be able to meet its daily SHP obligations during peak summer load months. Argonne staff estimate this probability by computing daily SLCA/IP hydropower powerplant capacity under many possible hydrological futures while accounting for the impacts of unit-level outages and environmental operating limits. This analysis is merely a retrospective study of WAPA's SHP level using current hydrological data. The methodology used in this analysis was not necessarily used by WAPA to determine its current SHP obligations.

SLCA/IP hydropower facilities span a large range of powerplant sizes and operational flexibility. For this analysis, WAPA's SLCA/IP hydropower resources are divided by size as shown in Figure K.1-20.

The capacity from the WAPA SLCA/IP system is estimated using the models and method shown in Figure K.1-29, which leverages LTEMP tools and methods. A brief overview of capacity computations is as follows:

1. Glen Canyon Dam Powerplant resource capacity under many plausible futures is based on Reclamation's CRSS and SBM models, along with maximum daily production levels projected by the Argonne GTMax-Lite model;

2. Other CRSP and Fontenelle daily capacities under many plausible futures are estimated by the Large Powerplant spreadsheets that compute unit-level maximum output based on CRSS model results and unit-level outages;

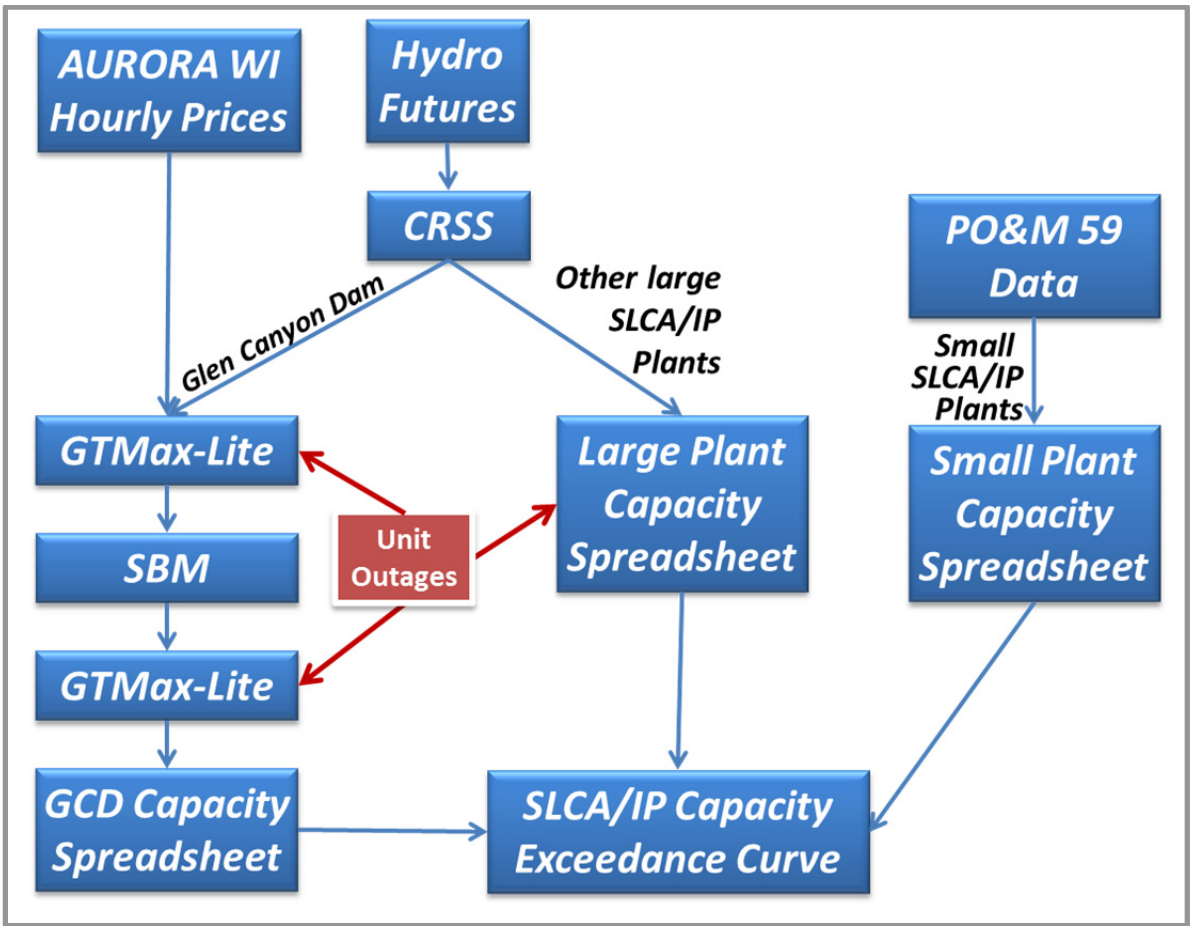


FIGURE K.1-29 SLCA/IP Models Used for Estimating SHP Capacity

3. Flaming Gorge capacity is further reduced under most hydrological conditions because operating criteria and other agreements further constrain its maximum daily output; and

4. For the remaining SLCA/IP resources (i.e., Towaoc, McPhee, Elephant Butte, Upper Molina, and Lower Molina), monthly capacity computations are based on historical monthly operating information contained in Form PO&M-59.

After trace-specific time series of plant-level capacities are computed, the Firm Capacity Spreadsheet creates SLCA/IP hydropower capacity exceedance curves. For each day in a month, the routine totals the daily coincidental peak capacities of all large powerplants. To this sum the routine adds monthly capacities for all small powerplants and subtracts capacity that is reserved for other purposes as described in previous sections.

After a time series of plant-level capacities was computed for all facilities and all traces over the 20-year study period, the data were processed further in a separate routine to determine exceedance levels for the peak loads months of July and August. For each day in a month, the routine totals the daily coincidental peak capacities for both Glen Canyon Dam and the other large SLCA/IP federal facilities for 21 hydrology traces over the 20-year study period. The resulting values are used to create SLCA/IP hydropower marketable capacity exceedance curves.

WAPA's current sustainable hydropower (SHP) commitment level was located on these exceedance curves to determine how much of the time SLCA/IP resources would be able to meet all of WAPA's current contractual and operating obligations. SHP is the minimum aggregate level of LTF capacity and energy that will be provided by WAPA to all SLCA/IP customers through the contract period, regardless of the hydropower condition. The location of the WAPA's SHP commitment on the exceedance curve will determine the level of capacity risk to which WAPA is currently exposed.

From WAPA's data over at least the last 10 years, its SHP commitment for July has been about 750 MW. As shown on the SLCA/IP capacity exceedance curve in Figure K.1-30, this level is exceeded about 89.5% of the time; in other words, there is a 10.5% probability that WAPA will need to make purchases to fulfill its entire SHP. In August the risk is somewhat lower. Figure K.1-31 shows that WAPA has enough SLCA/IP hydropower capacity to meet its SHP capacity obligation of 721.4 MW about 91% of the time. Therefore, WAPA's current capacity risk is at about the 90% exceedance level.

K.1.7.4 Firm Capacity Curves for LTEMP Power Systems Analyses for the Peak Month of August

Similar to the above assessment of risk for the CRSP Management Center, exceedance curves were constructed to analyze risk levels associated with firm capacity used for SLCA/IP system reserve margin calculations. The left panel of Figure K.1-32 shows the marketable capacity for the seven primary alternatives at exceedance levels ranging from 10% to 99% for

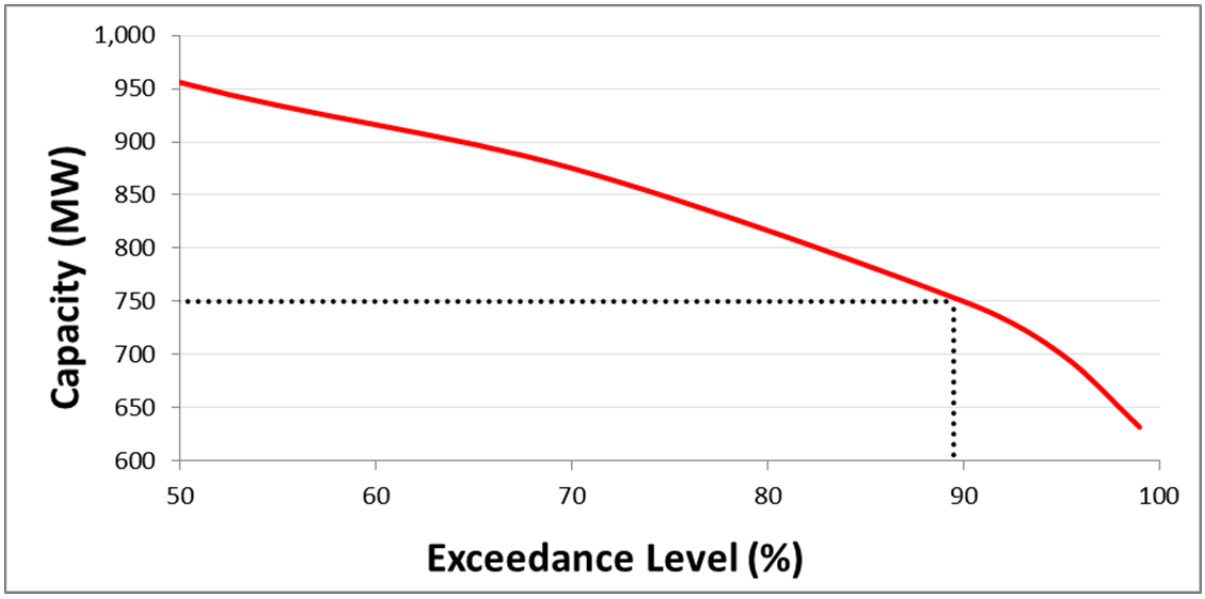


FIGURE K.1-30 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in July

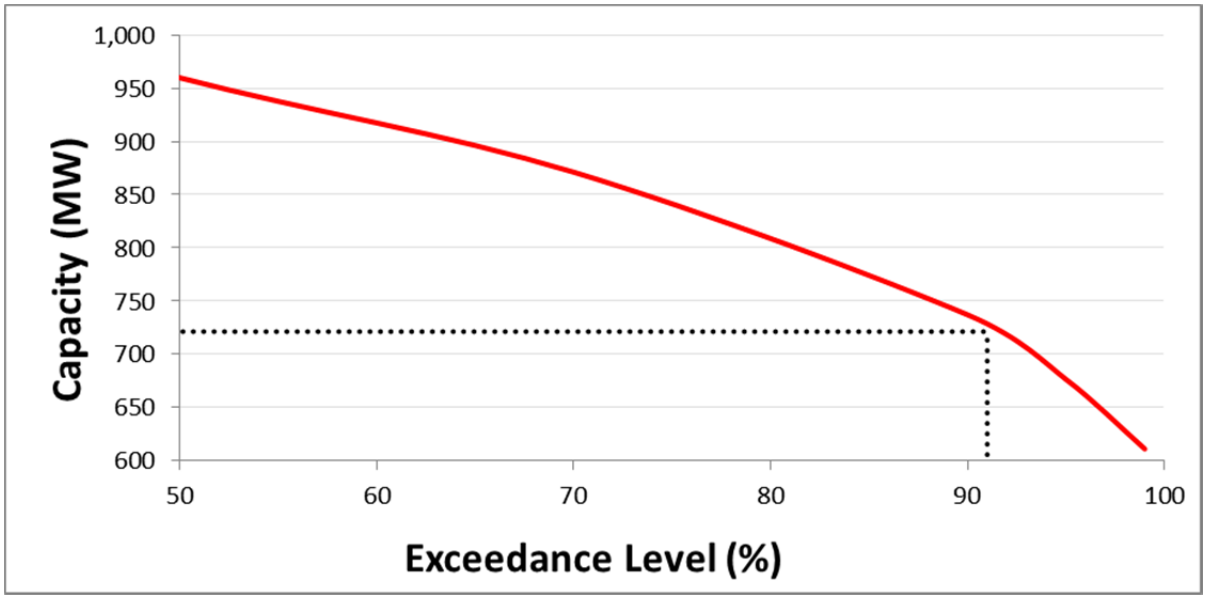


FIGURE K.1-31 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in August

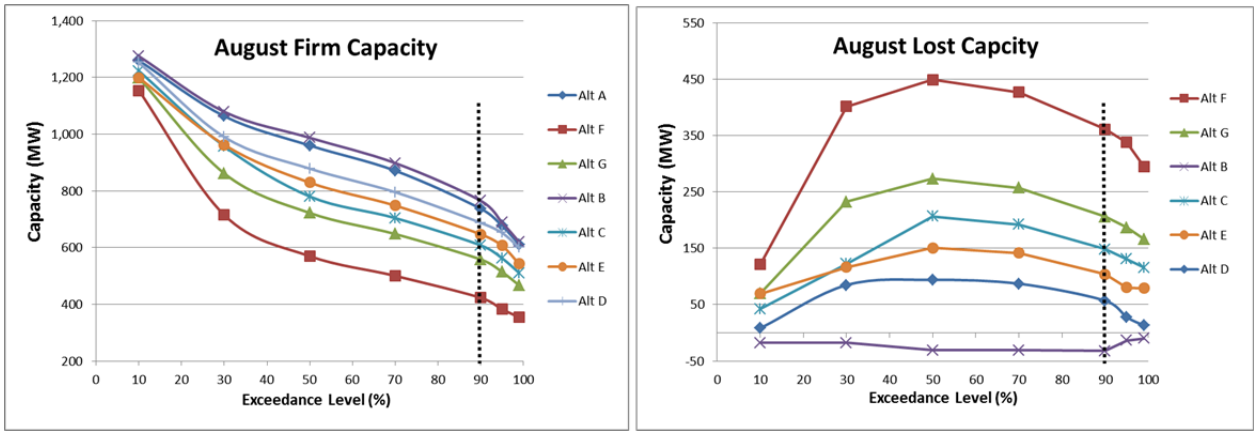


FIGURE K.1-32 Comparison of Firm Marketable Capacity Determinations across Alternatives, Exceedance Levels, and Summer Peak Months

combined SLCA/IP federal hydropower resources. These results assume that the peak system load will occur in August. All alternatives except for Alternative B have less firm capacity at all exceedance levels than Alternative A; this is expected, however, because Alternative B has the least restrictive operating restrictions of any alternative.

Under the assumption that the peak load occurs in August, the right panel of Figure K.1-32 shows the difference in firm capacity compared to Alternative A. The graphs show that the greatest difference in capacity occurs at the 50% exceedance level and the smallest at the 99% exceedance level. Based on the current CRSP Management Center risk exposure of 10%, the determination of firm capacity for all LTEMP alternatives will also be based on this risk level. Note that the results reported in Chapter 4 of the main document also assume a 10% risk level (90% exceedance level) for a peak load that is anticipated to occur in August. However, WAPA has no obligation to use this exceedance level when setting future LTF capacity offers to its preference customers; therefore a sensitivity analysis that uses a range of exceedance levels was conducted. The results of the analysis are presented in Section K.1.10.4.

The power systems methodology assumes that lost Glen Canyon Dam Powerplant capacity replacement costs due to more stringent operating criteria under an alternative will be assessed at the systems level.

The costs of past expenditures to build a powerplant, including the Glen Canyon Powerplant, cannot be altered. Therefore, capital investment differences among alternatives for these facilities are zero. Similarly, fixed O&M costs are assumed to be unaffected by any of the alternatives because retirement schedules and powerplant improvements are assumed to be static. It is also assumed that the total physical 1,320 MW of nameplate capacity at Glen Canyon Dam is identical under all LTEMP EIS alternatives, and that the capacity of all powerplant units will not change over the study period. Therefore, the only differences in the economic cost of capital and fixed O&M costs among alternatives is due to changes in capacity expansion pathways. The sections below describe the method that is used to determine these pathways.

Capital costs only factor into LTEMP EIS economic calculations for capacity expansion units because the retirement schedule of existing units and the online date of committed units does not change among alternatives; therefore, the economic cost difference between Alternative A and other alternatives is equal to zero. Fixed O&M costs only factor into LTEMP EIS economic calculations for capacity expansion units because the retirement schedule of existing units and online dates for committed units do not change among alternatives; therefore, the economic difference of these "fixed" costs between Alternative A, which serves as a reference point, and other alternatives is equal to zero.

K.1.7.5 AURORA Capacity Expansion Reserve Margin Targets and Capacity Additions

The AURORA model was used as a tool to aid power system modelers and analysts at Argonne in finding reasonable capacity expansion plans for each LTEMP alternative using the topology previously shown in Figure K.1-3 and described in Section K.1.5.9. This section provides more details on how it was used for capacity expansion. The network topology shown in Figure K.1-3 consists of two power pools. Pool A is made up of all SLCA/IP hydropower resources and WAPA's eight large customers. Pool B consists of the aggregate of WAPA's small customers and all project use loads.

The network was modeled as two power pools for the purpose of calculating a system reserve margin. WAPA's eight large customers and hydropower resources were put into Pool A because these customers (except for NTUA) satisfy their loads from a combination of their own generation, generation owned jointly with another large customer(s), WAPA firm hydropower allocations, bilateral contracts, and market purchases. Customers in Pool B have no generation and serve loads only through WAPA firm hydropower allocations, bilateral contracts, and market purchases. It is assumed that customers in Pool A would satisfy their combined reserve margin by constructing new generation. Customers in Pool B would satisfy their reserve margin by making individual purchases from large Pool A customers and from the Western Interconnection market transactions.

The model builds new units when the capacity reserve margin of the aggregate SLCA/IP system, which includes WAPA and all of its LTF customers, would otherwise drop below 15%. Based on a review of utility IRPs in the Western Interconnection, it was found that a 15% reserve margin is a typical capacity expansion goal. This value was therefore used as a reserve margin goal for the LTEMP power systems analysis.

Capacity that is credited toward the reserve margin frequently differs from the rated nameplate capacity, because the maximum output from the powerplant may differ from the rated level. For example, a high atmospheric temperature typically reduced the maximum output from gas-turbine technologies. Therefore, the firm capacity that is used in the reserve margin calculation is less than the nameplate capacity if the system peak load is expected to occur during a hot summer afternoon. The firm capacity that is given to VERs can be very complicated. It is often based on system-level reliability calculations that determine an equivalent "100% reliable" capacity that yields the same loss-of-load probability as the VER.

The power system analysis uses an estimate of firm capacity for all existing and new units instead of the nameplate capacity. In some cases, this requires that sometimes the nameplate capacity is significantly derated. For example, it is assumed that the firm capacity credit of new solar and wind farms is only 10% of the nameplate capacity. This is the default used by AURORA. The firm capacity of WAPA's SLCA/IP hydropower resources that is credited toward this system reserve margin was described in Section K.1.7.4. In addition, as noted previously, only the daily capacity of Glen Canyon Dam differs among alternatives.

Figure K.1-33 provides a simplified illustration of the impact of the firm capacity credit at Glen Canyon Dam on the timing of new construction to meet future loads and the reserve margin target. Two cases are shown in this example for illustrative purposes only. Under Case 1, Glen Canyon Dam has a larger firm capacity and Case 2 has a smaller credit. The orange line shows the annual coincidental peak load for the system. Because WAPA's firm allocation is non-contingent, that capacity amount can be subtracted from the system peak load before calculating the reserve margin. The reserve margin is then applied to that resulting curve to obtain a revised load curve that includes the required reserve margin. This curve is then compared with the capacity in Pool A to determine where they intersect. The year in which they intersect is when

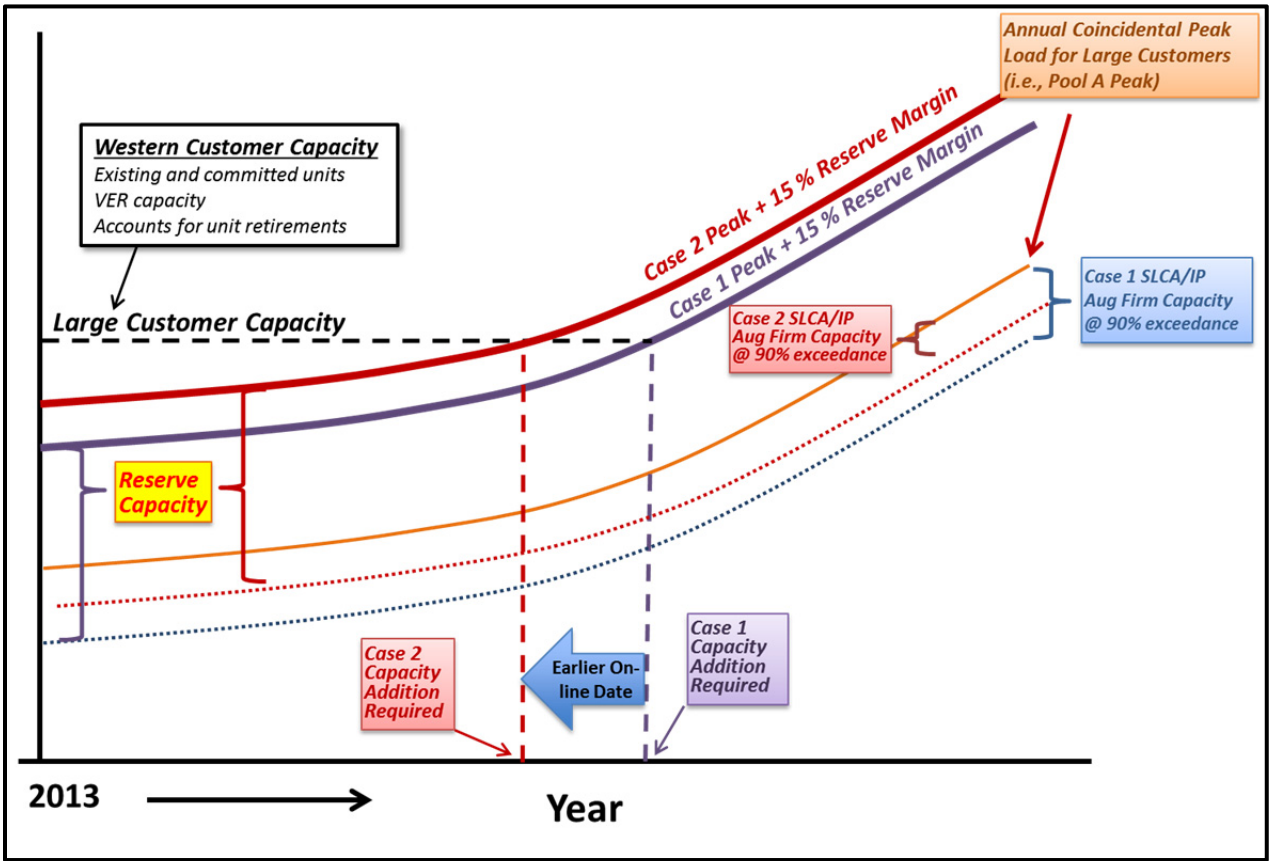


FIGURE K.1-33 Timing of Capacity Additions in AURORA

new capacity is needed to meet the reserve margin. The graph shows that Case 2 needs new capacity before Case 1 because WAPA's firm capacity credit under Case A is smaller.

To reliably serve projected load growth, fossil and non-fossil generation units are constructed by AURORA. AURORA also sheds load at specified market price trigger points.

Capacity shortfalls that remain after complying with renewable resource expansion goals specified in each utility's IRP are resolved by building new electric generating units from a list of candidates. The cost and characteristics of candidate technologies for future capacity expansion that were used for power systems analysis were provided in Table K.1-1. These technologies and associated attributes and costs were based for data found in EIA's 2014 AEO (EIA 2014).

The AURORA capacity expansion feature was used to guide the selection of a plausible capacity expansion plan for the SLCA/IP system. The methodology utilized models the expansion path for an aggregate eight large customer pool labeled "Pool A" in Figure K.1-3. The expansion plan determined under each alternative meets a 15% target reserve margin for pool A (large customers and SLCA/IP federal hydropower resources), plus additional capacity to replace lost Glen Canyon capacity that is allocated to small customers. Under an alternative, large customers therefore replace the entire lost capacity even though only a portion (i.e., about 75% under current SLCA/IP LTF capacity allocations) of this lost capacity would contractually affect these larger utilities. Small customers pay for this capacity by purchasing it from the large customers via LTF contracts.

Because the AURORA model builds capacity for the "joint system," it implicitly assumes that a capacity shortfall in one customer utility system could be temporarily fulfilled by another utility that has excess. Conceptually, this could be achieved via a short-term firm bilateral capacity contract between the two systems, thereby delaying a physical capacity addition by the utility that is "short" capacity. For example, because small customers would most likely not build capacity in the future, it was assumed the lost capacity allocated to these small utilities (i.e., about 25%) would be replaced via the capacity expansion pathways of the aggregate eight large systems (Pool A).

The modeling approach used simplifies reality because currently, there is no centralized energy or capacity market in the region of the Western Interconnection where SLCA/IP federal hydropower resources and WAPA's LTF customers are located. Capacity expansion decisions and energy transactions in this area are done autonomously to meet the objectives of each independent utility. In addition, each utility has limited information about the entire grid and the independent actions/decisions made by other entities in the system. In contrast, the AURORA mode assumes "perfect" information about the entire system to optimize a system-wide objective and builds new powerplants to meet the pool-level reserve margins, not to serve the objectives of each independent utility.

The "joint system" capacity expansion model therefore assumes a level of cooperation and coordination that currently exceeds current-day practices. However, it would be unrealistic for each individual utility to build capacity independently. Only a few customers own capacity;

most rely solely on purchasing capacity and energy resources from other utilities to serve all of its load requirements. Also, it is not uncommon for utilities in the region to cooperate. For example, some of the large customer utilities that own capacity have jointly built generating resources. For example, Salt River Project, Platte River Power Authority, and Tri-State G&T all have joint ownerships in both Units 1 and 2 at the Craig plant. The Salt River Project partly owns Unit 2 at the Hayden Plant. Also, Desert and UAMPS have ownership shares in Hunter Unit 2, and Desert and UMAP have joint ownerships in both Units 1 and 2 of the Bonanza power plant.[1] These cooperative ventures have benefited all parties involved, because a large plants is less expensive to build on a $/MW basis than several smaller ones.

Another modeling simplification is that transmission capacity limits were not considered in the AURORA model topology. It was assumed that capacity replacement would be built by customers at locations such that power injections did not create additional transmission congestion. It should also be noted that Glen Canyon Dam output under all alternatives except Alternative B tend to be lower during critical times of daily peak load, thus freeing some transmission line capacity that could potentially be used to transfer power among customers. Under most alternatives, generation at Glen Canyon tends to be higher during off-peak hours, but transmission congestion is normally minimal during these times. In addition, WAPA customers can also take advantage of customer displacement power (CDP) that allows customer utilities to use WAPA's transmission lines up to CROD levels when lines are not congested. Lastly, EIS power transfers among customers account for transmission costs that tend to dampen energy transactions among utilities. These costs are included in both AURORA capacity expansion and dispatch model runs.

The two modeling simplifications discussed above regarding utility cooperation and transmission may potentially underestimate capacity expansion costs. For example, a customer utility may decide to add capacity instead of making a short-term firm capacity purchase and/or reject CDP for long-term planning purposes based on reliability considerations. Underestimates, however, would occur under all alternatives, including Alternative A. Therefore, these errors tend to either cancel out or be significantly reduced because the power systems analysis uses a comparative analysis that focuses on the difference between Alternative A and another alternative, not the absolute value of each alternative independently. Also, the methodology is based on the economics of the entire system. Financial transactions among individual utilities, such as short-term firm capacity purchases and sales, are considered.

As discussed previously, new units are constructed when the capacity reserve margin of the aggregate system would otherwise drop below 15%. Additions are made in unit capacity increments resulting in a plan that has a "lumpy" reserve margin time series. The reserve margin requirement (i.e., modeled as a "hard" constraint) also produces a solution that almost always exceeds the 15% target. These relatively small excess capacities that fluctuate over time are beneficial to the system dispatch and production-cost economics. Although most analyses would assume that this excess capacity has no value, it could potentially be sold to a neighboring utility outside the SLCA/IP marketing area, thereby reducing expansion costs. A simple post-model

[1] It should be noted that there are several other joint ownerships in addition to those described in this paragraph.

sensitivity study was performed that assumed this capacity could be sold. The results of the study are reported later in this appendix.

Depending on AURORA model parameters and run settings, the expansion plans suggested by AURORA can be considerably different for Alternative A, and, in many instances, add significantly more generating units than the number required to maintain a 15% reserve margin. This in part stems from the fact that the optimization problem AURORA attempts to solve is extremely difficult to find. After discussion with EPIS staff and examinations of expansion results, Argonne concluded that new capacity addition decisions made by the model are based on financial objects rather than a single global economic objective. AURORA builds a new unit if it is financially attractive. The end result is a realistic expansion path. However, solutions that focus on local unit additions that are financially viable based on the NPV of costs and revenues over the study period result in expansion pathways that often differ from the one that costs the least over the entire multi-utility system.

Given the size of the modeled SLCA/IP area, the focus/capabilities of AURORA, and Argonne staff skill level in the use of the model, finding the global least-cost economic solution for Alternative A is intractable; that is, Argonne could not mathematically prove that any one of the many solutions produced by AURORA was the global least-cost solution. It was also judged that the mathematical optimum path would most likely not be found within a reasonable amount of time and effort (i.e., several weeks or months). Given this modeling limitation, however, the technologies selected by AURORA consistently indicated that combustion turbines (CTs) and natural gas-fired combined cycle units will be constructed in the future. This solution is consistent with available IRPs that Argonne reviewed for SLCA/IP large customers and several large systems (typically investor-owned utilities) that neighbor the SLCA/IP marketing area. A summary of these IRPs is shown in Table K.1-6 (see Table 2 of Attachment K.9 for additional information). More detailed information about these IRPs is provided in Attachment K.9.

It should be noted that the methodology only represents SLCA/IP physical assets and production levels. It does not reflect changes in SLCA/IP contract that may be implemented in October 1, 2024, or financial implications as they affect WAPA and individual customers. This topic will be discussed in the Wholesale Rate Analysis section.

K.1.7.6 Dispatch Performed by AURORA Model Capacity Expansion Runs

The methodology used represents all of SLCA/IP hydropower energy assets in the AURORA model to measure the economics of changes in Glen Canyon Dam operating criteria. GTMax-Lite and customized small SLCA/IP resource spreadsheet results provide AURORA with alternative-specific SLCA/IP dispatch and an hourly schedule of energy injections into the power grid. By doing so, AURORA recognizes the basic role of hydropower resources as they affect the dispatch of the SLCA/IP system and energy transactions with the Western Interconnection.

Due to the complexities of SLCA/IP hydropower operating criteria and non-power considerations, AURORA could not model the dispatch of these resources at the level of detail

TABLE K.1-6 Summary of Utility IRPs for Four Large SLCA/IP Customers and Other Large Utilities in Areas Neighboring the SLCA/IP System

Utility	Utility Type	Type of Generation Added	When Added	Capacity Added (MW)
Public Service of CO	Investor	Gas Turbines	2018 to 2022	1,211
	Owned	Combined Cycle	2023 to 2032	1,929
Public Service of NM	Investor	Gas Turbines	2016 to 2033	736
	Owned	Solar PV	2015 to 2022	283
Rocky Mountain Power	Investor	Combined Cycle	2014, 2024	645, 423
	Owned	Wind	2024	432
Arizona Public Service	Investor	Natural Gas (unspecified)	2019 to 2029	4,200
	Owned	Renewable (unspecified)	2019 to 2029	425
Tucson Elect. Power	Investor	Natural Gas (unspecified)	2015 to 2028	1,214
	Owned	Renewable (unspecified)	2014 to 2028	529
Nevada Power Company	Investor	Combined Cycle	2018 to 2024	3,813
	Owned	Gas Turbines	2023 to 2032	2,043
		Solar PV	2016 to 2021	50
Sierra Pacific Power	Investor	Gas Turbines	2023 to 2029	1,975
	Owned	Combined Cycle	2025	571
Platte River Power	WAPA Customer	Gas Turbines	2021	Unspecified
Colorado Springs Utilities	WAPA	Gas Turbines	2029 to 2031	39
	Customer	Renewable (unspecified)	2018 to 2029	20
Tri-State G & T Assn.	WAPA	Combined Cycle	2019 to 2026	1,176
	Customer	Renewable (unspecified)	2016 to 2027	350
Salt River Project	WAPA Customer	Natural Gas (unspecified)	FY2018+	Projected 581-MW gap in 2017

required for this study. Instead, powerplant-specific hourly production levels were projected over the study period using the previously discussed two GTMax-Lite model configurations and the Small SLCA/IP Powerplants Spreadsheet. Energy injections into the system from Glen Canyon Dam are based on average hourly GTMax-Lite results over all 21 hydrology traces from the SBM. Hourly energy injections from all other large SLCA/IP resources are based on GTMax-Lite results, which use average monthly hydrological conditions over the 21 hydrology traces produced by CRSS. Last, energy injections from small SLCA/IP hydropower plants are based on average historical conditions reported in Form PO&M-59.

Annual CY energy generation for Glen Canyon Dam and all other SLCA/IP hydropower resources combined are shown in Figure K.1-34 under Alternative A. Annual generation from the Glen Canyon Dam Powerplant averages about 4,114 GWh, and ranges from about 3,665 GWh to 4,338.2 GWh. The lowest generation value occurs in 2013 due to low initial reservoir elevations that were observed at the end of CY 2012. That is, because the simulation starts out at a point in time when the Glen Canyon Dam reservoir is low, water releases tend to be less since more water is retained in the reservoir in an attempt to increase the water storage level. On average, Glen Canyon Dam is expected to account for about 72% of the total annual SLCA/IP hydropower generation. Because annual WY releases are nearly the same under all

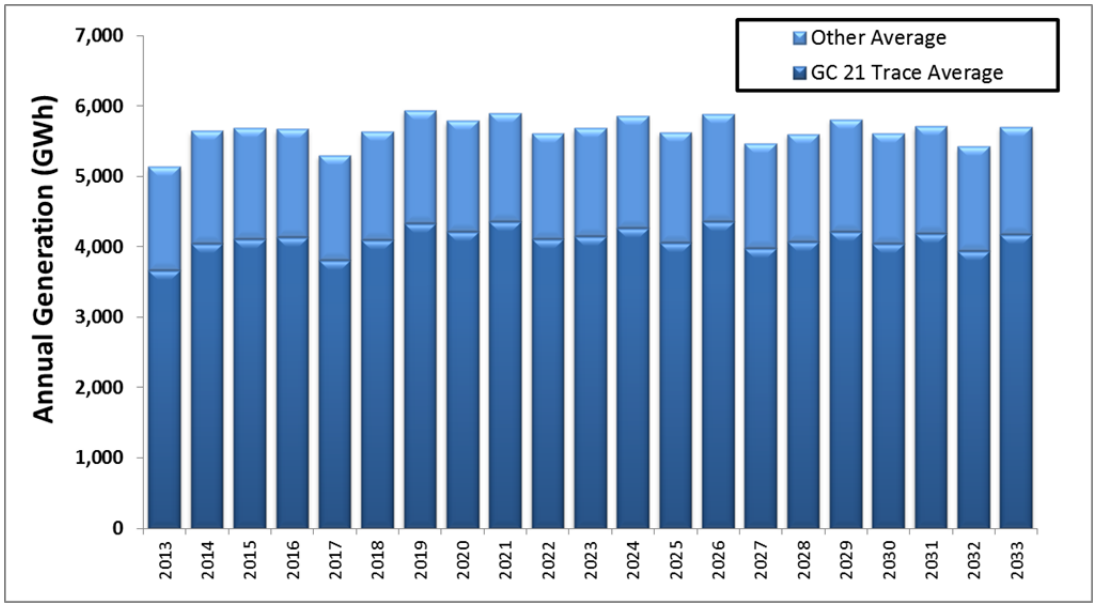


FIGURE K.1-34 Annual Average Hydropower Generation for the Glen Canyon Dam Powerplant and the Aggregate Generation for All Other SLCA/IP Resources

alternatives, total CY annual generation levels for all alternatives are within about 1.7% of Alternative A. Those alternatives that have more HFEs tend to have lower annual average generation levels. This topic will be discussed in more detail in Section K.1.10.

Although annual Glen Canyon Dam generation levels are similar among alternatives, the monthly distribution of generation within a year is substantially different among alternatives. Projected monthly generation produced by other SLCA/IP hydropower resources is essentially identical under all alternatives. Figure K.1-35 shows that alternatives such as Alternatives A and B have high Glen Canyon Dam average daily generation levels during the peak summer months when marginal energy production costs are relatively expensive. These energy levels produce higher economic values than those with lower summertime generation levels, such as Alternative F.

Interactions between all entities in the SLCA/IP marketing area and the rest of the Western Interconnection are represented by a single point where non-firm hourly energy transactions occur. This point, labeled "Spot Market" in Figure K.1-3, contains an inelastic time vector of market prices for system energy purchase and sales.

Power transfers between utilities and the Western Interconnection node incur a charge that varies by on-peak and off-peak periods. All purchases and sales that a customer makes incur an additional transfer cost that also varies by on-peak and off-peak periods. The eight large customer utilities and small customers only purchase energy from the spot market node; spot sales are not possible. This assumption was made to ensure that the SLCA/IP system would not construct capacity on a speculative basis for the purpose of selling energy to the Western Interconnection; that is, it constructs capacity primarily for internal purposes. Because the

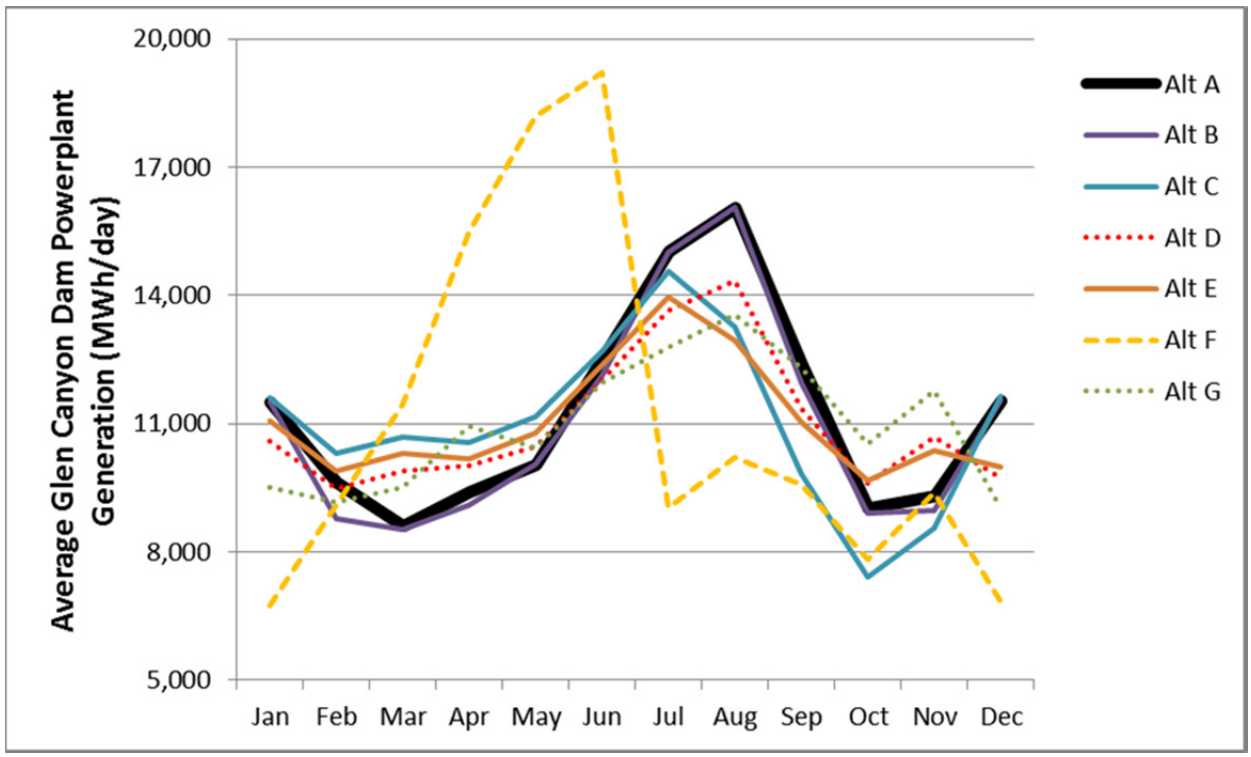


FIGURE K.1-35 Average Daily Glen Canyon Dam Powerplant Hydropower Generations by Month Based on the Average of All 21 CRSS/SBM Hydrology Traces

Western Interconnection prices tend to be more expensive than production costs in the SLCA/IP system, purchases from the Western Interconnection tend to be small. However, the Western Interconnection energy was made available for purchase by the SLCA/IP systems in situations where internal production costs became expensive. In addition, reserve margin requirements were configured to exclude Western Interconnection purchases as a source of firm capacity. Therefore, the SLCA/IP system is prevented from leaning on the Western Interconnection for capacity during times of peak load.

Depending on the customer's location, loads and resources are designated as east or west regional entities. Energy flows among entities via system linkages. Some links have limitations and/or associated costs. Energy flows on links connecting SLCA/IP resources to WAPA's customer loads. Limits on energy transfers on those links represent customer CROD allocations. Under hydrological conditions in which SLCA/IP total generation exceeds the total CROD, the excess energy flows on links that represent WAPA's shorter-term energy transactions with its LTF customers.

Very small cost premiums are placed on some connections to represent WAPA's service priorities and to roughly approximate energy flows. Energy generated by Glen Canyon Dam is transmitted to loads in the following priority order: (1) project use in the west region, (2) project use in the east region, (3) LTF customers in the west region, and (4) LTF customers in the east region. The higher the priority, the lower the power delivery cost; that is, the lower the assigned

link cost. Energy flow priorities for other SLCA/IP resources mirror the Glen Canyon Dam pattern. The priority order for SLCA/IP resources other than Glen Canyon Dam is (1) project use in the east region, (2) project use in the west region, (3) LTF customers in the east region, and (4) LTF customers in the west region.

Figure K.1-3 also shows that an LTF customer has direct connections to all other LTF customers in the region where the customer resides. These connections are used for energy transactions but are subject to transmission costs of $3.5/MWh during off-peak hours and $6.5/MWh during on-peak hours based on historical information provided by WAPA. This topology/configuration assumes a higher level of cooperation and coordination among WAPA and its customers than what actually occurs. However, WAPA and its customers do buy and sell energy via both day-ahead and hour-ahead bilateral agreements using market signals, insights, and data such as that provided by ICE as a guide. Also, energy transfer costs among LTF customers dampen power transfer levels relative to a centralized market arrangement, such as a regional transmission operator (RTO) market, which does not incur these transmission costs in the system dispatch. The resulting system dispatch for large customers is consistent with historical operations as shown in see Figure K.1-14).

K.1.7.7 Rationale for the Selection of Hydrology Conditions Used for Capacity Expansion Runs

The low hydropower condition of 90% exceedance used to select SLCA/IP hydropower capacity credits is fairly conservative because the system is slow to respond to capacity shortfalls. New units take a relatively long time (years) to plan/engineer, permit, construct, test, and eventually bring online. Therefore, if insufficient capacity is built, the system may experience years of unacceptably high reliability risks when hydrology/hydropower capacity is low.

On the other hand, average energy conditions are used for power injections into the grid for capacity expansion modeling because the system quickly adapts to various hydrological situations through system dispatch and short-term energy transactions (e.g., purchases when hydropower energy production is below normal). Although it does not provide an exact estimate of energy economics, given all of the other uncertainties involved with long-term projections, an average hydrological condition provides a good approximation of the *relative* economics among the enormous number of capacity expansion pathways that are theoretically possible for the SLCA/IP study area.

K.1.8 Glen Canyon Dam Energy Economic Benefits Methodology

The Glen Canyon Dam Powerplant generates large amount of energy that yields significant economic benefits to the grid. It serves SLCA/IP market system demands and this system responds/reacts to its powerplant operations. Therefore, the economic impacts of changes in Glen Canyon Dam operations are measured for the system as a whole by computing SLCA/IP market system operating costs. On the production side, costs include energy production costs that

are comprised of fuel expenditures, variable O&M costs, and unit startup expenses. Costs are also incurred to deploy price-sensitive loads. The AURORA model run in dispatch mode was used to estimate production levels and associated costs for each generating unit and DSM program in the SLCA/IP market system during the study period.

AURORA dispatch mode computations are based on a given set of resources, as previously determined by AURORA runs that were made in capacity expansion mode. Hourly SLCA/IP federal hydropower production input into AURORA is based on GTMax-Lite runs for Glen Canyon Dam and the other five large hydropower plants. These runs adhere to all physical and institutional operating criteria, including those needed to supply project use loads and fulfil ancillary service requirements. Energy costs for each LTEMP alternative are computed as the difference between the AURORA dispatch results for Alternative A and another alternative.

The LTEMP EIS affects the system-level operating costs and therefore energy economics because operating criteria bind the timing and routing of water releases through Glen Canyon Dam. From a system dispatch perspective, power produced by the Glen Canyon Dam Powerplant yields the highest economic benefits when the limited amount of water it releases during a WY is routed through the powerplant's generating turbines to produce power that either displaces energy generation or demands curtailment from expensive grid resources. For example, Glen Canyon Dam has a high economic value when the energy it produces reduces or eliminates the operation of an old, inefficient gas turbine with high production costs. On the other hand, it has a much lower value when it displaces low-cost power generation. As discussed earlier, LMPs that are specified at the Western Interconnection spot market node interface represents Western Interconnection marginal cost production savings when it purchases power from the SLCA/IP market system. On the other hand, when the SLCA/IP market system buys from the Western Interconnection, operating costs of the system are reduced, but it pays for the purchase at the LMP price. For the LTEMP EIS, these prices were determined by the Western Interconnection model run and a scaling algorithm applied to the Palo Verde market hub. Purchases are only made when the LMP is less expensive than the incremental cost of both power production and DSM deployment.

The average annual energy produced by the Glen Canyon Dam Powerplant varies by less than 2% among alternatives. However, at varying levels of stringency, alternative criteria bind the daily and hourly operational flexibility at Glen Canyon Dam and affect both Lake Powell monthly reservoir elevations and Glen Canyon Dam monthly water release volumes. One of the primary differences between the AURORA dispatch in capacity expansion mode and when AURORA is run in dispatch mode is the hydrological information used for SLCA/IP federal hydropower conditions. When run in dispatch mode, the AURORA model uses GTMax-Lite results for Glen Canyon Dam and the other five large SLCA/IP federal hydropower plants, based on hydrological information for the representative trace. As shown in Figure K.1-36, average annual SLCA/IP federal hydropower plant generation for the representative hydrology trace (i.e., Trace 14) used for economic dispatch runs is significantly different from that used for AURORA capacity expansion runs, shown in Figure K.1-33. It should be noted that there is significantly more generation volatility in Glen Canyon Dam Powerplant energy production used for economic dispatch runs. The lowest annual Glen Canyon Dam generation level using Trace 14 is 2,781 GWh, which occurs in CY 2015. Generation under that same trace is

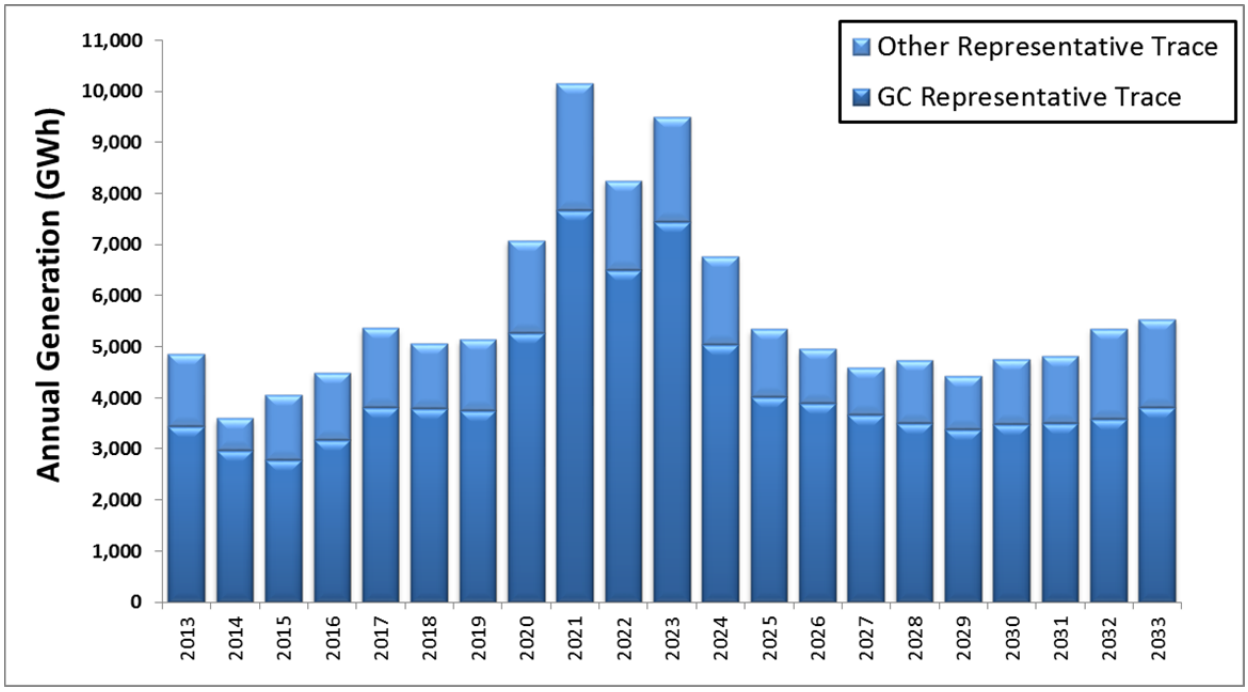


FIGURE K.1-36 Average Annual Glen Canyon Dam Powerplant Generation for the Representative CRSS/SBM Hydrology Trace

7,677 GWh in CY 2021; therefore, those years differ by a factor of about 2.7. This is consistent with historical volatility levels. As described in Section K.1.2, Glen Canyon Dam Powerplant annual generation varied by a factor of 2.6 between CY 1980 and CY 2013.

Trace 14 average daily generation over the LTEMP period produced by the Glen Canyon Dam Powerplant by month is shown in Figure K.1-37. These values are similar to the ones used for the AURORA capacity expansion runs shown in Figure K.1-34. It is one of the attributes of Trace 14 that make it "representative."

As described in more detail in Section K.1.10, the combination of LTEMP operating criteria, Glen Canyon Dam monthly water releases volumes, SLCA/IP market system loads, and spot market LMPs drive EIS differences in economic dispatch cost among alternatives. The system-level dispatch methodology for computing energy economic costs captures the following key aspects of EIS alternative operating criteria:

- Marginal dispatch costs at a location to serve loads increase as the system load-level increases. Resources with low costs are dispatched first. As the load increases, more expensive resources are dispatched to balance the supply and demand.

- The Glen Canyon Dam energy value is based on SLCA/IP market system cost reduction as a consequence of powerplant energy injections into the grid.

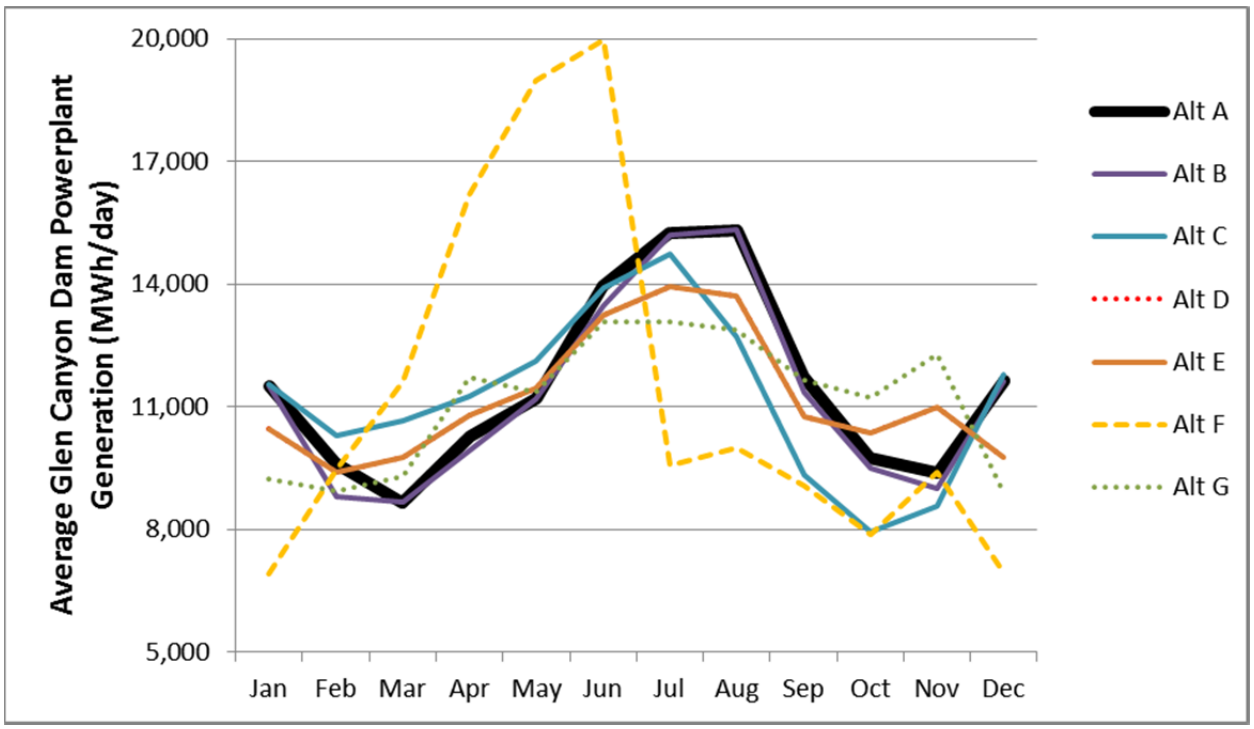


FIGURE K.1-37 Representative Trace Average Daily Glen Canyon Dam Powerplant Generations by Month

- Over short-term operations such as daily and weekly dispatch, energy economic differences among alternatives are highly dependent on operational flexibility allowed under the alternative and the marginal production cost and LMP spread between off- and on-peak periods. If costs and prices are always the same, operational criteria would have minimal impacts.

- On an annual timeframe, energy economic differences among alternatives are dependent on the correlation of monthly water release volumes to monthly marginal production costs and LMP. Alternatives with a positive correlation have a much higher energy economic value than those with a negative correlation. The larger the monthly price and cost spreads, the greater the economic cost of the alternative. If costs and prices are always the same, monthly water release volumes would have minimal impacts.

- Unlike daily, weekly, and monthly economic differences that are a function of price/cost spreads, economic differences from HFEs are a function of absolute energy price/cost levels. Some water bypasses the turbines because the required HFE flow rate can exceed the turbines' maximum flow capability. Water that bypasses the turbines does not generate electricity for sale to customers and therefore has zero power value.

K.1.9 Net Present Value Calculations and Study Period Adjustments

As described in previous sections, all costs input into GTMax-Lite and AURORA are expressed in 2013 dollars. For many of these inputs, this required that input values reported in the literature be converted to 2013 dollars. For example, the cost of candidate technologies for new construction was expressed in terms of 2012 dollars. The index used for dollar conversion is application specific. Attachment K.10 provides more information on the dollar year conversion process.

By expressing all present and future cost inputs in terms of real dollars, the effects of inflation are removed from all AURORA model calculations. Therefore, for each year all costs projected by the model are measured on a common and consistent basis. However, LTEMP EIS alternatives incur different levels of cost at different times over the study period. Therefore, to account for the time value of money in which the present worth of money is typically, but not necessarily, higher today than the same amount of money in the future, the NPV of all costs are calculated to facilitate a common point in time for cost comparisons among alternatives. The process of discounting is used to make costs that occur at different points in time commensurate with each other.

The NPV computation takes a chronological stream of values over time and discounts each one to a specified point in time based on a defined discount rate. These values are then summed. Although the mechanics of the discounting process are very straightforward, the magnitude of the discount rate greatly influences the degree to which future costs and benefits "count" in the decision. As a result, the choice of discount rate is the subject of much debate. For the LTEMP EIS, NPV calculations are based on a discount rate of 3.375%. The use of this discount rate was in part based on information contained in Attachment K.4, which was provided by Reclamation staff. At the recommendation of WAPA staff, a second discount rate of 1.4% was used in a sensitivity study.

Because of discounting, the NPV calculation places more importance on near-term economic costs as compared to those that occur in the more distant future. For example, a dollar cost incurred during the first year of the study period has a $1 NPV impact. However, at a 3.375% discount rate, the same dollar impact in the 20th year of the analysis has only a $0.5322 impact (i.e., slightly more than half) on the NPV. The selection of the representative trace does not consider the discount effect on NPV outcomes. It may be important, however, because the energy costs of an alternative are sensitive to hydrological conditions. The selected representative hydrology trace starts out dry, becomes very wet in the middle of the period, and by the last few years it returns to a dry condition. All other factors constant, the NPV calculation would yield a different value if the sequence of dry, average, and wet hydrological conditions differed from Trace 14. A sensitivity analysis of the impacts of the sequence of hydrological conditions on EIS energy NPVs would help quantify the range of possible outcomes.

All detailed model calculations were made and expressed in 2013 dollars. This was in part due to CRSS and SBM, which used the beginning of CY 2013 as a starting point. Cost was computed over the 20-year length of the long-term experiment: a period that begins at the start of CY 2013 and ends at midnight on the last day of CY 2032. However, to be consistent with other

EIS disciplines, the power system analysis period was directed by project co-leads to cover CY 2015 through CY 2034 and express all costs in terms of 2015 dollars. The request was made at a point in the modeling process when all model runs, computations, and most aspects of the analysis had been completed. It was therefore necessary to make adjustments to the CY 2013 to CY 2032 results. The power systems team and co-leads agreed that the following adjustments were reasonable given time and budget constraints.

1. All energy costs were shifted by 2 years. That is, CY 2013 energy costs were assumed to take place in CY 2015 using Trace 14 hydrology for CY 2013, energy costs in CY 2014 were assume to occur in CY 2016, and so on.

2. The energy costs were then adjusted to account for real changes in energy prices over time. This was accomplished in a two-step process. First, an energy price index benchmarked to 2013 dollars was computed. The index is based on the yearly average energy cost to serve load from the AURORA SLCA/IP market systems model. This index was then applied to the shifted energy costs from step 1 for all years. For example, because energy prices in real 2013 dollars decreased during CY 2013 to CY 2015 timeframe (according to AURORA and in actuality), the costs are adjusted downward using the AURORA-generated energy price index. The end result is chronological annual costs from CY 2015 through CY 2034 in beginning year 2013 dollars.

3. The energy cost time series is then converted to 2015 dollars using a general price index. For this analysis, the seasonally adjusted GNP IPD was applied to the 2013 dollars (see Table 1 in Attachment K.10).

4. The capital cost dollar for new unit construction from the EIA's 2014 AEO (EIA 2014) expressed in nominal 2012 was adjusted to beginning year 2015 dollars using the "Powerplants" index contained in Reclamation (undated). Fixed O&M costs were converted to 2015 dollars used the same table, except that the "Powerplant Accessory elect. & misc. equip" index was used.

5. No adjustments were made to the online dates of new units constructed to the study period, because the capacity reserve margin was greater than 15% in 2015 under all alternatives. However, because the analysis period is shifted, there were no AURORA capital or fixed O&M cost computations for the last 2 years. Therefore, average cost values over the last 5 years of the AURORA model run were assumed for CY 2033 and CY 2044.

6. The stream of all future costs are discounted to beginning year 2015 at an annual discount rate (i.e., 3.375%) specified by the Reclamation for cost-benefit studies of projects.

A final EIS and ROD will not be completed until after WY 2015. The reader should recognize that the economic analysis for electrical power systems is sensitive to the years that are modeled. Currently, the region affected by a change in the operation of Glen Canyon Dam is in

"capacity surplus." This means that generating capacity in the affected region currently exceeds peak electrical demand more than is necessary to achieve an acceptable level of reliability. However, a growing regional economy and population will soon cause electrical demand to catch up to supply. Depending on the actual ROD implementation date, the SLCA/IP market system and the Western Interconnection may need to build additional capacity above committed levels before completion of the ROD.

K.1.10 Power Systems Results

This section details the results of the power systems analysis, focusing primarily on total SLCA/IP market system costs under each alternative relative to Alternative A. It also describes the sensitivity studies that were performed to test the robustness of model results and analysis conclusions. One set of sensitivity studies was on the risk preference or exceedance level that is used to determine SLCA/IP federal hydropower firm capacity. The results in the main EIS were based on a 90% exceedance level. This section presents power system results for exceedance levels of 50% and 99% to reflect the possibility of WAPA considering different risk levels in future marketing efforts.

Another sensitivity study was performed on discount rate. The discount rate used in the main EIS was 3.375% because the Bureau of Reclamation is required to employ an administratively determined discount rate known as the federal plan formulation and evaluation rate, when undertaking economic analyses of water resource and related matters pursuant to 42 U.S.C. 1962d–17. The plan formulation and evaluation rate for fiscal year (FY) 2015 is 3.375% (Reclamation 2014a,b). This section will show how power system results will change if a lower discount rate, namely, 1.4%, is used. This value was used to explore a "real" interest rate based on treasury notes and bonds, as determined by the Office of Management and Budget in Circular A-94 Appendix C.

Two other sensitivity studies were also performed. One studied the sensitivity of the baseline capacity expansion pathway used in Alternative A to different assumptions about the candidate plants that would be constructed. AURORA invariably chose a combination of advanced combustion turbines and advanced combined cycle plants as the preferred expansion path. However, to test the sensitivity of the results to different expansion pathways, we ran the AURORA model for two extreme expansion pathways for Alternative A: one allowed construction of only advance combustion turbines, and the other only natural gas combined cycle plants.

The next study determined the sensitivity of the AURORA results to the choice of hydrological conditions. The results of another hydrological condition were compared against the results of the representative trace (i.e., Trace 14).

Finally, as described in Section K.1.7.3, ancillary services are no longer expected to increase as much and as rapidly as assumed in GTMax-Lite model runs. Therefore, a sensitivity study was performed to determine whether and by how much power system results would change if current ancillary service projection had been used. The results of the sensitivity study showed

that ancillary services assumptions under a range of plausible futures have little to no effect on firm capacity and energy value for the LTEMP alternatives (see Section K.1.10.8 for further detail).

K.1.10.1 Main Drivers of Differences among Alternatives

Among all alternatives, annual water release volumes differ by less than 1% and the total volume of water released from Glen Canyon Dam over the 20-year LTEMP period is nearly identical. Therefore, the economic cost of an LTEMP alternative is not caused by changes in long-term water release volumes, but rather from altering the routing and timing of water releases during monthly, daily, and hourly timeframes within a year.

Figure K.1-38 shows monthly average daily generation produced by water releases that are routed through the powerplant's turbines. Each alternative has a unique monthly water release pattern. For example, as compared to Alternative A, Alternative F turbine releases are much higher during March, April, May, and June and much lower during July and August. When water/generation is shifted from a month that has higher system production costs to a month with lower costs, the economic value of power produced by the Glen Canyon Dam Powerplant is reduced. Ultimately, this generation shift increases costs to the SLCA/IP market system, and therefore the cost of the alternative, because more expensive generation serves system electricity demand. Figure K.1-39 shows the average daily minimum, maximum, average, and range of electricity market prices by month forecasted for the Palo Verde market hub during the 20-year LTEMP period. In general, the more generation is produced in months with high electricity prices, the lower the alternative's cost will be relative to Alternative A. This allocation of limited water resources allows Glen Canyon Dam to serve system loads when the power it generates has the highest value.

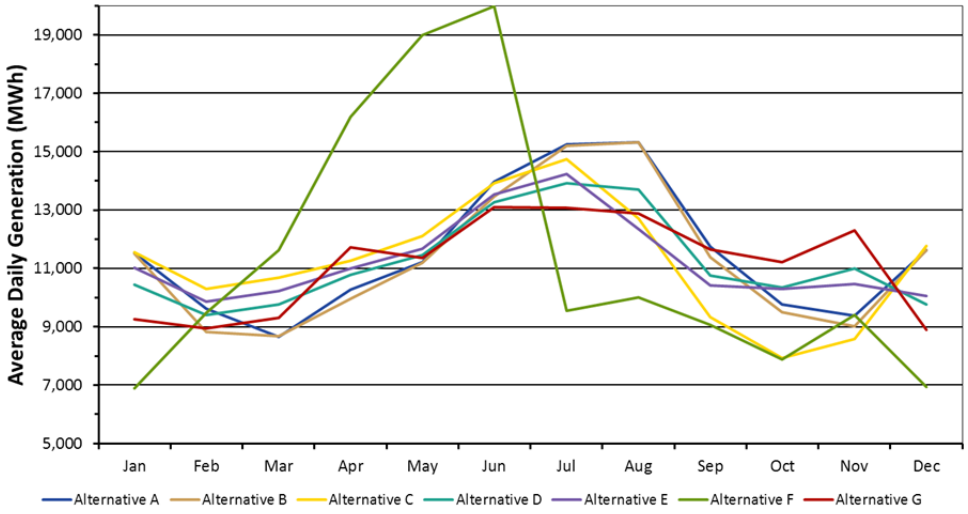


FIGURE K.1-38 Average Daily Generation by Month for Each Alternative

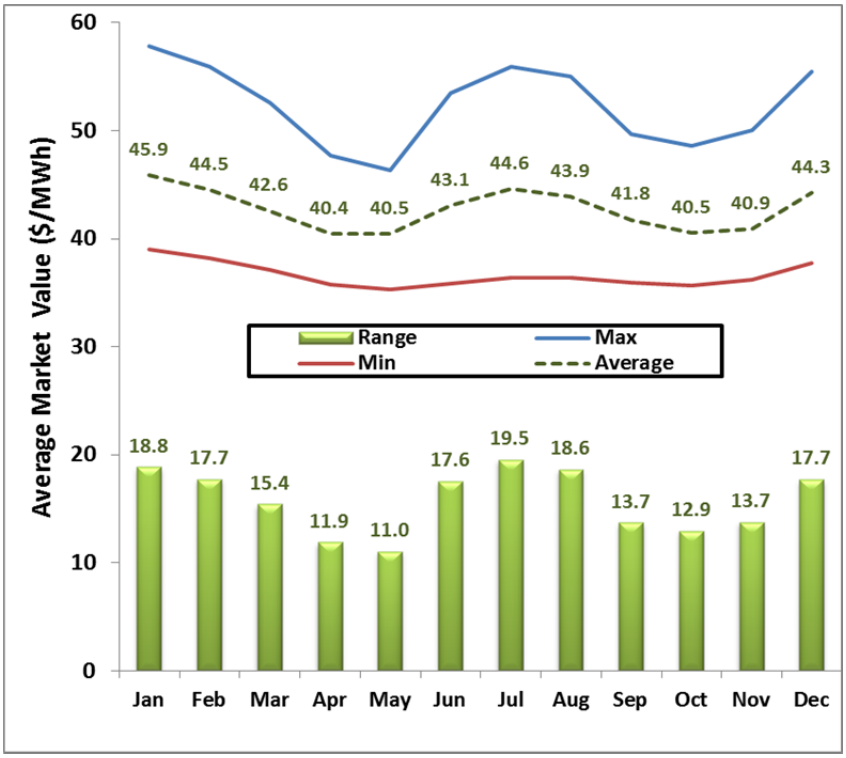


FIGURE K.1-39 Palo Verde Average Daily Electricity Market Price Statistics by Month during the 20-Year LTEMP Period

Alternatives also impact the daily profile of water releases. Changes in operating criteria, such as maximum and minimum release restrictions and mandates that limit water release changes over time, result in very different release patterns during most days. For example, except when transitioning between months or when HFEs are being conducted, Alternatives F and G require water releases from Glen Canyon Dam to be at a constant rate during each month. In contrast, other alternatives allow powerplant operators to change water release levels during a day in response to market price signals and system marginal production cost patterns. Alternatives that allow for only a small range between maximum and minimum releases and permit only minimal changes in water releases over time decrease the value of Glen Canyon Dam power production by shifting water releases from high price peak hours to low price off-peak hours. Figure K.1-40 shows typical Western Interconnection hourly electricity price patterns for winter and summer and the price spread between peak and off-peak hours.

Finally, alternatives affect the routing of water releases from the dam. Water is typically released through one or more of Glen Canyon Dam's eight turbines to produce electricity. However, depending on the pressure exerted by the water elevation in Lake Powell, only a limited amount of water can flow through turbines during an hour. In addition, the generating capacity of a unit indirectly limits the flow of water through it. Therefore, whenever a water release is required to exceed the combined flow capabilities of the generating units that are in operation, some of the water is released through hollow jet tubes (bypass) and spillways. These non-power releases produce no energy. Each alternative has a unique set of HFE specifications

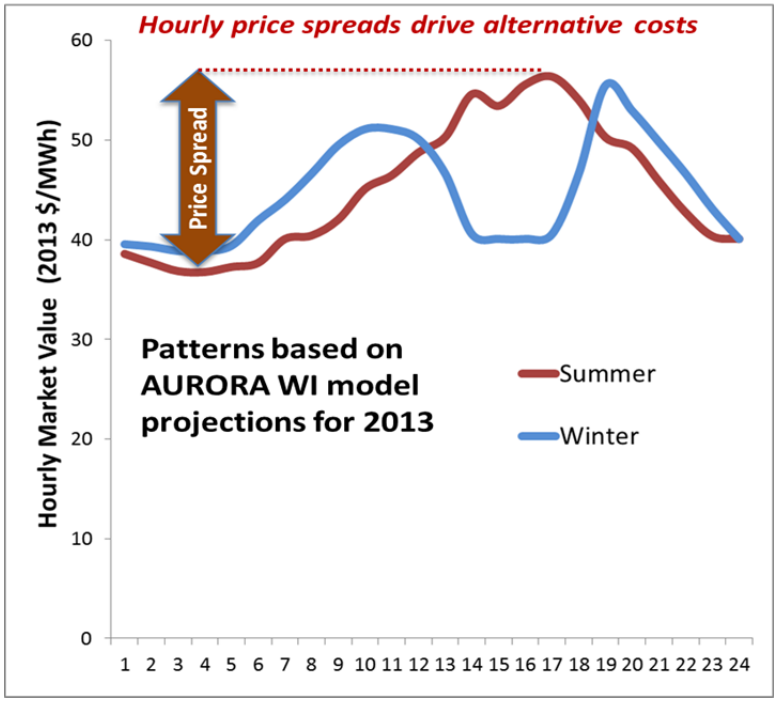


FIGURE K.1-40 Typical Hourly Winter/Summer Price Patterns in the Western United States

that affect the frequency and duration of Glen Canyon Dam non-power releases. Water is only released over the spillway (referred to as spilled water or spills) under emergency conditions associated with dam safety. Figures K.1-41 and K.1-42 show the average number of HFEs and the average amount of water spilled by alternative over the LTEMP period, respectively. Averages shown are based on all 21 hydrology traces of sediment Trace 2 and disaggregated by type of HFE. Alternative G has the highest number of HFEs; Alternatives C, D, E, and F have fewer HFEs; and Alternatives A and B have the fewest HFEs. Similarly, the greatest average volume of non-power releases occurs under Alternatives D and G; a lower volume of non-power releases occurs under Alternatives C, E, and F; and the lowest volume of non-power releases occurs under Alternatives A and B.

Water is also bypassed during very low (i.e., dry) hydropower conditions when the water elevation in Lake Powell is below the minimum turbine water intake level. During those times, it is assumed that all of the water released from Glen Canyon Dam produces no electricity until the water level rises to the minimum intake level. Figure K.1-43 shows the average annual number of hours, by alternative, the Lake Powell elevation is below the minimum penstock intake over the 20-year study period for all 21 traces of sediment Trace 2. Alternative G averages the greatest number of hours when the elevation is too low, resulting in an average of 8.5 hr over the 8,760-hr year, or 0.1% of the time; Alternatives A, B, C, D and E have somewhat fewer hours; and Alternative F has no hours when the elevation is too low to produce electricity.

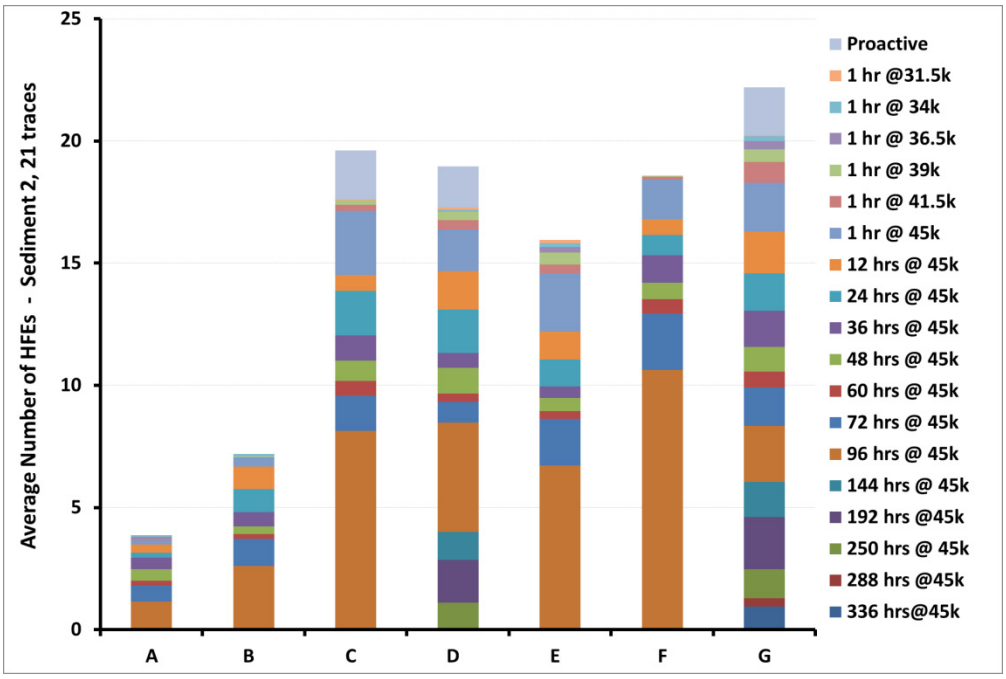


FIGURE K.1-41 Average Number of HFEs by Alternative for All 21 Hydrology Traces of Sediment Trace 2

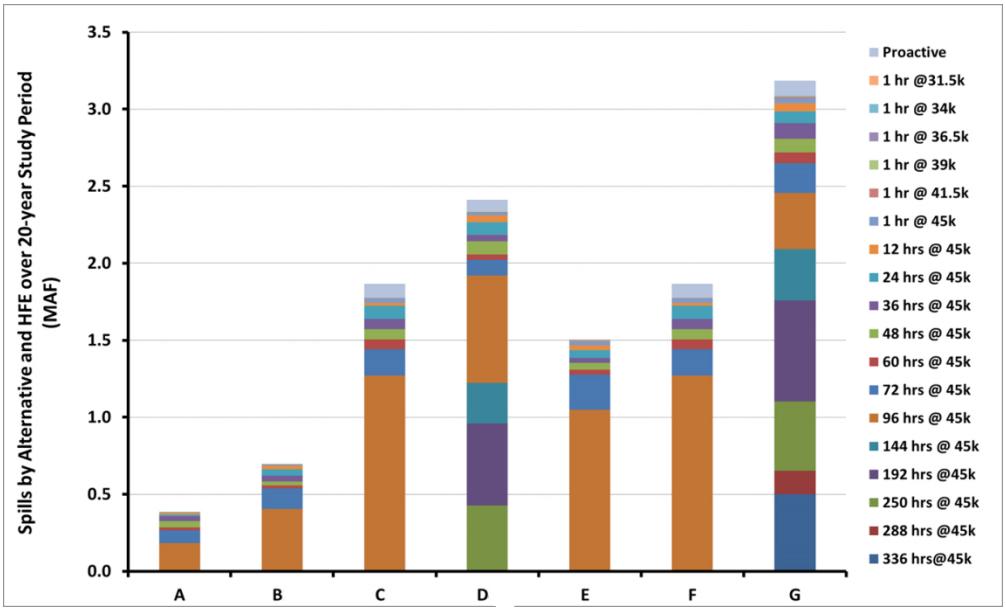


FIGURE K.1-42 Average Amount of Non-Power Water Releases by Alternative for All 21 Hydrology Traces of Sediment Trace 2

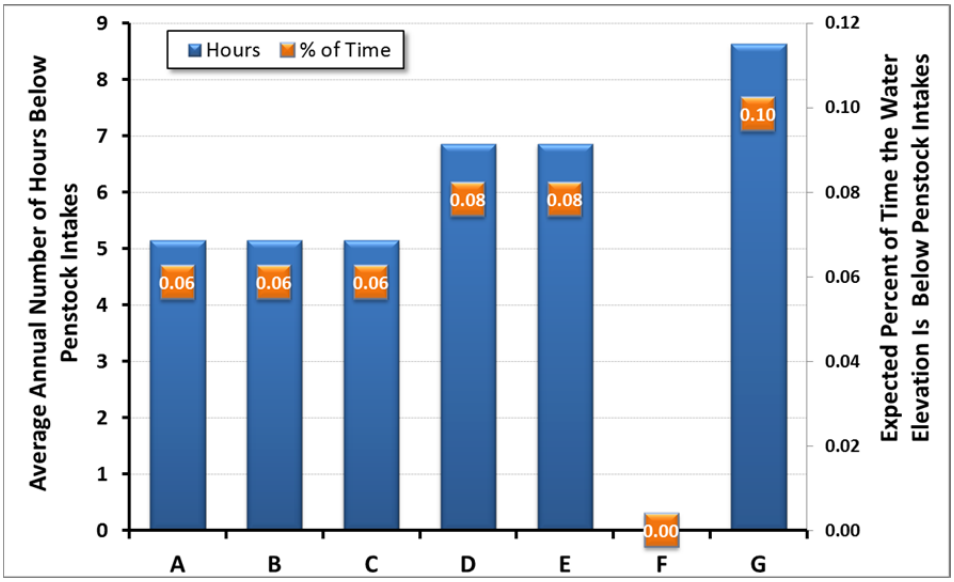


FIGURE K.1-43 Average Annual Number of Hours the Lake Powell Elevation Is below the Penstock Intake by Alternative for All 21 Hydrology Traces of Sediment Trace 2

Figure K.1-43 also shows that the percentage of time the reservoir at Glen Canyon Dam is expected to be below the penstock is very small (i.e., at most about one hourly occurrence out of every 1,000 hr). However, most of these occurrences are concentrated in fairly long, continuous periods of time. For example, under Alternative G, all hours with elevations below the penstocks occur during a continuous 3-month period starting in January 2018, under hydrology Trace 19, and during the entire month of April 2024, under hydrology Trace 8. Therefore, the risk of encountering zero generation periods is small, but when it does occur, the economic implications are very costly.

Finally, non-power water releases can also occur as a result of inflow forecast error. High reservoir conditions in combination with unanticipated large water inflow volumes into Lake Powell will result in bypassed or spilled water if there is inadequate spare reservoir capacity to accommodate all of the water inflows minus maximum turbine flow rates.

K.1.10.2 Capacity Expansion Modeling

Capacity expansion plans for each alternative during the study period are determined by running the AURORA model in capacity expansion mode. The plans specify the type of technology built, unit capacity, and the year a new unit begins operation. The model also computed the annual capacity investment and O&M costs for all new units built over the study period except those previously committed and contained in the unit inventory. As noted in section K.1.6.3, the AURORA model was given a wide selection of technologies from which to choose for future capacity additions, including conventional and advanced natural gas combustion turbines, conventional and advanced gas/oil combined cycle units, scrubbed and

pulverized coal units, integrated gasification combined cycle units, nuclear units, wind farms, and solar thermal and photovoltaic projects.

The firm SLCA/IP federal hydropower capacity input to the AURORA expansion model is credited toward meeting the system reserve margin. The quantity input depends on the combined operating capabilities of these resources at the time of the system peak demand, and on a defined exceedance level. Table K.1-7 shows marketable capacity by alternative at the 90% exceedance level (i.e., a 10% risk of having a lower peak operating capability than the specified firm level at the time of system peak load). The table also shows the difference in firm capacity compared to Alternative A (referred to as lost capacity). Except for Alternative B, which has 28.1 MW more firm capacity than Alternative A, all other alternatives have approximately 50 MW to 314 MW less firm capacity at the 90% exceedance level. This indicates that the need for additional generating capacity to replace capacity losses at Glen Canyon would range from 6.7 to 42.6% relative to Alternative A.

A retrospective study performed by Argonne on marketable capacity offered by CRSP Management Center over the last 10 years shows that it markets capacity at a 90% exceedance level. That is, WAPA has enough SLCA/IP federal hydropower resource capacity to meet its obligation 90% of the time. Therefore, the baseline LTEMP analysis used the same exceedance level to determine SLCA/IP federal hydropower firm capacity. However, in the future WAPA may choose another exceedance level to determine marketable capacity. Results are presented later in Section K.1.10.4 for exceedance levels of 50% and 99%; this range will bracket the risk preference level that the CRSP Management Center will likely, but not necessarily, choose to use when determining future LTF capacity commitment levels.

TABLE K.1-7 SLCA/IP Marketable Capacity at the 90% Exceedance Level

Capacity Type	Alternative A (No Action)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
SLCA/IP Firm Capacity (MW)[a]	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP Lost Capacity (MW)[b]	Not applicable	–28.1	129.1	49.6	90.2	314.1	179.0

[a] Marketable capacity is calculated based on all 21 hydrology traces with median sediment input (sediment Trace 2), which has the highest likelihood of occurrence. It is calculated at the 90% exceedance level, using August as the peak load month. That is, combined SLCA/IP federal hydropower resources are able to attain peak output at the firm capacity level or higher 90% of the time during the August peak load.

[b] Lost capacity is the difference between the marketable capacity in Alternative A and the marketable capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.

The AURORA expansion model only selected natural gas–fired technologies in its SLCA/IP market system plan to meet future demand; no other thermal or renewable technologies were chosen. Wind and solar plants were added in the expansion pathway, but only to meet the expansion goals specified in the utility IRPs as described in Section K.1.6.3. The natural gas–fired technologies chosen by AURORA were the 400-MW advanced combined cycle unit and 230-MW advanced combustion turbine.

The expansion pathway chosen by AURORA was consistent with projections made in the 2014 AEO (EIA 2014), and with expansion plans reported in IRPs developed by utilities in the region. Figure K.1-44 shows the 2014 AEO projects of cumulative capacity additions for the three geographic regions in the Western Interconnection for the next 20 years. In the future, the AEO projects only renewable generation; natural gas combined cycle plants and combustion turbines; and distributed peaking generation, which is most often fueled by natural gas.

As noted in Section K.1.6.3, Argonne conducted a survey of the current IRPs available on the websites (which typically had publication dates of either 2013 or 2014) of WAPA's customers and investor-owned utilities in the geographic and "electrical" area of WAPA's customers to determine the timing and type of resources these utilities were planning to meet future electric demand. The results of that survey were shown in Table K.1-6. As in the 2014 AEO (EIA 2014), utilities are forecasting that future capacity additions to their systems will consist of renewables (mainly wind and solar) and natural gas–fired combined-cycle plants and combustion turbines. A conclusion that can be drawn from Table K.1-6 is that because new generators are forecasted to come online in the very near term (the next 2 to 3 years) there will be little or no excess capacity in the region that would be available to replace capacity lost at Glen Canyon Dam at the time when the ROD is issued.

Figure K.1-45 shows the cumulative capacity additions selected by the AURORA expansion model for Alternative A (combustion turbines are labeled CT and natural gas combined-cycle units are labeled NGCC). Table K.1-8 shows the difference from Alternative A in cumulative capacity additions for each alternative. Because units are built in large increments, capacity expansion is often said to be "lumpy." The green line in the figure shows the amount of capacity in excess of the 15% reserve margin. Due to the lumpy expansion path, some years significantly exceed the 15% reserve margin target, while others have just enough to satisfy the reserve margin. However, the capacity above the reserve margin could be sold to utilities that are short of capacity at the market price, thereby reducing the total net cost to the SLCA/IP market system. Sales of excess capacity will be explored and quantified in the analysis of alternatives.

It should be noted that the first capacity addition under Alternative A comes online in 2018 under the current joint system analysis. Therefore, there will be very little or no excess capacity when operational changes at Glen Canyon Dam could possibly be implemented. Furthermore, lost capacity would need to be replaced soon after the ROD.

Although CRSP Management Center LTF customers typically engage in economical firm capacity and energy transactions, the joint planning approach assumes a higher level of coordination and cooperation among LTF customers than may currently exist. Results shown in Figure K.1-45 are based on a methodology that projects the expansion plan for the combined

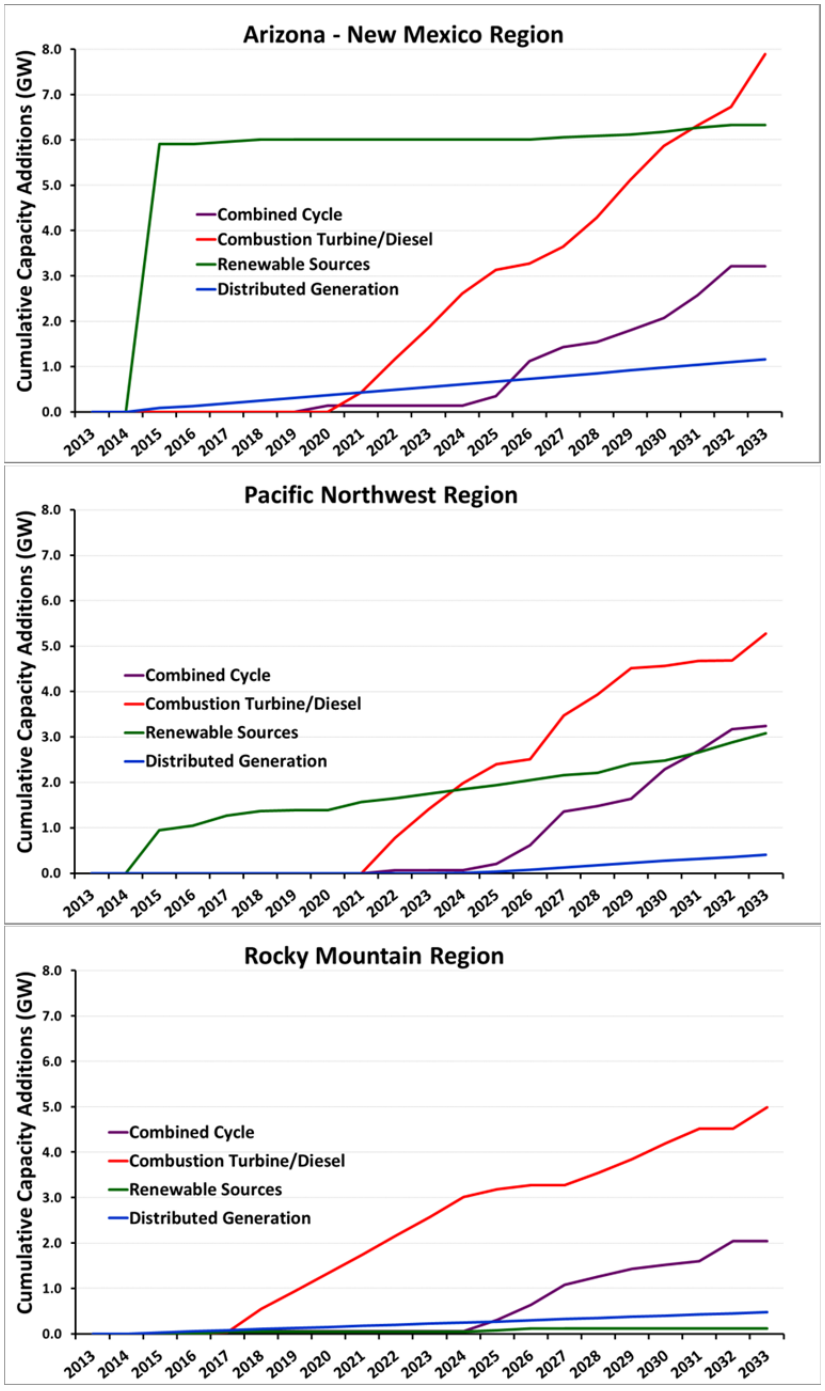


FIGURE K.1-44 2014 Annual Energy Outlook Projections of Capacity Additions in the Western Interconnection over the LTEMP Period

TABLE K.1-8 Difference in Cumulative Capacity Additions of Each Alternative Relative to Alternative A (90% Exceedance Level)

		Difference in Capacity (MW) per Year Relative to Alternative A					
Year	Alternative A Expansion (MW)	Alternative B, Long-Term Strategy 1	Alternative C, Long-Term Strategy 1	Alternative D, Long-Term Strategy 4	Alternative E, Long-Term Strategy 1	Alternative F	Alternative G
2013	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0
2017	0	0	0	0	0	230	0
2018	230	0	230	0	0	460	230
2019	630	0	230	0	0	460	230
2020	1,030	0	230	0	0	460	230
2021	1,030	0	230	230	230	460	230
2022	1,430	0	230	230	230	460	230
2023	1,830	0	230	230	230	460	230
2024	2,060	0	230	0	0	460	230
2025	2,290	0	230	0	0	460	230
2026	2,520	0	230	0	230	460	230
2027	2,750	0	230	230	230	460	230
2028	2,980	0	230	230	230	460	230
2029	3,440	–230	0	0	0	230	230
2030	3,670	0	0	0	0	230	230
2031	3,900	0	0	0	0	230	230
2032	4,590	0	230	230	230	460	230
2033	4,820	0	230	230	230	460	230
Average		–11	142	77	88	329	175
GC Reduction		–28	129	49	90	314	179
Difference		17	13	28	–2	15	–4

system in which the costs and benefits of new generating resources would be shared among both large and small customers. This approach has a number of advantages related to modeling efficiency while representing the general system response to changes in Glen Canyon Dam firm capacity, but understates the cost impacts. This joint planning approach indicates that numerous units would be constructed by the system. For example, by 2034, 14 new advanced combustion turbines and four advanced combined cycle units would be constructed under Alternative A (see Table K.1-9). Each unit could be operated by an individual utility or as a joint dispatch, whatever arrangement is more advantageous. If technical or institutional barriers did not allow joint unit dispatch, a new unit could be built by a single owner/operator. Furthermore, if the new unit created excess capacity in the owner's utility, it may be able sell capacity from other system resources that are more conducive to joint dispatch. Alternatively, the capacity-long system could sell the excess without specifying the individual supply resource.

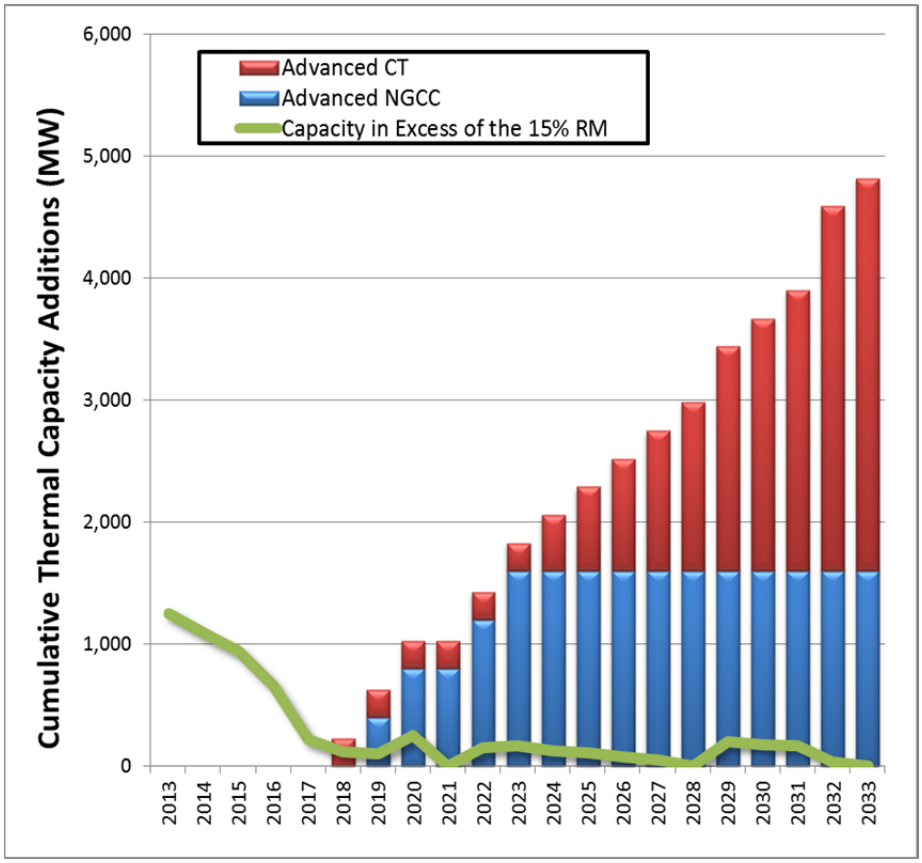


FIGURE K.1-45 Cumulative Capacity Additions for Alternative A (90% Exceedance Level)

The cost of capacity replacement in general would be higher if each individual utility were modeled as isolated entities (i.e., without mutually beneficial arrangements), which is how new units would actually be constructed. This model solution would, in many respects, be uneconomical and unrealistic because each utility that is capacity short would need to either (1) build a relatively large efficient unit to replace its allocation of the lost capacity, which in most cases is very small, or (2) build a very small unit that is typically less efficient and, because of economies of scale, is more costly per kilowatt of installed capacity to construct. Utilities that are capacity long may not need to construct any replacement capacity. The capacity expansion plan would also be very lumpy.

The capacity expansion pathway for Alternative A will replace existing powerplant capacity that will retire in the future and meet forecasted increases in electricity demand in the SLCA/IP market system. The expansion pathways for all other alternatives are a modification of this pathway. Differences in firm capacity among alternatives were evaluated in terms of the amount and timing of new generating units constructed in the future. All alternatives except Alternative B have a decrease in firm capacity compared to Alternative A. Alternatives that have less firm capacity would be expected to install capacity earlier and/or install more capacity than Alternative A. Conversely, Alternative B would be expected to have a delay in capacity additions

compared to Alternative A. Table K.1-9 compares the capacity expansion pathways for Alternatives A and F. Alternative F has the most lost capacity of all alternatives.

TABLE K.1-9 Comparison of the Amount and Timing of New Capacity Additions for Alternatives A and F (90% Exceedance Level)

On-Line Date	New Additions	
	Alternative A	Alternative F
2014		
2015		
2016		
2017		CTl
2018	CTl	CT2 & CT3
2019	NGCC1	NGCC1
2020	NGCC2	NGCC2
2021		
2022	NGCC3	NGCC3
2023	NGCC4	NGCC4
2024	CT2	CT4
2025	CT3	CT5
2026	CT4	CT6
2027	CT5	CT7
2028	CT6	CT8
2029	CT7 & CT8	CT9
2030	CT9	CT10
2031	CT10	CT11
2032	CT11–CT13	CT12–CT13
2033	CT14	CT16

Table K.1-9 shows that Alternative F installs combustion turbines (labeled CT1, CT2, etc.) 1 to 7 years earlier than Alternative A. By the end of the LTEMP period Alternative F also installs more capacity, two more combustion turbines. Because the number and timing of natural gas combined cycle units (labeled NGCC1, NGCC2, etc.) is identical under both alternatives, lost Glen Canyon Dam capacity is replaced exclusively by advanced combustion turbines. This accelerated capacity addition schedule occurs because Alternative F has 314 MW less SLCA/IP federal hydropower firm capacity than Alternative A.

Table K.1-8 shows a comparison of capacity additions for all alternatives. This table lists the cumulative additional capacity for Alternative A and then shows the difference in cumulative capacity between it and the other alternatives. The difference represents the capacity that is constructed to replace lost Glen Canyon Dam capacity. Note that the replacement capacity in the table are –230 MW, 230 MW, or 460 MW; capacity changes occur in increments of an advanced combustion turbine unit. At the bottom of the table are values showing the average annual amount of replacement capacity, the lost firm capacity, and the difference between those two values. As expected, for each alternative, the amount of lost capacity and average annual capacity replacement amount ranges from −4 MW to 28 MW.

Under Alternative A, an estimated 4,820 MW of new capacity is built in the SLCA/IP market system. Capacity additions are phased in over time, such that a minimum 15% capacity reserve margin is attained in each year of the 20-year LTEMP period. Under all alternatives except Alternative B, more new generating capacity must be built and the capacity must also be built sooner. Like Alternative A, Alternative B adds 4,820 MW of new capacity by CY 2034; however, because Alternative B has slightly more firm capacity, one new generating unit would be constructed a year later than under Alternative A. All other alternatives have less firm capacity than Alternative A. Under Alternatives C, D, E, and G, 5,050 MW of new capacity additions would be required by CY 2034; this amounts to one more combustion turbine than Alternative A, which is an increase in capacity of 4.8%. Under Alternative F, 5,280 MW of new capacity is built by CY 2034, which is two more combustion turbines than Alternative A. This amounts to an increase in capacity of 9.5%.

In addition, it is noteworthy that because capacity is built in discrete sizes/increments that do not match the amount of lost capacity, system expansion differences among the alternatives do not typically match the amount of lost capacity. In some years, the replacement capacity is larger than the lost capacity, while in other years it is smaller. Again, this result shows the "lumpiness" of capacity expansion, which allows for possible sale of capacity above the 15% reserve margin to be sold at market price to reduce the total cost of an alternative.

K.1.10.3 Economic Impacts

When the capacity expansion pathways were determined for each alternative, the AURORA model was run in dispatch mode to simulate the operation of the system for every hour in the entire study period for hydrological Trace 14, which is the representative trace. Selection of the representative trace was discussed in Section K.1.5.2, and Attachment K.3 of this appendix describes in detail how that trace was chosen.

The AURORA dispatch model computes all SLCA/IP market system costs associated with the production of electrical energy to meet the system load and to generate additional energy for power sales to the spot market. Production costs are the sum of powerplant fuel costs, variable O&M costs, and cost of power purchased from the spot market. Revenues from the power sales to the spot market are subtracted from these costs to compute the net economic cost. This technique was used to compute the production costs of serving only SLCA/IP market load. Results from the AURORA expansion and dispatch models (i.e., capital, fixed O&M, and production or energy costs) are combined to determine the total annual costs for each alternative. The net present value stream of costs is also calculated to facilitate comparison of each alternative to Alternative A. This single lump-sum value is based on a discount rate of 3.375%, a rate used by Reclamation for cost-benefit studies of projects pursuant to U.S.C. 1962d-17.

The total economic impacts at the 90% exceedance level by alternative are summarized in Table K.1-10. Costs are disaggregated by system-wide net production cost, which was obtained from AURORA dispatch model simulations, and by capital costs and fixed O&M costs, which were both obtained from AURORA expansion model simulations. This table also includes calculating a benefit from the sale of excess capacity above that required to satisfy the reserve margin. This benefit would reduce the total cost of each alternative.

All alternatives except for Alternative B have less firm SLCA/IP federal hydropower capacity than Alternative A. Therefore, the NPV of capital and fixed O&M costs are higher than under Alternative A. Alternative B had the same total amount of new capacity at the end of the LTEMP study period as Alternative A, but the construction of one combustion turbine was delayed by a year due to its slightly higher firm SLCA/IP federal hydropower capacity, which resulted in slightly lower capital and fixed O&M costs. Although Alternatives C, D, E, and G have the same amount of new capacity at the end of the LTEMP study period, they have different NPVs for capacity and fixed O&M because of the difference in the timing of the installation of the new capacity. The differences in timing are found in Table K.1-8.

TABLE K.1-10 Total Economic Impacts by Alternative at the 90% Exceedance Level

Economic Impact Measure	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
System-level generating capacity additions (MW)[a]	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
SLCA/IP system-wide production cost ($million)[b]	34,228 (no change from current condition)	34,221 (0.02% decrease)	34,255 (0.08% increase)	34,270 (0.1% increase)	34,249 (0.06% increase)	34,373 (0.4% increase)	34,345 (0.3% increase)
SLCA/IP Capital cost ($million) for capacity expansion[b]	1,643 (no change from current condition)	1,635 (0.5% decrease)	1,746 (6.3% increase)	1,696 (3.2% increase)	1,703 (3.7% increase)	1,882 (14.5% increase)	1,769 (7.7% increase)
Fixed O&M cost ($million) for capacity expansion[b]	345 (no change from current condition)	344 (0.3% decrease)	363 (5.2% increase)	354 (2.6% increase)	355 (2.9% increase)	385 (11.6% increase)	366 (6.1% increase)
Total cost ($million)[b]	36,216 (no change from current condition)	36,200 (0.04% decrease)	36,364 (0.41% increase)	36,320 (0.29% increase)	36,307 (0.25% increase)	36,640 (1.2% increase)	36,480 (0.73% increase)
Difference in Total Costs ($million) Relative to No Action	Not applicable	–16	148	104	91	424	264
Rank (lowest to highest total cost)	2	1	5	4	3	7	6
Potential capacity sales ($million)[b]	86	99	99	106	82	105	85
Adjusted total cost ($million)[b]	36,130 (No change from current conditions)	36,101 (0.08% decrease)	36,265 (0.37% increase)	36,214 (0.23% increase)	36,225 (0.26% increase)	36,535 (1.1% increase)	36,395 (0.73% increase)

TABLE K.1-10 (Cont.)

Economic Impact Measure	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Difference in Adjusted Total Costs ($million) Relative to No Action	Not applicable	–29	135	84	95	405	265
Adjusted Rank (lowest to highest total cost)	2	1	5	3	4	7	6

[a] Additional generation capacity required under the LTEMP alternatives for WAPA's customers over the 20-year LTEMP period to not only meet future load demand and replace unit retirements, but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.

[b] Net present value ($million 2015) of costs to meet total system electric demand over the 20-year study period for all SLCA/IP customers under representative trace. Discount rate is 3.375%. The excess capacity may have some economic value; however, that value would depend on the timing and details of the replacement, and thus results are presented both with and without this potential excess.

Table K.1-10 also shows the amount of potential sale of excess capacity of generating units constructed by WAPA's customers above that mandated by the reserve margin. As a result of the lumpy nature of capacity additions, there are short periods of time (i.e., typically less than 2 years) in which slightly more system capacity is built than is needed to meet the reserve margin target. It is assumed this small amount of capacity (i.e., less than the size of one generating unit) may have some value and could be sold to entities outside of the SLCA/IP system. Sales of this excess capacity lower the total cost of all alternatives, but do not substantially affect their relative ranking from lowest to highest cost alternative. If alternatives are ranked based on the difference in adjusted total cost, the order of alternatives from lowest to highest cost is as follows: Alternative B, Alternative A, Alternative D, Alternative E, Alternative C, Alternative G, and Alternative F. If the potential for sale of excess capacity is not factored into the total alternative cost, then the ranking of alternatives changes only slightly; Alternatives E and D change places in the ranking. All other alternatives remain in the same order.

Cost of Experimental Releases

LTEMP alternatives and associated long-term strategies are composed of operating criteria and several experimental elements, as shown in Table 4.1-1. Economic evaluations presented for the Structured Decision Analysis (SDA) (Appendix C) and detailed power systems analysis (Section 4.13 and Section K.1) bundle all of the costs associated with an alternative

(including operational changes and experiments) into a single value (NPV). This section provides estimates of the "unbundled" economic cost of several types of experiments.

These estimates are computed by comparing the estimated effects of long-term strategies of alternatives that differ only in inclusion of a particular experiment.[2] The one element that differs between the two alternatives is the element for which the economic impacts are measured. For example, to measure the economic cost of low summer flows, two long-term strategies for Alternative D are compared (D1 and D4). Both have identical operating criteria and the same experimental elements except that under long-term strategy D1 low summer flows are included in the second 10 years of the LTEMP period, while under long-term strategy D4 low summer flows would not be conducted. Subtracting NPV results for D4 from D1 yields the NPV cost of conducting the experiments over the 20-year LTEMP period. Using this methodology, the approximate cost of conducting different types of experimental elements can be "unbundled" from the total aggregate costs previously reported.

Although the SDA modeling results do not include all possible combinations of operating criteria and experiments, a general estimate of the relative costs of each type of experiment can be gained by comparing selected pairs of SDA NPV model results as described in the example above. Using information provided in Table 4.1-1, the following pairs of alternatives were selected to approximate costs associated with individual experimental elements:

1. Low summer flows

    a. Long-term strategies D4 (without low summer flows) and D1 (with low summer flows)
    b. Long-term strategies E3 (without low summer flows) and E5 (with low summer flows)

2. TMFs

    a. Long-term strategies D3 (without TMFs) and D1 (with TMFs)
    b. Long-term strategies E3 (without TMFs) and E6 (with TMFs)

3. Steady weekend flows for macroinvertebrate production

    a. Long-term strategies D1 (without steady weekend flows) and D2 (with steady weekend flows)

4. Fall HFE

    a. Long-term strategies C3 (without HFEs) and C4 (with HFEs)
    b. Long-term strategies E3 (without HFEs) and E4 (with HFEs)

[2] Mechanical trout removal is not included in the comparison of elements because it not a factor in estimates of either SDA or power systems costs.

Consistent with both the SDA and detailed power system results, costs for each experiment are computed for both Glen Canyon Dam Powerplant energy production and replacement capacity. These estimates are based on 21 hydrology traces over the 20-year LTEMP study period. Note that the cost of a single element type differs by alternative pairing. For example, the average NPV energy costs difference between long-term strategies E3 and E5 is bigger than the difference between long-term strategies D4 and D1. In this case, the difference is due to several factors including interactions among the experimental element that is being measured (i.e., low summer flows), and both the operating criteria and other experiments. Note that both E3 and E5 do not include other experiments while both long-term strategies D4 and D1 include TMFs and HFEs. It is therefore apparent that operating criteria and other experiments have an impact on the incremental cost of conducting a specific experiment.

As discussed in more detail below, the cost of conducting an experiment is dependent not only on the water release specifications of the experiment but also the frequency of the experiments and the length of time that it takes to conduct an individual experiment. For example, the energy cost to conduct each benthic invertebrate steady weekend flow experiment is relatively low, while it is much more costly to conduct an individual low summer flow. However, as shown in the following discussion, steady weekend flows are much more costly than low summer flows because of the high frequency of steady weekend flows throughout the 20-year LTEMP period. Approximately seventeen 2-day steady flows would take place every year under the former scenario while on average over all 21 traces less than one low summer flow 92-day experiment is expected over the entire 20-year LTEMP period under the latter scenario.

Capital costs for experimental elements display a pattern that is distinctly different from energy costs. For example, among the experimental elements, fall HFEs are one of the more expensive, while replacement capital costs are zero. Because these HFEs are conducted exclusively during the month of November, there are small impacts on Glen Canyon Dam Powerplant maximum output levels in August when firm capacity is measured. This is especially the case under dry hydrological conditions (e.g., 90% exceedance) under Alternative C and Alternative E operating criteria. There are also no firm capacity cost impacts associated with TMFs because these are conducted in May, June, and July and require no water reallocation among months of the year.

The following sections discuss in more detail each experimental element in terms of the cost to conduct an individual experiment, the frequency of experiments, and duration of each experiment.

Cost of Low Summer Flows. The average per trace difference in the NPV of energy costs over 20 years is $1.97 million between long-term strategies D1 and D4 and $3.36 million between long-term strategies E3 and E5. These costs are lower than both macroinvertebrate production flows and HFEs. This outcome is due to the timing and infrequent occurrence of low summer flow experiments. Among all 21 hydrology traces over the 20-year LTEMP period (i.e., 20 × 21 = 420 outcomes), only 15 low summer flow experiments were triggered

(an average of 0.714 experiments per trace). On an annual basis, the chance that a low summer flow will be conducted is only 3.6% (15/420 × 100). Furthermore, all low summer flows occur during the last 10 years of the LTEMP period. Because the NPV calculation uses an annual discount rate, a low summer flow experiment in a later year has a lower weight in the NPV calculation compared to the same experiment conducted in an earlier year. Based on the total energy cost of conducting low summer flow experiments over the 20-year LTEMP period and their frequency of occurrence, the average NPV energy cost of a single low summer flow experiment is about $2.76 million ($1.97 million/0.714) for Alternative D and about $2.21 million ($3.36 million/1.523, the average number of experiments for strategy E5) for Alternative E. Because a low summer flow experiment takes place during the entire months of June, July, and August (92 days), the average daily NPV cost to conduct a low summer flow experiment is about $30,000 for Alternative D and about $24,000 for Alternative E.

The annual levelized capacity replacement costs for low summer flows are approximately $0.91 million based on a comparison between long-term strategy D1 and long-term strategy D4 (or a per trace NPV cost of $13.03 million over 20 years), and about $1.24 million based on a comparison between long-term strategy E3 and long-term strategy E5 (or a per trace NPV cost of $17.86 million over 20 years). Because low summer flow experiments directly impact operations in the critical peak load month of August by reducing both monthly water release volumes and operational flexibility, there is an impact on firm capacity estimates and therefore the cost of lost capacity at the Glen Canyon Dam Powerplant. Based on the total NPV of the capacity replacement cost of the low summer flow experiments and their frequency of occurrence in the 20-year LTEMP period, the average NPV capital cost of a single experiment is about $18.25 million ($13.03 million/0.714) for Alternative D, and about $11.72 million ($17.86 million/1.523) for Alternative E; that is, an average daily NPV cost of about $198,000 for Alternative D and about $127,000 for Alternative E. Adding the low summer flow costs for energy and capacity yields a per experiment cost of $21.01 million and $13.93 million for Alternatives D and E, respectively.

In WY 2000, a low summer steady flow experiment was conducted and the financial energy cost of this experiment was estimated to be about $25 million in nominal dollars (Veselka et al. 2011). Because the low summer steady flow was a one-time experiment, it was assumed that there were no firm capacity impacts. The WY 2000 low summer steady flow experiment was several times more expensive than the projected energy costs of the low summer flow experiments considered for the LTEMP period, for which costs were estimated to be $2.76 million and $4.70 million for Alternatives D and E, respectively. Although both have similar-sounding names and are conducted in the summertime, there are several factors that make the historical low summer steady flow distinctly different from low summer flows under LTEMP. These include but are not limited to following:

1. The WY 2000 low summer steady flow lasted 6 months (Veselka et al. 2011). In contrast, LTEMP low summer flow experiments are 3 months long.

2. The WY 2000 low summer steady flow had zero operational flexibility, whereby water and therefore power plant output was almost always constant.

There is comparatively more operating flexibility allowed under the LTEMP low summer flow.

3. During WY 2000, energy prices were driven by the California market, which at that time experienced extraordinary price spikes due to the market design structure in place at that time (e.g., the average on-peak price in August was approximately $114.29/MWh) and daily price spreads between on- and off-peak periods were up to $90/MWh.

4. The WY 2000 low summer steady flow required two "spike flows" (the predecessor of HFEs) in the spring and fall.

Cost of Trout Management Flows. For TMFs,[3] the average per trace difference in the NPV of energy costs over 20 years is $3.49 million between long-term strategies D1 and D3 and $0.98 million between long-term strategies E3 and E6. Like low summer flows, these costs are relatively low compared to both the low steady weekend flow and the HFE experiments. The average number of TMFs conducted in a 20-year trace for Alternatives D and E is 7.76 and 2.38, respectively. Based on the total energy cost of conducting TMFs over the 20-year LTEMP period and their frequency of occurrence, the average NPV energy cost of a single TMF is about $450,000 ($3.49 million/7.76 TMFs over 20 years) for Alternative D and about $410,000 ($0.98 million/2.38 TMFs over 20 years) for Alternative E. Because a TMF takes place for a period of 5 days in May, June, and July, or a total of 15 days, the average daily NPV cost to conduct a TMF is about $30,000 for Alternative D and about $27,400 for Alternative E.

There is no capacity replacement cost for TMFs because these experiments only occur in the months of May, June, and July, and water is only reallocated within the same month to conduct the experiments; there is no water reallocation among other months of the year. Therefore, there is no capacity impact in the month of August when firm capacity is measured.

Cost of Macroinvertebrate Production Flows.[4] The average per trace difference in the NPV of energy costs over 20 years is $10.66 million between long-term strategies D2 and D1. Under this experiment, low steady weekend flows would be conducted each weekend in the months of May through August when implemented. The average number of macroinvertebrate production flow experiments conducted per trace under Alternative D was 12.24 over 20 years. Based on the total energy cost of conducting macroinvertebrate production flows and their frequency of occurrence, the average NPV energy cost of this experiment is about $871,000

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3 Trout management flows consist of repeated cycles of high and low flows over a season (see Section 2.2.3.2 for a description of TMFs). The modeling conducted for the LTEMP considered three cycles—one each in May, June, and July. In the cost of experiment analysis, a TMF experiment is assumed to be a single three-cycle implementation.

4 Under this experiment, weekend days from May through August would be held steady at the minimum flow for each month to support increased production of aquatic macroinvertebrates.

($10.66 million/12.24 experiments over 20 years). Since there are 34 weekend days from May through August, the average daily NPV cost is about $25,600 ($871,000/34 days).

Macroinvertebrate production flows would have a capacity benefit of 42.3 MW. This benefit occurs because in the months of May through August, weekend flows are limited to the minimum flow for that month. Since there is no change in monthly releases for this experiment, lower weekend water releases result in larger water releases, more electric generation, and higher capacity on weekdays. Because capacity exceedance values are based on the peak month of August, an alternative with this experiment has more capacity available during weekdays, when peak loads occur, than an alternative that does not have this experiment.

The annual levelized capacity benefit for this experiment is about $2.12 million (i.e., $30.5 million over 20 years). Based on the total NPV benefit and the number of flows that can occur over 20 years, the cost per experiment is $2.49 million ($30.5 million/12.24 flows over 20 years). The average daily benefit would be about $73,200 ($2.49 million/34 days per year). Adding the cost of energy and the capacity benefit yields a per-experiment benefit of about $1.62 million. The average daily NPV benefit is about $47,600.

Cost of Fall High Flow Experiments. The average per trace difference in the NPV of energy costs over 20 years is $24.98 million between long-term strategies C3 and C4 and $24.54 million between long-term strategies E3 and E4. These costs are relatively high compared to the energy cost for other experiments. This outcome is due to the frequent occurrences of fall HFEs and the high energy cost associated with conducting each individual fall HFE. On average, 15.4 HFEs per hydrology trace would be conducted under long-term strategy C4, and 16 HFEs would be conducted under long-term strategy E4. Based on the total energy cost of conducting fall HFEs over the 20-year LTEMP period and their frequency of occurrence, the average NPV energy cost of a single fall HFE is about $1.62 million ($24.98 million/15.4 HFEs per 20-year trace) for Alternative C and about $1.65 million ($24.54 million/14.9 HFEs per 20-year trace) for Alternative E.

The number of days it takes to conduct a fall HFE experiment varies based on the type of HFE. An HFE can last from 2 to 16 days, including the up and down ramping periods. On average, a fall HFE lasts about 4.7 days under long-term strategy C4 and 4.6 days under long-term strategy E4. Therefore, the average daily NPV costs to conduct a fall HFE experiment in November is about $345,000 for Alternative C and about $358,000 for Alternative E. As discussed previously, there is no lost capacity cost associated with a fall HFE because November HFEs have little to no impact on maximum output levels at the Glen Canyon Dam Powerplant in August (i.e., the month with the highest peak load).

The cost for an individual HFE computed in this analysis is somewhat lower than the estimated cost of the fall HFE conducted in WY 2014, which ranged from $2.44 million to $2.59 million (Graziano et al. 2015). Several factors contributed to the higher historical costs and include (1) WY 2014 HFE was a longer 6-day event; (2) costs were not discounted; and (3) the WY 2014 HFE study was a financial analysis.

Experimental Element Summary. Table K.1-11 summarizes the results of the pairwise comparison of alternatives to determine the costs of individual experiments.

K.1.10.4 Sensitivity of Results to Exceedance Level

One sensitivity study investigated the effect of exceedance level on results. The previous section discussed results at the 90% exceedance level. This section will show results at the 50% and 99% exceedance levels and discuss how they compare to each other and to results at the 90% exceedance level. Table K.1-12 shows at each exceedance level and alternative the firm capacity, the capacity replacement requirement, and the system-level capacity additions at the end of the LTEMP study period.

Table K.1-12 shows that, compared to the 90% exceedance level, the 99% exceedance level results in a lower firm capacity and the 50% exceedance level results in a higher firm

TABLE K.1-11 Estimated Cost of LTEMP Experiments

Experimental Element and Pair	Average NPV Cost Difference over 20 Years ($ million)			Average NPV Cost Per Experiment ($ million)			Average Daily NPV Cost ($ million)		
	Energy	Capacity	Total	Energy	Capacity	Total	Energy	Capacity	Total
Low summer flows (long-term strategies D4, D1)	1.97	13.03	15.00	2.76	18.25	21.01	0.03	0.20	0.23
Low summer flows (long-term strategies E3, E5)	3.36	17.86	21.22	2.21	11.72	13.93	0.02	0.13	0.15
TMFs (long-term strategies D3, D1)	3.49	0.00	3.49	0.45	0.00	0.45	0.030	0.00	0.030
TMFs long-term strategies (E3, E6)	0.98	0.00	0.98	0.41	0.00	0.41	0.027	0.00	0.027
Macroinvertebrate production flows (long-term strategies D1, D2)	10.6	–30.5	–19.9	0.871	–2.49	–1.62	0.026	–0.073	–0.048
Fall HFEs (long-term strategies C3, C4)	24.98	0.00	24.98	1.62	0.00	1.62	0.35	0.00	0.35
Fall HFEs (long-term strategies E3, E4)	24.54	0.00	24.54	1.65	0.00	1.65	0.36	0.00	0.36

TABLE K.1-12 Comparison of Marketable Capacity, Replacement Capacity, and Capacity Additions by Exceedance Level

Capacity Type	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
99% Exceedance Level							
SLCA/IP Marketable Capacity (MW)[a]	611.2 (no change from current condition)	619.9 (1.4% increase)	510.7 (16.4% decrease)	599.8 (1.8% decrease)	542.2 (11.3% decrease)	354.5 (42.0% decrease)	466.8 (23.6% decrease)
SLCA/IP Replacement Capacity (MW)[b]	Not applicable	–8.8	100.5	11.3	68.9	256.7	144.3
System-Level Generating Capacity Additions (MW)[c]	5,050 (no change from current condition)	5,050 (no change from current condition)	5,050 (no change from current condition)	5,050 (no change from current condition)	5,050 (no change from current condition)	5,280 (4.6% increase)	5,280 (4.6% increase)
90% Exceedance Level							
SLCA/IP Firm Capacity (MW)[a]	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP Lost Capacity (MW)[b]	Not applicable	–28.1	129.1	49.6	90.2	314.1	179.0
System-Level Generating Capacity Additions (MW)[c]	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
50% Exceedance Level							
SLCA/IP Firm Capacity (MW)[a]	959.9 (no change from current condition)	987.0 (2.8% increase)	780.2 (18.7% decrease)	878.3 (8.5% decrease)	829.1 (13.6% decrease)	569.6 (59.3% decrease)	722.1 (24.8% decrease)
Lost (positive values) or Gained (negative values) Capacity (MW)[b]	Not applicable	–27.2	179.7	81.6	130.8	390.3	237.8

TABLE K.1-12 (Cont.)

Capacity Type	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
System-Level Generating Capacity Additions (MW)[c]	4,820 (no change from current condition)	4,590 (4.8% decrease)	5,050 (4.8% increase)	4,820 (no change from current condition)	4,820 (no change from current condition)	5,280 (9.5% increase)	5,050 (4.8% increase)

[a] Additional generation capacity required under the LTEMP alternatives for WAPA's customers over the 20-year LTEMP period to not only meet future load demand and replace unit retirements, but also to account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.

[b] Lost capacity is the difference between the marketable capacity in Alternative A and the marketable capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.

[c] Additional generation capacity required under the LTEMP alternatives for WAPA's customers over the 20-year LTEMP period to not only meet future load demand but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints

capacity. A higher exceedance level means SLCA/IP federal hydropower resources will be able to supply the system with all of the computed firm capacity more often than when a lower exceedance level is used. In addition, in the 50 to 99% exceedance range, the higher the exceedance level, the lower the firm capacity difference among alternatives. Therefore, the higher the exceedance level, the smaller the difference in in capital and fixed O&M costs among alternatives.

The AURORA model was run both in capacity expansion and dispatch mode to determine the NPV costs of the new expansion pathways and the production costs for the 50% and 99% exceedance levels for the representative trace. Figures K.1-46, K.1-47, and K.1-48 show results for the 50%, 90%, and 99% exceedance levels, respectively. These figures also show the difference in cost between various alternatives and Alternative A for each of the three components that compose the total cost of the alternative: capital, fixed O&M, and production or energy. The black bar for each alternative shows the total cost of the alternative if excess capacity above the amount required to satisfy the reserve margin is sold to the market. This sale of excess capacity could either raise or lower the total alternative cost compared to Alternative A. Results shown in all three figures are based on a 3.375% discount rate. The relative ranking of alternatives for these two sensitivity analyses are similar to the 90% exceedance level (that is, in order from highest to lowest, Alternatives B, A, D, E, C, G, and F). In addition, this ranking is identical whether excess firm capacity is either sold or not sold.

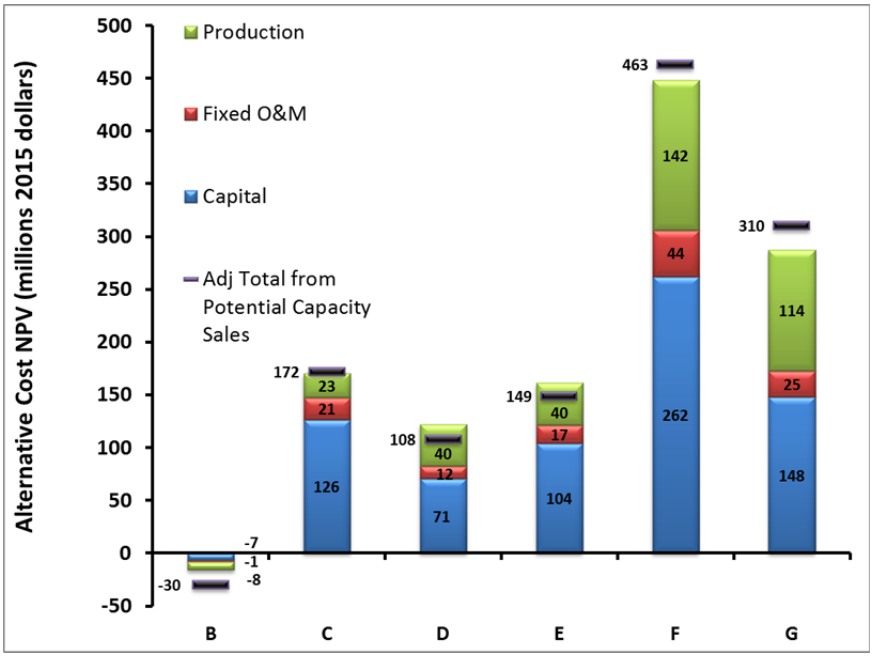

FIGURE K.1-46 Cost Difference of Alternatives Compared to Alternative A at 50% Exceedance Level and 3.375% Discount Rate

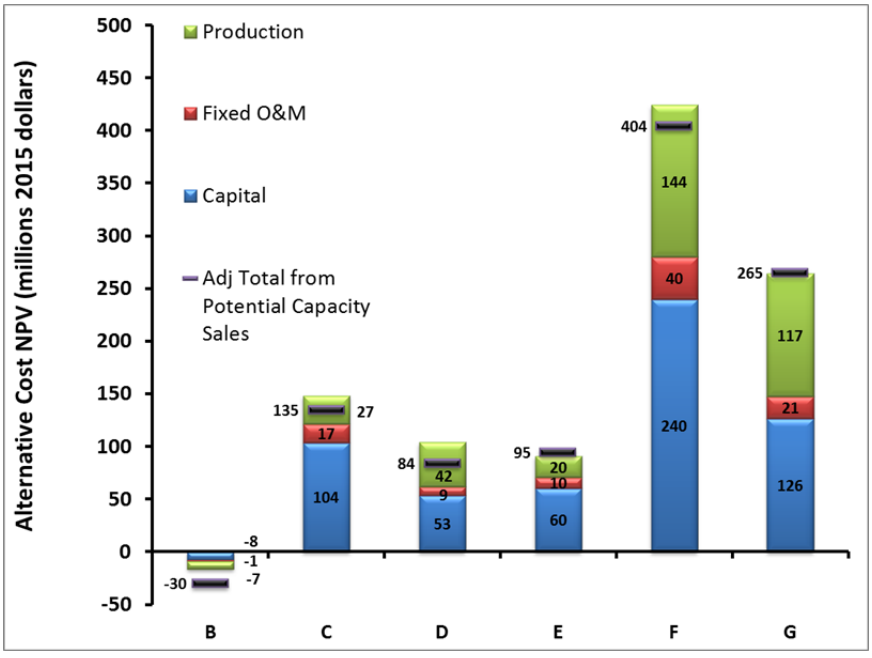

FIGURE K.1-47 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate

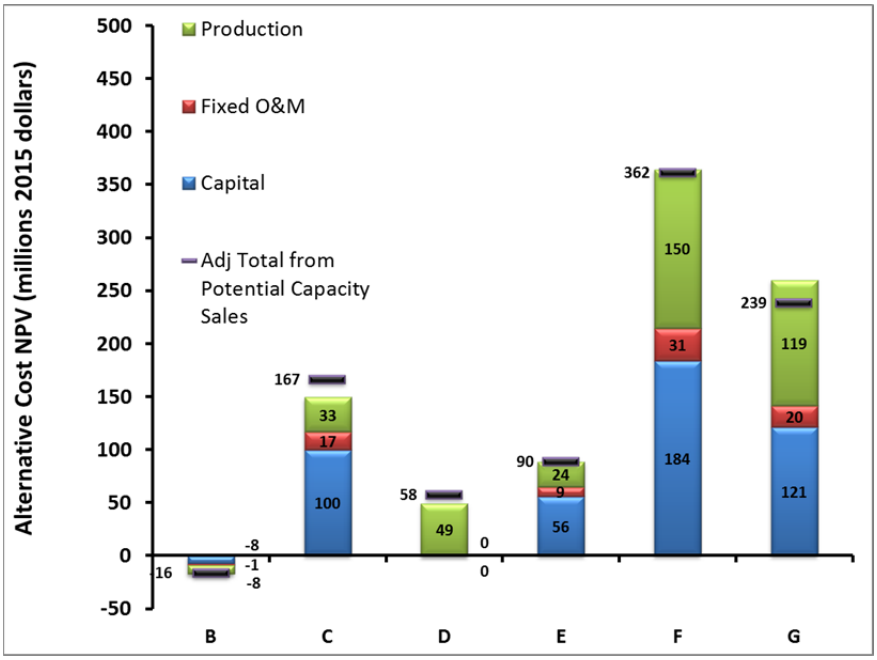

FIGURE K.1-48 Cost Difference of Alternatives Compared to Alternative A at 99% Exceedance Level and 3.375% Discount Rate

The figures show that as the exceedance level increases, the difference in the cost of each component and the total cost compared to Alternative A decreases. The alternative cost differences are smaller because the difference in firm SLCA/IP federal hydropower capacity between the various alternatives and Alternative A is lower as the exceedance level increases. Because a smaller amount of new capacity is needed to replace capacity lost at Glen Canyon Dam compared to Alternative A, each cost component and the total cost of the alternative is reduced.

At all exceedance levels, the cost of Alternatives F and G, which both have steady flow operating requirements, have the highest costs of all alternatives because they have the lowest firm capacity and no operational flexibility. Therefore, both require the largest amount of new capacity additions to replace lost Glen Canyon Dam capacity. Alternative F is the highest cost because, unlike Alternative G, it has very high monthly water releases at a time of the year (i.e., spring) with relatively low marginal production costs, and low releases during the high-production-cost summer months of July and August. In contrast, Alternative B is always the lowest cost alternative because it has a higher firm capacity than Alternative A and slightly more operational flexibility. The other three alternatives also have approximately the same ranking across all three exceedance levels.

Note that in Figure K.1-48 (the 99% exceedance level), the capital and fixed O&M cost differences between Alternatives A and D are zero. This occurs because the capacity expansion schedule is identical in both alternatives; that is, the amount and type of capacity is brought online at exactly the same time. Table K.1-12 has examples of other alternatives that have the same amount of capacity additions at the end of the LTEMP period as Alternative A, but still

have a difference in the capital and fixed O&M costs compared to Alternative A. This occurs because of the difference in timing of capacity additions. This result again illustrates the lumpy nature of capacity expansion due to the fact that plants used for capacity expansion have a discrete size; thus, adding one or a combination of several may exceed the capacity needed to just fulfill the reserve margin requirement.

Finally, the cost differences between an alternative and Alternative A are a very small percent of the total cost of the alternative across this wide range of exceedance levels. For example, Alternative F is the highest cost alternative at all three exceedance levels. At the 50% exceedance level, Alternative F costs more about $448 million more than Alternative A. However, this difference is only about 1.2% of the total cost of Alternative A, which is about $36.2 billion.

K.1.10.5 Sensitivity of Results to Discount Rate

Up to this point NPVs have been calculated using an annual discount rate of 3.375%, which is a rate used by Reclamation for project cost-benefit studies. The LTEMP hydropower subject matter expert team that helped guide this power systems study expressed concern that the 3.375% rate appears to be too high under current economic conditions. Therefore, a real annual discount rate of 1.4% was used for the sensitivity study. That value was obtained from the Office of Management and Budget Circular A-94, Appendix C (available at https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c). That rate is the real interest rate on treasury notes and bonds with a maturity of 30 years.

Figure K.1-49 shows the 20-year NPV cost differences between each alternative and Alternative A for the representative trace at the 90% exceedance level using the 1.4% real discount rate. This figure should be compared to Figure K.1-47, which is the same exceedance level but for the baseline discount rate. When using a lower discount rate, the NPV costs of alternatives relative to Alternative A are larger because costs at the end of the study period have a larger contribution to the NPV. Note that the NPV cost difference between Alternatives F and A is approximately a half billion dollars ($508 million, if adjustment for potential excess capacity sales is not included). However, the relative ranking of alternatives from lowest to highest cost, and relative percent difference from Alternative A do not change for these two discount rates. Alternative B is the lowest cost alternative, followed by Alternatives A, E, D, C, G, and F. If it is assumed that excess capacity will be sold to an entity outside of the SLCA/IP market system, then Alternatives D and E change places in the alternative ranking.

K.1.10.6 Sensitivity of Results to the Base Capacity Expansion Path

The new generating unit additions projected by the AURORA capacity expansion model run for Alternative A represents a reasonable and plausible outlook that is consistent with utility IRPs in the region and the 2014 AEO (EIA 2014) projections. However, as stated earlier, the AURORA model bases capacity expansion decisions more on local financial objectives than on economic ones. Argonne power systems analysts also discovered that small changes in some

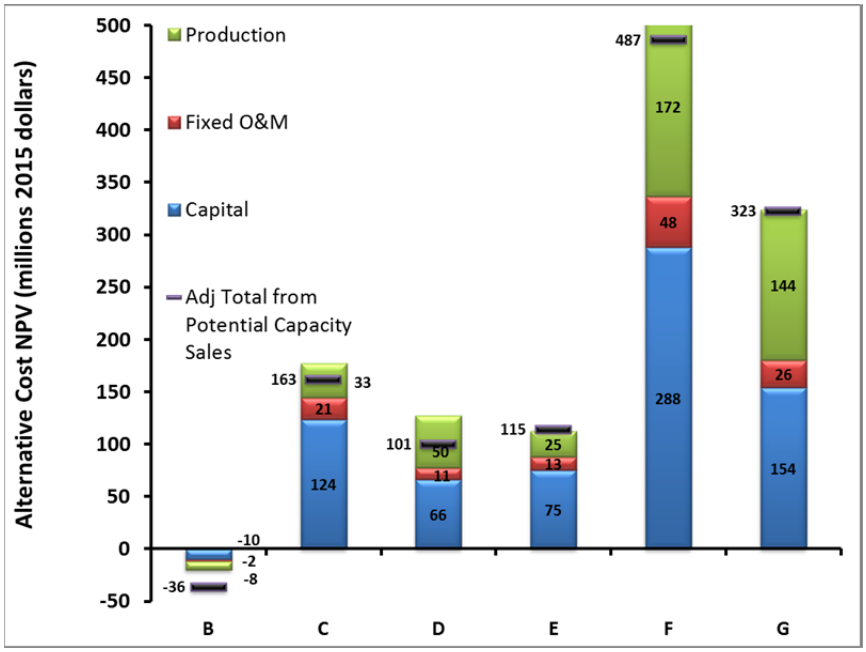

FIGURE K.1-49 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 1.4% Discount Rate

AURORA inputs would lead to substantial changes in capacity expansion pathways. This model behavior leads to uncertainty about the impact of Alternative A's expansion pathway on the final results and about the conclusions that could ultimately be made about power systems economic impacts.

Although pathways were different, it became apparent that the advanced combustion turbines and advanced combined cycle units were the two expansion candidates used almost exclusively by AURORA for new future additions. Therefore, additional model runs were made to measure the sensitivity of the base capacity expansion pathway on economic outcomes. Two extreme Alternative A pathways were tested. Both were based on a 90% exceedance level and a 3.375% discount rate. One pathway built exclusively advanced combustion turbines and the second pathway build only the advanced combined cycle plants. The base construction pathway (i.e., the type and timing of additions) for Alternative A was used as the starting point for each of the other alternatives. Advanced combustion turbines were added to (or in the case of Alternative B, subtracted from) a base expansion pathway to accommodate capacity changes at Glen Canyon Dam. Results for these two extreme pathways are shown in Figures K.1-50 and K.1-51.

For both pathways, the comparative results show the same basic pattern as all of the previously discussed results. Alternative ranking is basically the same. However, under the advanced combined cycle base expansion pathway, costs (stacked bars) are noticeably higher for Alternatives D and E as compared to the primary assumption set reported in Chapter 4 (i.e., mixed technology expansion, 90% exceedance, and a 3.375% discount rate shown in Figure K.1-47). Also under the advanced combustion turbine base expansion pathway, costs for

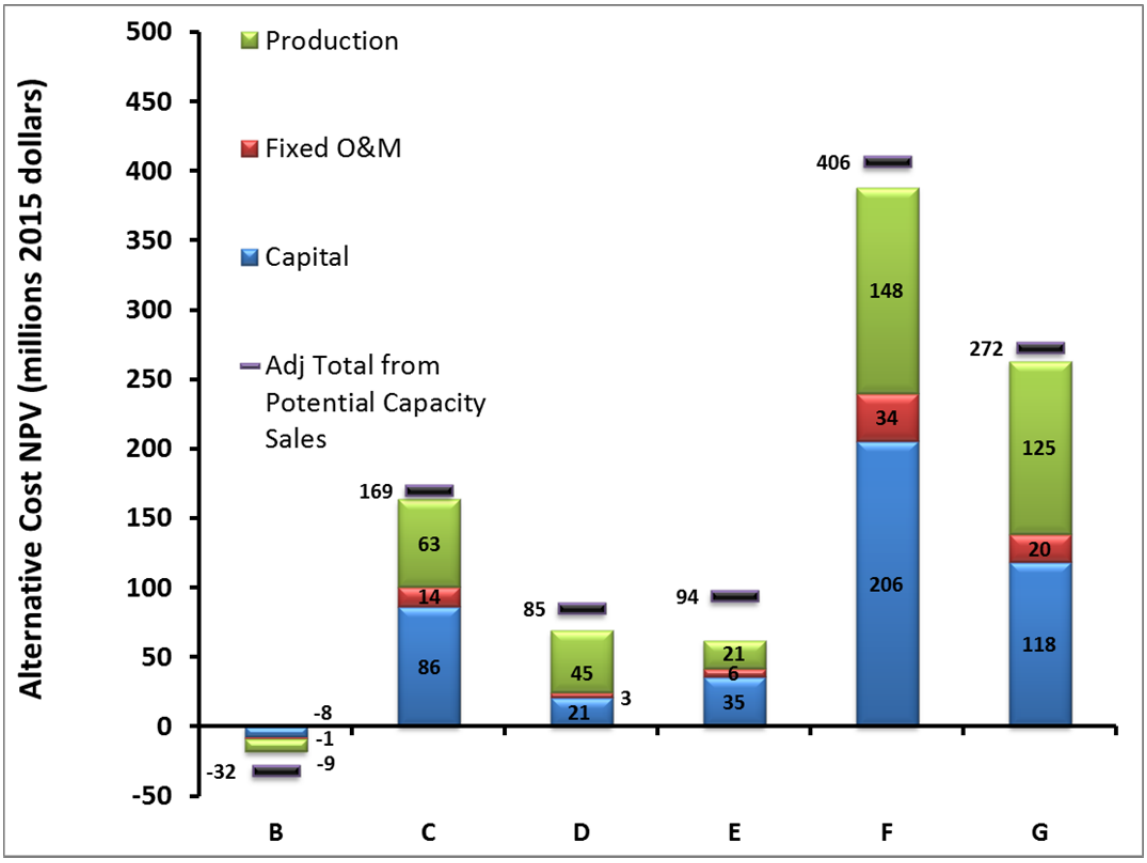

FIGURE K.1-50 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combustion Turbines

Alternatives D, E, F, and G are lower. This is due primarily to the lumpy nature of capacity additions. If excess capacity can be sold, the effects of this lumpy behavior are significantly reduced. Note that for each alternative the black bars for the three base expansion pathways are very similar.

K.1.10.7 Sensitivity of Results to the Assumed Future Hydrological Conditions

Hydrology Trace 14 in combination with sediment Trace 2, which was the most probably sediment condition, was used as the representative trace. However, as noted earlier, the impacts of an alternative are dependent on the hydrological conditions. Therefore, the timing of dry, average, and wet hydrological condition is important because discounting in the NPV computation gives a higher weight to near-term costs as compared to costs that are incurred in the more distant future.

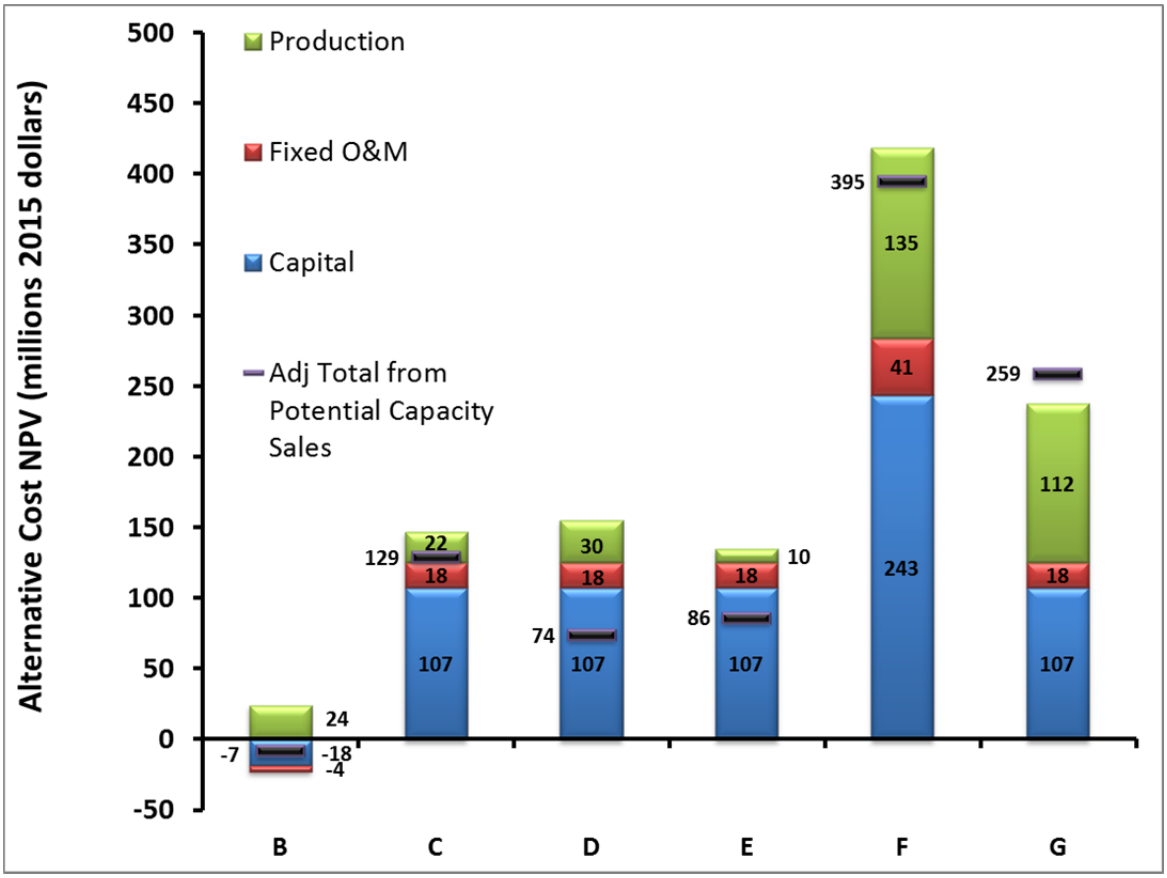

FIGURE K.1-51 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combined Cycle

This section is intended to provide insights into the economic results' sensitivity to the selected hydrological condition. Ideally, all possible combinations of the 21 hydrology traces and three sediment traces would be simulated with the AURORA model in dispatch mode over the 20-year study period. However, such an effort would be very time consuming. As a simplification, only one other hydrological condition was run. For each hour of the LTEMP study period, this condition uses the average hourly generation from all 21 traces under sediment Trace 2 as projected by GTMax-Lite runs of Glen Canyon Dam. Results for this average hydropower condition are shown in Figure K.1-52.

Note that all capital and fixed O&M costs in Figure K.1-52, as shown by the blue and red bars, respectively, are identical to those shown in Figure K.1-47 for the primary assumption set. This occurs because capacity expansion decisions are made under uncertainty. For this power systems study, the expansion pathway for each alternative is based on a set of 21 plausible future hydrological conditions. It is also assumed that once the firm capacity level is determined and input into the AURORA model to determine an alternative-specific expansion path, the firm capacity level does not change regardless of the sequence of actual hydrological conditions that occur in the future. Therefore, the representative trace and the average trace use identical

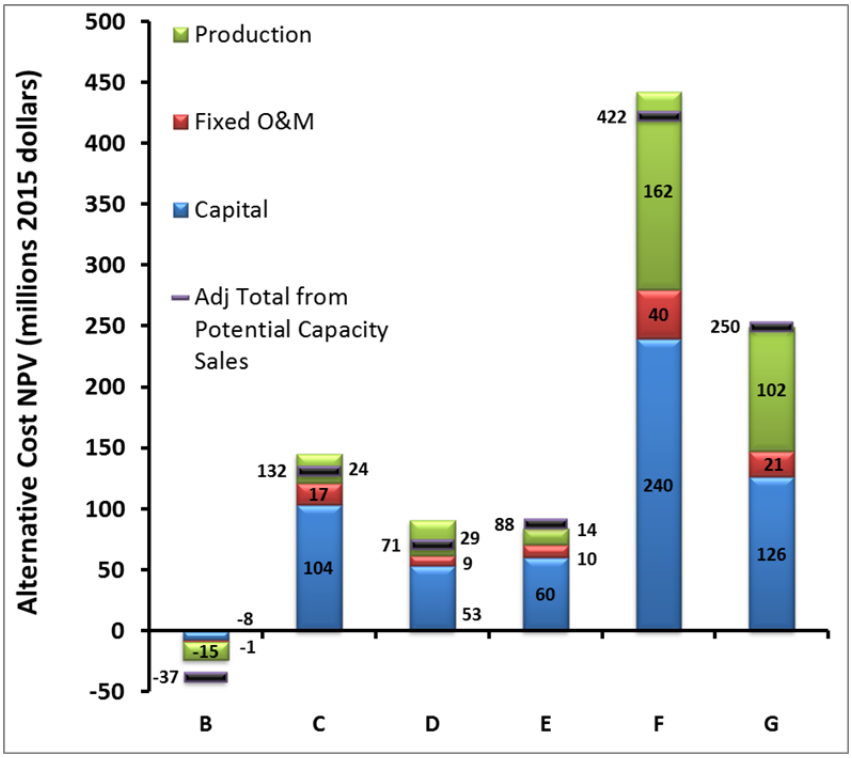

FIGURE K.1-52 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate Assuming Average Hydropower Conditions

capacity expansion pathways. If other hydropower conditions were run, each one would use this fixed expansion path.

Although capital and fixed O&M costs are identical, production costs (green bars) are slightly different. This does not provide definitive proof that the selected trace does not have a substantial impact on economic outcomes, but it does show that the representative trace—which has a sequence of dry, average, wet, average, and dry conditions over the study period—produces a result that is very similar to a sequence of average hydropower conditions.

K.1.10.8 Sensitivity of Results to Changes in Ancillary Services

A sensitivity study was performed on the effect changes in ancillary services (AS), which is the sum of regulation and fast spinning reserves, would have on the value of energy and firm capacity from Glen Canyon Dam. It was performed because assumptions about ancillary service requirements changed from when the GTMax-Lite model was run for the swing-weighting exercise in March 2014 (swing-weighting described in Appendix C). For this modeling, ancillary service requirements at Glen Canyon Dam were projected to be 103 MW in 2013 and then to increase to 160 MW by 2030. This case was called the high AS scenario. However, subsequent to this modeling, a second scenario was determined by WAPA to be more likely (i.e., ancillary

service requirements would remain at the same levels that exist today). Glen Canyon Dam currently supplies 67 MW of ancillary services and WAPA currently expects this not to increase during the LTEMP study period. This case was called the current AS scenario. This section reports the results of the study.

Using a lower ancillary service requirement will affect Glen Canyon Dam dispatch, firm capacity levels, and economic evaluations. In addition, alternatives that allow higher operational flexibility may be affected more than ones with very stringent limitations. Therefore, a sensitivity analysis was conducted to evaluate the magnitude of change that would occur in model results if the current AS scenario had been used.

Because it would have been costly to redo the entire analysis using current ancillary service requirements, a sensitivity analysis was performed that used a simpler methodology to gage differences in firm capacity and energy economics among Alternatives A, D, and F under two disparate ancillary service market assumptions. Prior to conducting the sensitivity analysis, it was determined that, if differences in the marketable capacity and energy for these three alternatives were dissimilar (e.g., more than 5% different) under the two AS cases, a second phase analysis would be performed. Since the results showed very little difference between the ancillary services scenarios, the more detailed second phase analysis was deemed unnecessary.

Alternatives A, D, and F were chosen because they span a wide range of firm capacities that the LTEMP alternatives exhibit. Alternative A is the current operating regime and has the second highest firm capacity; Alternative F is a steady flow alternative and has the lowest marketable capacity; and Alternative D represents a mid-range firm capacity level. To expedite the analysis, end-of-month elevations and monthly release values from the CRSS model for just Trace 14 (i.e., the representative hydrology trace) was analyzed. Monthly releases input to the Glen Canyon Dam GTMax-Lite model were not adjusted for experiments (either HFEs or TMFs) because CRSS results did not account for them. Experiments are only added by the SBM and are assumed to have relatively small impacts on firm capacity at exceedance levels over 50%.

The GTMax-Lite model was run and results were stored for hourly generation over the entire study period. Firm capacity for several exceedance levels above 50% under the three alternatives were then estimated for both sets of ancillary service values. The value of generation was determined by multiplying hourly generation levels by corresponding hourly Palo Verde LMPs. Hourly values were then summed to determine the total economic energy value. Next, differences in firm capacity and energy value among the three alternatives were computed and results from the ancillary services cases were compared.

Ancillary services sensitivity analysis results are shown in Tables K.1-13 through K.1-15 below. Table K.1-13 shows the capacity at exceedance levels ranging from 0 to 100% for the three alternatives and the two ancillary service scenarios. At capacity exceedance levels of interest for the LTEMP analysis (namely, 50% to 99%), the capacity differs by less than 5% between the two ancillary services scenarios.

TABLE K.1-13 Firm SLCA/IP Federal Hydropower Capacity (MW) at Various Exceedance Levels at Glen Canyon Dam by Alternative and Ancillary Service Scenarios

	Alternative A (No Action Alternative)		Alternative D (Preferred Alternative)		Alternative F	
Exceedance	Current AS	High AS	Current AS	High AS	Current AS	High AS
100	519	495	458	458	191	191
99	519	495	458	458	191	191
90	550	549	484	481	212	212
80	575	575	525	511	232	232
70	630	623	546	544	241	241
60	647	647	564	564	251	251
50	673	673	591	584	259	259
40	694	694	595	595	267	267
30	716	716	620	607	276	276
20	890	830	887	827	692	692
10	975	967	987	967	985	985
1	1097	1097	1097	1097	1097	1097
0	1097	1097	1097	1097	1097	1097

Table K.1-14 shows capacity (MW), energy (GWh), energy lost in non-power releases (bypasses and spills) (GWh), and the NPV of all cost components for the 3 alternatives. The capacity shown in Tables K.1-14 and K.1-15 is at the 90% exceedance level; it shows that there is a very small difference (less than 0.8%) in the capacity and energy, in terms of MW and GWh, respectively, between the high AS and current AS scenarios for Alternatives A and D. There is no difference between the ancillary service scenarios for Alternative F. The difference in total NPV between the two scenarios for Alternatives A and D is $2.86 million (0.08%) for Alternative A and $4.71 million (0.14%) for D. There is no difference between the ancillary services scenarios for Alternative F.

Table K.1-15 compares the differences in firm capacity and energy in Alternatives D and F relative to Alternative A for both ancillary services scenarios. Again, the ancillary services scenario has only a very minor effect on the relative difference between each alternative and Alternative A.

These results show very little difference among ancillary services scenarios. The primary reason for this is that under all three alternatives operating criteria do not allow the Glen Canyon Dam Powerplant to utilize a significant amount of its capacity under most hydropower conditions; that is, the criteria almost always restrict the maximum Glen Canyon Dam output to a level that is significantly below the physical maximum capacity. This gap between maximum output and physical capacity can be used for ancillary services because all alternatives allow exception criteria and restrict hourly average flow rates, but not instantaneous rates. For example, under Alternatives A and D, daily change specifications typically limit maximum output levels far (more than 160 MW) below the maximum physical output of the plant. Therefore, ancillary services requirements do not usually bind operations. Note that the power

TABLE K.1-14 Comparison of Capacity and Energy Values at Glen Canyon Dam by Alternative and Ancillary Services Scenarios at the 90% Exceedance Level

Ancillary Service Scenario and Alternative	Capacity (MW)	Energy (GWh)	Energy Lost in Non-Power Releases (GWh)	NPV ($millions)			Increase in Value Compared to Current AS
				Capacity	Energy	Total	
High AS Scenario							
Alternative A	548.9	88,754	1,824	422.77	3,054.06	3,476.82	Not Applicable
Alternative D	480.7	88,794	1,552	370.29	3,043.68	3,413.97	Not Applicable
Alternative F	212.3	88,081	1,918	163.53	2,916.39	3,079.92	Not Applicable
Current AS Scenario							
Alternative A	550.3	88,757	1,821	423.87	3,055.81	3,479.68	2.86
Alternative D	484.2	88,798	1,548	372.95	3,045.73	3,418.68	4.71
Alternative F	212.3	88,081	1,918	163.53	2,916.39	3,079.92	0.00

TABLE K.1-15 Difference Relative to Alternative A (value of Alternative A minus value of alternative)

Strategy	Capacity (MW)	Energy (GWh)	Non-Power Releases (GWh)	NPV ($millions)		
				Capacity	Energy	Total
High AS Scenario						
Alternative D	68.13	-40.77	272.04	52.48	10.38	62.85
Alternative F	336.55	672.59	-93.50	259.23	137.67	396.90
Current AS Scenario						
Alternative D	66.10	-41.04	272.31	50.92	10.09	61.00
Alternative F	337.98	676.04	-96.95	260.33	139.42	399.76
Difference (Current−High)						
Alternative D	-2.02	-0.27	0.27	-1.56	-0.22	-1.78
Alternative F	1.43	3.45	-3.45	1.10	1.76	2.86

systems analysis did not evaluate the value of any unused capacity (i.e., the differences between the physical powerplant capacity minus the sum of generation plus ancillary services).

Based on insights gained from this study, it was concluded that ancillary services assumptions under a range of plausible futures have little to no effect on firm capacity and energy value for the LTEMP alternatives. Therefore, it was not necessary to conduct more detailed analyses on ancillary services.

K.1.10.9 Sensitivity of Results to Customer Capacity Expansion Assumptions

There are uncertainties regarding the actual capacity replacement that may come to fruition. For example, utilities usually consider other factors beyond costs when determining new thermal power plant additions. Also capacity expansion models such as AURORA make many simplifying assumptions regarding plant siting, system unit commitments, and power plant operations in order to make the expansion problem it solves tractable. Models are therefore only an approximation of reality and decision makers typically factor modeling limitations into the capacity expansion planning process.

Because of modeling limitations and the complexity of determining optimal build schedules, a sensitivity analysis was performed. The sensitivity analysis considered a separate case in which capacity expansion changes relative to Alternative A would be made using a mix of 60% NGCC and 40% CT in terms of MW of capacity. This mix is approximately equal to the current average thermal capacity expansion mix contained in the IRPs in the joint system and utilities in surrounding area. It was derived from a review of IRPs that were available online in May 2016. Attachment K.11 provides a summary of capacity additions through the end of CY2034.

The capacity expansion analysis performed with the AURORA model and described in Section K.1.10.2 shows that in the future, the joint system would build a combination of advanced CT and NGCC units along with renewable technologies under all alternatives. However, as shown in Table K.1-8, only the timing and number of CT unit additions differ among alternatives; that is, the NGCC build schedule remained static. Therefore, the lost capacity at Glen Canyon Dam due to more restrictive operating criteria under Alternatives C, D, E, F, and G would be exclusively replaced by CT capacity additions. Alternative B shows a delay in the construction of one CT unit.

In terms of $/MW, both capital and fixed O&M costs are higher for the advanced NGCC technology as compared to the advanced CT technology (see Table K.1-1). Therefore, assuming a mix of replacement technologies impacts the estimated cost of alternatives. Similar to the sensitivity analysis that was performed for ancillary service assumptions (Section K.1.10.8), the GTMax-Lite model was used to estimate the range of LTEMP alternative capital and fixed O&M costs. This modeling method was selected because it runs more rapidly with far fewer resources than AURORA, yet it produces similar results in terms of both differences in total NPV among

alternatives and alternative ranking.[5] To roughly estimate costs under the mixed capacity replacement assumption, GTMax-lite was run for the two cases under consideration—replacement capacity provided by new CT plants only or a mix of 60% NGCC/40% CT plants. The difference between the two cases represents the higher cost of replacing lost Glen Canyon Dam capacity via a mix of thermal technologies instead of adjusting only CT capacity additions.

Table K.1-16 shows that using a mix of CT and NGCC replacement technologies at the 90% exceedance level would increase costs for all alternatives except for Alternative B which has a higher benefit (shown as a negative cost) of approximately $11.0 million. The costs for all other alternatives increase from $17.1 million under Alternative D (Preferred Alternative) to $93.4 million under Alternative F. Note that assuming a mix of capacity replacements does not change alternative rankings.

The estimated incremental cost shown in Table K.1-13 uses a simplified method and should therefore be viewed as an approximation of changes in costs between the CT only replacement case and the mixed technology replacement case. It does not capture the impact of capacity additions on the system dispatch and therefore changes in production costs. Because NGCC technologies are more efficient than CTs, the higher capital and fixed O&M costs for

TABLE K.1-16 Alternative Cost Increase Estimates for Mixed NGCC/CT Technology Capacity Replacement Relative to CT Only Replacement as Estimated Using GTMax-Lite

Alternative	Relative Cost of CT Only Replacement (million 2015$)[a]	Relative Cost of Mixed NGCC/CT Replacement (million 2015$)[b]	NGCC/CT Cost Increase (million 2015$)	Rank
A	0.0	0.0	0.0	2
B	-46.2	-57.2	-11.0	1
C	133.8	175.9	42.0	5
D (Preferred)	81.3	98.4	17.1	3
E	93.2	125.0	31.8	4
F	395.0	488.4	93.4	7
G	260.7	317.1	56.4	6

[a] Costs are relative to those of Alternative A. Assumes natural gas combustion turbines would be used to replace all capacity from Glen Canyon.

[b] Costs are relative to those of Alternative A. Assumes a 60% natural gas combined cycle/40% natural gas combustion turbine mix would replace lost capacity.

[5] The GTMax-lite expansion approach produced rankings that are identical to the AURORA model except that Alternative D (Preferred Alternative) has a slighter higher power systems ranking (i.e., lower cost) using GTMax-lite, and Alternative E has a slightly lower one.

NGCCs are partially offset by lower system production costs. Compared to an advanced CT, the advanced NGCC technology would be operated more frequently, generates more energy, and displaces more generation from expensive energy producing resources. Also, the GTMax-Lite methodology immediately replaces lost capacity compared to the AURORA method that, under most alternatives, replaces capacity 2 to 3 years after the start of the study period. As a result, the GTMax-Lite method tends to overestimate the incremental cost associated with replacing lost capacity with a mix of technologies.

K.1.10.10 Summary of Economic Ranking

Power systems analysis results show that there are three distinct groups of outcomes. Alternatives A and B are clearly the most favorable for hydropower economics, while Alternatives F and G are the least favorable. Alternatives C, D, and E rank between these two extremes. As shown in Table K.1-17, the ranking of alternatives is very consistent regardless of changes in assumptions that were made in the sensitivity runs. Alternatives D and E switched ranking under only two sets of assumptions. This order switch between the third and fourth rank is mainly attributed to the lumpy nature of capacity expansion paths. Among the sensitivity analyses conducted the discount rate assumption had the largest impact on absolute economic costs, but in terms of percent changes in total system costs that were tracked, it had negligible effects.

It is noteworthy that as the exceedance level increased from 50% to 99% the cost of the alternatives decreased, but the rankings did not change except for the aforementioned switching of Alternatives D and E. Although cost differences among alternatives decrease, higher exceedance levels increase overall SLCA/IP market system costs for all alternatives; however, system reliability improves with higher exceedance levels since there is more capacity built in the system.

Last, the rankings of alternatives are also in general agreement with those found in the structured decision analysis (SDA). The SDA report shows that the value of GCD hydropower production is the highest under Alternative B followed closely by Alternative A. Alternatives F and G have the least value, respectively, and the remaining alternatives are between these bookends.

K.2 WAPA'S SLCA/IP FIRM ELECTRIC SERVICE RATE IMPACTS[6]

The SLCA/IP firm electric service (FES) rate is the price paid per unit of product sold by WAPA's CRSP Management Center to its SLCA/IP FES customers. Two SLCA/IP commodities are sold, namely firm capacity and firm energy. Each has a separate price. This section

6 New terms and acronyms used in this section are defined at first use, and definitions of those terms are provided at the end of the section.

TABLE K.1-17 Summary of Economic Rankings for Baseline and All Sensitivity Scenarios

Assumptions					Alternative Rank (lowest to highest total cost)						
Exceedance Level (%)	Excess Capacity Sales	Hydrology	Base Expansion Path	Discount Rate (%)	A	B	C	D	E	F	G
90	No	Representative Trace	CT & NGCC	3.375	2	1	5	4	3	7	6
90	Yes	Representative Trace	CT & NGCC	3.375	2	1	5	3	4	7	6
50	No	Representative Trace	CT & NGCC	3.375	2	1	5	3	4	7	6
50	Yes	Representative Trace	CT & NGCC	3.375	2	1	5	3	4	7	6
99	No	Representative Trace	CT & NGCC	3.375	2	1	5	3	4	7	6
99	Yes	Representative Trace	CT & NGCC	3.375	2	1	5	3	4	7	6
90	No	Representative Trace	CT & NGCC	1.4	2	1	5	4	3	7	6
90	Yes	Representative Trace	CT & NGCC	1.4	2	1	5	3	4	7	6
90	No	Average Hydropower	CT & NGCC	3.375	2	1	5	4	3	7	6
90	Yes	Average Hydropower	CT & NGCC	3.375	2	1	5	3	4	7	6
90	No	Representative Trace	CT	3.375	2	1	5	4	3	7	6
90	Yes	Representative Trace	CT	3.375	2	1	5	3	4	7	6
90	No	Representative Trace	NGCC	3.375	2	1	4	5	3	7	6
90	Yes	Representative Trace	NGCC	3.375	2	1	5	3	4	7	6

documents the methods and calculations used to determine the impact of the LTEMP EIS alternatives on the SLCA/IP capacity and energy rates.[7] The analysis was performed by WAPA CRSP Management Center staff with assistance from Argonne.

The analysis in this section begins with the calculations of economic impact performed and described in Section K.1. Section K.1 describes the economic impact on electrical power production, which is the impact—measured in dollars—on the economy. It includes the system cost of changing the timing and routing of water releases at Glen Canyon Dam. It also includes the expense of constructing (or savings resulting from forgoing construction of) additional electrical generators because of changes in firm SLCA/IP hydropower capacity.

Several calculations were performed to determine the impact of the LTEMP EIS alternatives on the SLCA/IP rates. Three rates were calculated for each of the seven alternatives: (1) a firm energy rate, (2) a firm capacity rate, and (3) a composite rate. This section describes the methods and assumptions used to determine these financial rate impacts.

7 The term "rate" will be used rather than "price." This is the standard convention for wholesale electrical commodities. Rate is the price charged for an energy unit, whether capacity or energy. Rate is often used to describe wholesale prices because it is the price of wholesale units and not necessarily the units used for retail sales.

This analysis is a financial study. It uses the economic estimates described in Section K.1 as input values to conduct a financial analysis. Because existing FES contracts are firm obligations to deliver electrical power, the economic impact described in Section K.1 will affect the SLCA/IP rates through the period specified under contract. This analysis describes how the economic impacts are "stepped down," through changes in the SLCA/IP rate, to utilities that purchase Glen Canyon Dam electrical power. The analysis assumes that WAPA's contractual obligation to deliver power to its current FES customers remains unchanged from current levels through the end of the marketing period.

K.2.1 Relationship between the Economic Impacts of LTEMP Alternatives and Impacts on SLCA/IP FES Rates

It is important that this analysis of the impacts of LTEMP alternatives on SLCA/IP FES rates be compatible with the economic analysis of the impacts of alternatives on Glen Canyon Dam power production and value (as presented in Section K.1). Economic impacts are changes in the value of power systems resources. The power system economic analysis described in Section K.1 determines the economic loss (or gain) of changing the operation of Glen Canyon Dam. The economic information resulting from the analysis presented in Section K.1 is used as input values for the SLCA/IP rate analysis. This financial analysis is a "step down" from the economic analysis described in Section K.1. It demonstrates how the economic impact of alternative-specific differences in Glen Canyon Dam electric power generation affects the per-unit cost of electricity to FES customers through changes in the SLCA/IP rate.

K.2.2 Temporal Scope of the Analysis and Input Data

The SLCA/IP rate analysis is a 20-year analysis encompassing the CY 2015 through CY 2034 time period. It is assumed that the SLCA/IP rate associated with the alternative does not change throughout the power repayment study (PRS) repayment period, which extends beyond CY 2034.

As explained in Section K.2.3, the SLCA/IP rate is required to be sufficient to repay authorized irrigation projects, which have construction and repayment periods that extend for another 50 years. Therefore, although the analysis includes LTEMP EIS alternative-specific costs that differ by alternative over the 20-year time frame of the LTEMP EIS, the rate study continues with other operations and repayment expenses for many years thereafter.

Rate changes as a result of alternative operating criteria for Glen Canyon Dam impact all FES customers.[8]

8 "FES customers" and "SLCA/IP LTF customers" are used synonymously.

Data described in Section K.1 are key input data for the SLCA/IP rate impact analysis. These data include:

- The hourly SLCA/IP electrical production under each alternative for the representative 20-year trace[9] that is simulated by both the GTMax-Lite model and the Small SLCA/IP Powerplant Spreadsheet that is produced for the economic impact analysis;

- The hourly FES customer requests for energy and capacity under the terms of their contractual agreements with WAPA; and

- The estimated capacity cost for each alternative that is set equal to the AURORA model's capacity expansion plan multiplied by the technology-specific levelized cost of capital plus annual fixed O&M expenses.

K.2.3 SLCA/IP Rate Setting

A typical regulated electrical utility sets a rate based on a "test year" using a formula that recoups its estimated operations expenses and allows a fair return on its capital investment. For electrical utilities regulated by State Commissions, their rates are reviewed and approved by the Commission. This approach is quite different from the rate setting process required of WAPA.

WAPA sets SLCA/IP rates in order to repay all costs associated with power generation. WAPA must establish power rates sufficient to recover operating, maintenance, and purchase power expenses. In addition, WAPA sets rates in order to repay the federal government's investment in building these generation and transmission facilities within 50 years. Outside of the 50-year repayment period, this is similar to a regulated electrical utility. The biggest difference lies in the requirement that WAPA's rates must also be set to cover certain non-power costs Congress has assigned to power users to repay. These are authorized irrigation costs in excess of water users' ability to repay. For the CRSP, authorized irrigation projects have repayment periods that extend for another 50 years. WAPA must demonstrate to the Federal Electrical Regulatory Commission (FERC) that its SLCA/IP rate is set appropriately to make required repayment of all authorized projects. Even though FERC approves a SLCA/IP rate that expires in 5 years, it is a rate that has been demonstrated to make all required repayment of all authorized projects.

Another approach to this analysis would be to add LTEMP EIS alternative-specific expenses for 5 years, estimate a SLCA/IP rate based on that, do it again for another 5 years, and again and again. The LTEMP EIS alternative-specific impact would then show four SLCA/IP rates that cover the 20-year temporal scope of the EIS. We could then do a net present value

9 The basis for selection of a representative trace is described in Attachment K-3 of Appendix K.

calculation to 2015. This approach would have made the SLCA/IP rate analysis more comparable to the approach used in Sections K.1 and K.3. This approach would be a straight-forward calculation similar to that of a regulated utility that uses a "test year" to set rates. The expenses related to a "test year" would be available for each of the 20 years included in the LTEMP EIS time frame from the analysis in Section K.1. As explained in the previous paragraph, this approach would be significantly different from WAPA's required method of setting SLCA/IP rates. In addition, the schedule for completion of this analysis did not allow for the added time required

K.2.4 Calculation of Net Electrical Energy Expense

Figure K.2-1 illustrates the method used to determine the yearly expense of electrical energy over the 20-year study period.

K.2.4.1 SLCA/IP Electrical Production

Data on the combined amounts of electrical energy produced by all of the SLCA/IP federal hydropower plants under each alternative were generated for the economic analysis described in Section K.1, and were used as input to the SLCA/IP wholesale rate analysis. The data are hourly over the 20-year study period. There is one set of these hourly data for each LTEMP EIS alternative.

K.2.4.2 Sustainable Hydropower (SHP) and Available Hydropower (AHP) Capacity and Energy

WAPA's Energy Management and Marketing Office (EMMO) schedules electrical capacity and energy to serve FES customer energy requests. Each FES customer requests energy according to the terms and conditions of CRSP Management Center FES contracts. An FES customer can schedule an amount of energy to be delivered up to a specified capacity amount. This is known as the SHP capacity.[10] SLCA/IP FES customers also have a monthly amount of electrical energy that WAPA is obligated to deliver. A customer schedules the monthly allocation of electrical energy within the capacity limit mentioned above. This is known as the SHP energy allocation. Both capacity and energy amounts differ by customer and by month. Table K.2-1 shows CRSP Management Center current total SHP contractual obligations and project use required deliveries by month.

[10] Specific descriptions of the terms and conditions of FES contracts will not be discussed here. The abbreviated descriptions provided here are intended only to explain the process of calculating the impact of the LTEMP DEIS alternatives on the SLCA/IP wholesale rate.

TABLE K.2-1 SHP Contractual Obligations and Project Use Required Deliveries by Month

	Firm Electric Service			Project Use		Total	
Month	Capacity (kW)	Energy (kWh)	CROD[a] (kW)	Capacity (kW)	Energy (kWh)	Capacity (kW)	Energy (kWh)
Jan.	863,726	463,462,717	1,403,777	7,639	4,200,824	871,365	467,663,541
Feb.	851,326	409,824,542	1,403,777	7,639	4,200,824	858,965	414,025,365
Mar.	765,761	422,665,276	1,403,777	42,539	21,916,824	808,300	444,582,100
April	638,196	365,283,663	1,317,779	52,634	23,184,158	690,830	388,467,820
May	623,515	378,216,775	1,317,779	52,634	23,184,158	676,149	401,400,933
June	646,035	397,635,769	1,317,779	52,634	23,184,158	698,669	420,819,927
July	740,916	434,536,678	1,317,779	52,634	23,184,158	793,550	457,720,836
Aug.	714,683	437,867,014	1,317,779	52,634	23,184,158	767,317	461,051,172
Sept.	618,576	380,082,095	1,317,779	52,634	23,184,158	671,210	403,266,253
Oct.	739,646	398,608,181	1,403,777	42,539	21,916,824	782,185	420,525,004
Nov.	775,589	408,041,232	1,403,777	7,639	4,200,824	783,228	412,242,055
Dec.	869,160	455,561,848	1,403,777	7,639	4,200,824	876,799	459,762,672

[a] CROD = Contract Rate of Delivery

Because SLCA/IP FES customers are allowed to schedule SHP energy according to their individual needs, the hourly shaping of energy differs from day to day and from customer to customer. Therefore, it is necessary to estimate the aggregate daily shape of electrical energy schedules submitted to the EMMO by all FES customers. WAPA used average weekday, Saturday, and Sunday shapes for each month of WY 2014 to represent these schedules. When a holiday occurs, the load shape for Sunday is used. These SHP loads are provided in Table K.2-2.[11] In addition, the EMMO must serve project use loads that vary over time. WAPA used WY 2014 data, rather than averaging several years of loads or projecting different load shapes for future years, because the SHP daily shape does not differ substantially from year to year.

[11] In some situations, it is difficult to separate customer SHP and project use loads that are submitted to Western's EMMO. For this analysis, it is assumed that the loads in Table K.2-2 are only SHP loads even though small amounts of project use loads are included. This assumption will have minimal impact on the results, since the same hourly loads are used for all alternatives.

TABLE K.2-2 SHP Hourly Load Shapes by Month and Type of Day

Month	Day of the Week	Hour of Day																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Oct.	Wkday	275	271	267	279	320	454	594	596	673	695	714	707	717	713	720	727	734	742	748	750	729	656	451	366
	Sat.	294	288	282	280	297	417	539	538	625	653	676	671	680	672	676	686	691	701	707	711	701	640	427	352
	Sun.	272	290	275	269	287	384	467	459	494	518	562	581	588	590	599	620	632	643	652	658	627	558	382	340
Nov.	Wkday	354	295	287	291	363	460	643	676	676	697	689	677	665	657	656	680	721	773	780	776	770	734	507	441
	Sat.	351	299	290	294	363	449	580	617	639	677	672	666	654	647	644	665	702	758	767	762	753	707	504	433
	Sun.	314	270	268	267	331	391	490	518	525	525	525	525	510	506	509	543	591	673	702	699	696	648	426	399
Dec.	Wkday	346	325	319	322	391	525	698	794	785	764	760	740	721	676	665	676	719	836	853	849	833	791	612	506
	Sat.	356	342	332	334	386	496	654	751	747	735	738	722	704	662	643	652	707	823	839	835	820	776	601	489
	Sun.	324	307	309	297	347	448	568	602	586	565	570	551	537	511	509	521	586	698	765	764	752	712	490	453
Jan.	Wkday	375	358	351	379	445	586	771	810	810	784	749	735	714	698	692	689	724	845	854	850	833	793	565	441
	Sat.	376	381	375	398	435	516	691	710	725	714	691	680	662	648	639	641	677	822	835	831	788	750	559	430
	Sun.	356	343	343	340	400	449	548	562	582	559	536	523	514	504	501	511	567	688	723	721	683	629	457	394
Feb.	Wkday	360	346	340	343	374	481	769	793	805	806	740	711	691	677	624	633	664	838	861	860	843	807	608	464
	Sat.	363	361	353	352	356	425	684	725	729	736	676	652	636	621	576	587	616	780	813	815	777	745	624	446
	Sun.	341	338	344	333	334	379	557	558	569	576	520	504	490	473	470	489	531	693	777	780	739	637	532	360
Mar.	Wkday	348	334	334	359	465	585	671	704	726	723	711	703	698	689	685	689	698	744	765	770	733	641	523	411
	Sat.	367	354	351	368	450	531	609	625	682	685	677	670	667	653	645	646	664	715	747	746	719	643	513	425
	Sun.	347	342	346	353	413	479	535	541	558	552	536	537	539	527	525	536	562	622	658	660	661	586	462	409
Apr.	Wkday	307	299	296	342	396	501	548	589	601	604	632	640	646	633	632	629	630	636	649	653	633	600	510	415
	Sat.	318	309	304	328	363	471	529	562	581	587	615	618	623	609	611	613	613	619	635	641	618	585	497	409
	Sun.	301	299	293	305	328	406	428	460	479	486	490	504	517	532	541	548	554	560	573	587	570	538	446	386
May	Wkday	379	339	335	345	412	513	552	593	609	630	632	641	640	637	633	642	644	657	647	645	641	615	528	452
	Sat.	392	358	348	354	397	488	510	523	560	595	600	607	607	607	605	619	622	639	636	638	631	602	524	467
	Sun.	373	333	323	326	368	449	463	469	480	506	557	580	582	584	584	589	593	613	609	612	604	573	509	413
Jun.	Wkday	475	435	398	422	438	519	605	634	672	681	681	685	691	691	691	696	695	692	682	681	673	666	632	511
	Sat.	474	442	420	404	401	473	549	606	640	658	667	675	679	680	681	687	686	681	675	675	662	648	626	507
	Sun.	410	395	410	403	375	396	446	457	471	501	521	571	576	592	599	612	608	604	599	607	594	572	548	491
Jul.	Wkday	478	428	425	421	443	553	582	617	649	675	685	711	747	751	752	756	755	771	762	761	736	693	609	554
	Sat.	489	443	428	423	441	520	562	576	605	653	669	700	738	739	741	745	743	758	754	748	723	678	598	532
	Sun.	449	418	442	438	442	509	526	526	542	610	624	635	683	702	707	710	708	721	714	695	671	629	577	528
Aug.	Wkday	499	433	413	412	438	531	644	678	667	667	679	696	727	763	764	768	766	761	757	745	736	700	663	571
	Sat.	490	446	431	414	429	510	594	638	631	640	662	680	720	760	762	767	764	759	753	740	728	691	656	572
	Sun.	472	402	425	421	402	424	484	491	511	552	616	633	677	683	683	686	687	688	683	674	665	609	589	561
Sep.	Wkday	428	394	391	399	440	500	549	576	608	616	621	623	637	663	666	668	667	663	661	657	652	646	577	512
	Sat.	446	392	382	378	408	467	502	548	594	605	612	613	628	652	653	656	654	653	653	648	639	629	567	501
	Sun.	400	383	375	375	395	436	471	476	492	521	564	605	620	638	640	643	653	650	649	645	641	629	546	478

When seasonal SLCA/IP federal hydropower resources are significantly greater than combined SHP commitments and project use loads plus the energy required to cover delivery losses,[12] the CRSP Management Center offers its FES customers capacity and/or energy above the SHP levels. These additional offers plus SHP are referred to as available hydropower (AHP). The methodology applied for the wholesale rate analysis offers a seasonal AHP, which is distributed monthly. The seasons that met the AHP offer criteria were largely a function of hydrological condition rather than of the alternative. Each of the seven alternatives had the same number of seasons that met the AHP criteria. The alternatives differed, however, in the amount of AHP that was offered.

Based on the sequence of hydrological conditions contained in the representative trace, AHP offers were calculated for any season that met the 20% excess AHP offer criterion; that is, an AHP offer is made only if hydropower resources in a season are at least 20% greater than the seasonal SHP level.

WAPA is required under its FES contracts to provide AHP, by season, when available. However, the contracts do not specify how much energy above SHP is required to make a seasonal AHP offer. There are no set criteria for offering AHP. It is the current practice of the CRSP Management Center to review and release information for the upcoming season and decide whether to offer AHP. CRSP Management Center power marketing managers confer with EMMO managers and consider anticipated release information, market prices, the amount of anticipated energy and capacity above SHP, and other factors in making an AHP offer for the upcoming season.

For the purposes of completing this analysis, CRSP Management Center managers and staff that are involved in the seasonal determinations were surveyed to establish a criterion based on past practices. The 20% trigger represents a reasonable amount of additional available hydropower that could be efficiently and equitably offered to WAPA's more than 135 customers. Offers to FES customers are made prior to the beginning of the season.[13] If the predicted energy production above AHP levels did not occur, and an AHP offer was made, the resulting short position must be resolved by energy market purchases. When available seasonal hydropower is less than 20% it is assumed that the excess energy would be offered to the market. The 20% trigger used for this analysis is for modeling purposes only and does not represent an established policy or practice.

The amount of AHP offered in a particular month was the smaller of the percent energy above the SHP energy and the percent capacity above the SHP capacity. Once this was determined, the SLCA/IP hourly energy delivery obligation (i.e., SHP load) was scaled by the

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12 Energy delivery losses were conservatively set equal to 8.5% of the total SLCA/IP hourly federal hydropower generation when computing FES rates and seasonal customer offers above AHP levels. This level is consistent with historical levels used for ratemaking, but somewhat higher than the 5% loss rate used for power systems economic analyses presented in Section K.1.

13 SLCA/IP power is marketing in two seasons: the "summer" season is April through September, the "winter" season is October through March.

appropriate percentage for each hour in the months that offer seasonal AHP. Project use loads were not adjusted.

AHP is sold to SLCA/IP FES customers at the FES energy rate. Since the FES energy rate is typically lower than the hourly spot market price, the addition of AHP tends to reduce CRSP Management Center revenues when compared to selling this excess (or long) energy to the spot market. There is typically a relatively minor (if any) financial impact on WAPA from offering AHP capacity. All SLCA/IP FES customers are billed monthly for the CROD capacity allocation, regardless of the particular SHP or AHP capacity allocation for the month. However, there is a financial impact on WAPA when SHP capacity offers exceed the amount available from SLCA/IP federal hydropower resources (due to, for example, the aforementioned forecast error), because WAPA must purchase capacity to fill the deficit.

Seasonal SLCA/IP federal hydropower generation is almost always either above or below the SHP obligation. The logic that is used to model this energy imbalance is shown in Figure K.2-1. If generation is below the SHP obligation, it is assumed that WAPA will be a net seasonal power purchaser and cover the short energy position via the spot market at spot market prices.[14] If generation is above the SHP obligation, the excess seasonal energy is sold to the spot market at spot market prices, unless it is a season in which the AHP offer criteria are met, in which case the seasonal excess energy is sold to SLCA/IP customers at the FES energy rate.

Although WAPA may be short during a specific season, on an hourly basis it may produce SLCA/IP federal hydropower in excess of FES SHP loads (i.e., FES customer energy requests). For example, during the middle of the night, under a steady flow alternative, loads may be less than generation. Likewise, there are some hours when hydropower resources produce less energy than loads when there is excess seasonal energy. Therefore, the wholesale rate analysis uses a methodology in which long and short positions along with associated costs and revenues are computed hourly under each alternative. Spot prices are the same scaled AURORA Western Interconnection LMPs at the Palo Verde hub that are used for power system economic analyses.

K.2.5 Calculation of Capacity Expenses and Total Net Costs

In addition to the annual net expense related to electrical energy for each alternative, WAPA will have a cost related to electrical capacity purchases or, in the case of Alternative B,

[14] Western's CRSP Management Center has several decades of experience with the vicissitudes of hydrological conditions in the Colorado River basin. There have been years in which electrical production from the SLCA/IP was inadequate to meet SHP commitment levels. Western once hedged its risk of dealing with this condition by making a long-term capacity and energy purchase. Outside of one instance, Western's firming purchases have only been on the day-ahead market or for a season when conditions were forecasted to require this.

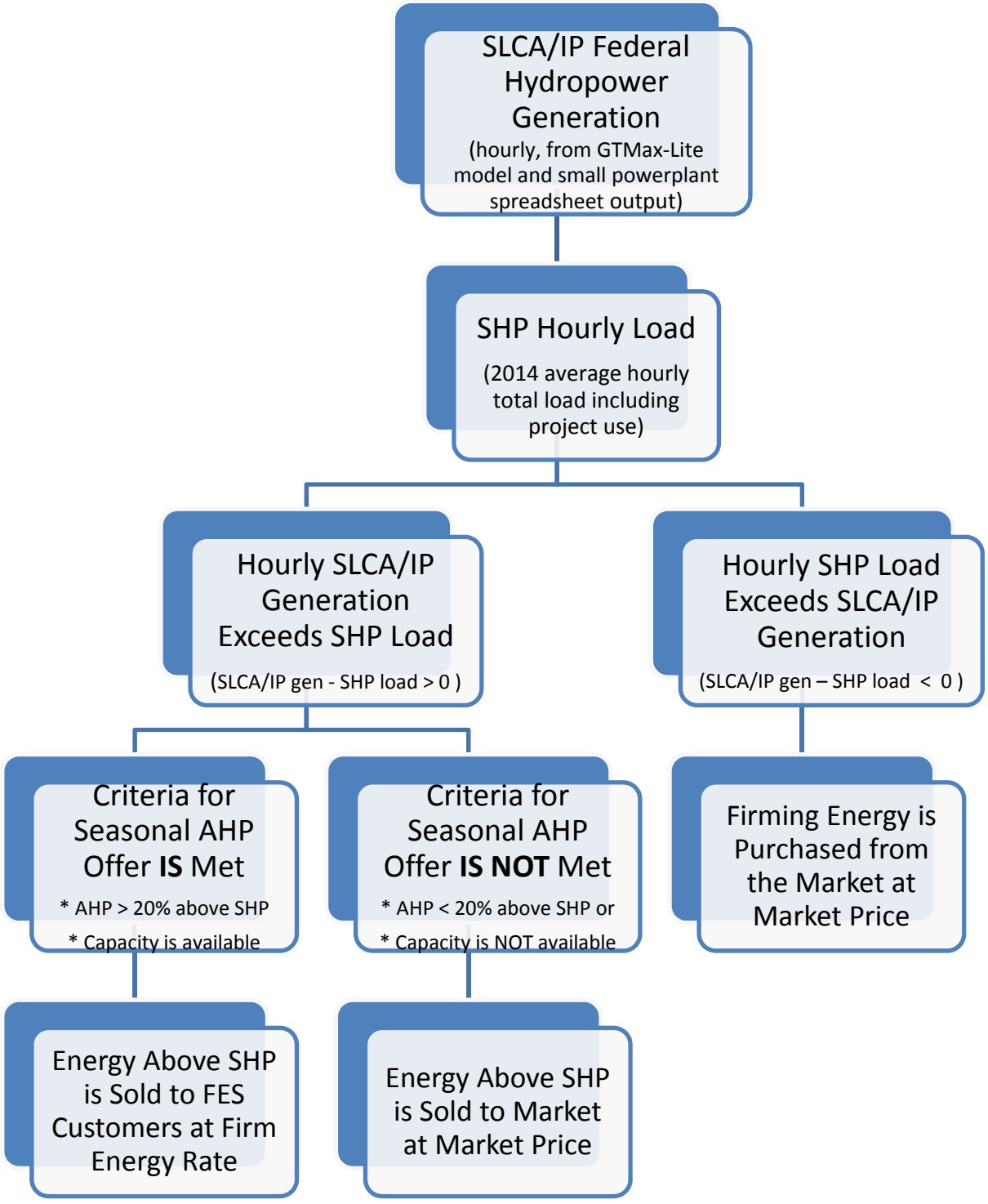

FIGURE K.2-1 Determination of Energy Hourly Expense or Revenue

capacity cost avoided.[15] As explained in Section K.2.1, an important requirement of this SLCA/IP wholesale rate analysis is to maintain compatibility with the economic analysis presented in Section K.1. The AURORA capacity expansion module applied in the analysis indicated that additional capacity facilities (construction of new generation) would be required over the 20-year LTEMP period. Table K.2-3 contains the same costs that were used in the power systems economic analysis described in Section K.1. It shows the capacity expense required over the 20-year period for each alternative.

The net energy expense for each alternative is computed as described above and illustrated in Figure K.2-2. Added to this figure is the capacity cost, by year, for each alternative. The sum of these two numbers is the total WAPA expense that is incorporated into the computation of wholesale rates (Figure K.2-2).

TABLE K.2-3 Total Levelized Capital and Fixed O&M Cost (million 2015$) for System Capacity Expansion by Alternative and Year

Year	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2017	0.0	0.0	0.0	0.0	0.0	12.2	0.0
2018	12.2	12.2	24.5	12.2	12.2	36.7	24.5
2019	46.7	46.7	58.9	46.7	46.7	71.2	58.9
2020	81.1	81.1	93.4	81.1	81.1	105.6	93.4
2021	81.1	81.1	93.4	93.4	93.4	105.6	93.4
2022	115.6	115.6	127.8	127.8	127.8	140.1	127.8
2023	150.0	150.0	162.2	162.2	162.2	174.5	162.2
2024	162.2	162.2	174.5	162.2	162.2	186.7	174.5
2025	174.5	174.5	186.7	174.5	174.5	199.0	186.7
2026	186.7	186.7	199.0	186.7	199.0	211.2	199.0
2027	199.0	199.0	211.2	211.2	211.2	223.5	211.2
2028	211.2	211.2	223.5	223.5	223.5	235.7	223.5
2029	235.7	223.5	235.7	235.7	235.7	248.0	248.0
2030	248.0	248.0	248.0	248.0	248.0	260.2	260.2
2031	260.2	260.2	260.2	260.2	260.2	272.5	272.5
2032	297.0	297.0	309.2	309.2	309.2	321.5	309.2
2033	309.2	309.2	321.5	321.5	321.5	333.7	321.5
2034	270.0	267.6	274.9	274.9	274.9	287.2	282.3

[15] Capacity in this context is LTF capacity that Western must acquire as a result of a reduction in Glen Canyon Powerplant output that is caused by a change in operating criteria specified under an LTEMP alternative. It is distinctly different from the short-term capacity discussed in the previous section that is dependent on natural short-term hydrological variability.

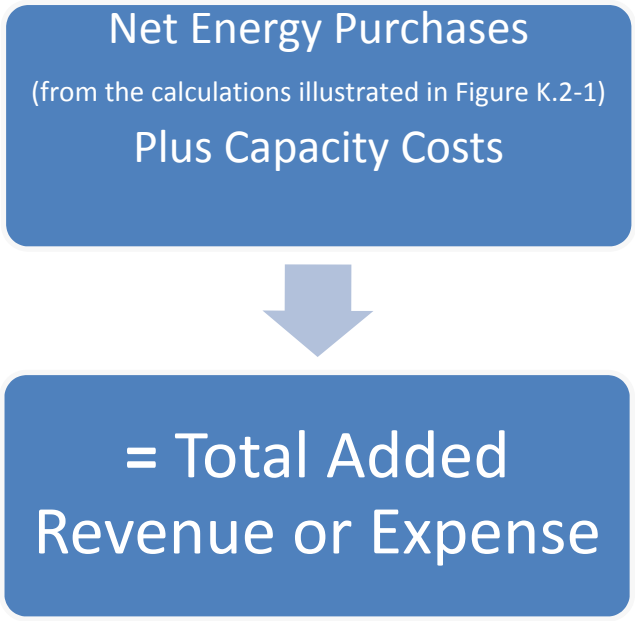

FIGURE K.2-2 Determination of Total Net Expense or Revenue by Year for Each Alternative

Table K.2-3 is a reproduction of a table from Section K.1. It is the estimated expense of capacity construction under each alternative. Alternative A includes capacity expenses, not because of a changed operation at Glen Canyon Dam or a change in SLCA/IP commitment levels by WAPA, but because of growth in electrical demand and the need for SLCA/IP customers to have to build new generating units to meet growing electrical demand. Based on the analysis described in Section K.1, existing generating units are sufficient to meet electrical demand until 2017.

The difference between the capacity expenses under Alternative A and the other alternatives is a function of how the LTEMP EIS alternatives affect the available capacity at Glen Canyon Dam. Differences in capacity expenses from Alternative A are a result of implementing the alternative. Table K.2-4 shows the differences in capacity expenses from Alternative A. The numbers in Table K.2-4 (differences from Alternative A) were used in this analysis. Notice that no capacity expense is required until 2018 under all alternatives except for Alternative F, which requires a capacity expense in 2017.

TABLE K.2-4 Total Levelized Capital and Fixed O&M Cost (in millions of 2015$) for System Capacity Expansion by Alternative and Year Expressed as the Difference from Alternative A

	Total Levelized Capital and Fixed O&M Cost (millions 2015$)—Difference from Alternative A					
Year	Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
2015	0	0	0	0	0	0
2016	0	0	0	0	0	0
2017	0	0	0	0	12.2	0
2018	0	12.3	0	0	24.5	12.3
2019	0	12.2	0	0	24.5	12.2
2020	0	12.3	0	0	24.5	12.3
2021	0	12.3	12.3	12.3	24.5	12.3
2022	0	12.2	12.2	12.2	24.5	12.2
2023	0	12.2	12.2	12.2	24.5	12.2
2024	0	12.3	0	0	24.5	12.3
2025	0	12.2	0	0	24.5	12.2
2026	0	12.3	0	12.3	24.5	12.3
2027	0	12.2	12.2	12.2	24.5	12.2
2028	0	12.3	12.3	12.3	24.5	12.3
2029	-12.2	0	0	0	12.3	12.3
2030	0	0	0	0	12.2	12.2
2031	0	0	0	0	12.3	12.3
2032	0	12.2	12.2	12.2	24.5	12.2
2033	0	12.3	12.3	12.3	24.5	12.3
2034	-2.4	4.9	4.9	4.9	17.2	12.3

K.2.6 WAPA Replacement Resources

Using AURORA capacity expansion path modeling, the power systems analysis identified lost Glen Canyon Dam Powerplant capacity that would result from alternative-specific differences in operations and changed system capacity expansion paths. However, WAPA's FES power obligations are unaltered over the time period of this analysis, at least through FY 2024. Therefore, it is assumed for this analysis that WAPA purchases this capacity and incurs capacity firming costs.

When capacity in the region is in short supply, WAPA's firming purchases either include a capacity premium or WAPA makes a capacity purchase. For this analysis, it is assumed that WAPA purchases the electrical capacity projected by the AURORA capacity expansion module. The capacity expenses included in this analysis are the differences from those for Alternative A.[16]

16 See Section K.1 for details on the generation types, years in which construction occurs, and pricing assumptions.

WAPA's purchase of electrical power to meet contractual obligations is a common occurrence. It is quite typical for WAPA to make these purchases during drier years with low release targets. Even in average years, WAPA purchases firming energy on some days or for some hours. Typically, WAPA purchases electrical energy on an hourly basis for the days or months ahead. However, WAPA's CRSP Management Center has also purchased firming energy for a future season or year. WAPA has also once contracted for electrical power and energy over a multi-year period.

It is also assumed that, when electrical capacity in the region is in short supply, utilities that buy electricity at a price that covers the average cost, including the cost of capital and fixed O&M. For this analysis, it is assumed that WAPA purchases the capacity needed to make up for losses in capacity that results from alternative-specific changes in Glen Canyon Dam operations (i.e., the difference between FES capacity and the alternative-specific SLCA/IP federal hydropower firm capacity that is based on a 90% exceedance level).

Electrical capacity additions by WAPA's FES customers are required under Alternative A over the 20-year analysis period, with existing SLCA/IP contractual obligations in place. These additions are required because of growth in electrical demand. However, if there is a change in the operation of Glen Canyon Dam that reduces the powerplant's firm capacity—as would occur under most of the LTEMP alternatives—additions to electrical capacity would be required.[17] The assumption used for this analysis is that WAPA purchases the capacity identified as the amount lost under each alternative, costing the amounts specified in Table K.2-3. The differences in total costs include levelized capital and fixed O&M between each alternative and Alternative A.

To be clear, Table K.2-3 is a duplication of the power economic analysis (Section K.1). WAPA would not incur the capacity expansion costs for Alternative A. Added capacity costs needed for load growth in Alternative A are not included. Only the differences in capacity costs between Alternative A and the other alternatives are included in the analysis.

K.2.7 Post-2024 Marketing Period

WAPA markets SLCA/IP electrical power under firm, long-term contracts. Under these contracts, WAPA is required to deliver this electrical power to federal points of delivery regardless of hydrological conditions or changes in the operational criteria of the SLCA/IP hydropower plants. The current FES marketing contracts expire on September 30, 2024. For the period following 2024, WAPA is currently engaged in developing a marketing plan. This requires a formal public process in compliance with applicable federal law.

[17] This is not the case for Alternative B. Under Alternative B, Glen Canyon Dam marketable capacity is increased over that of Alternative A. Fewer capacity additions are required.

For the purpose of completing this analysis, certain assumptions had to be made. First, it was assumed that WAPA will continue with its current SLCA/IP obligations until the current marketing period ends and the existing contracts expire.[18] This requires that WAPA deliver the same amount of electrical power and energy to SLCA/IP customers until the end of FY 2024, regardless of the alternative analyzed. Second, recognizing that there is a period of uncertainty between 2025 and 2034, net firming expenses for the post-2024 time period were analyzed under two sets of assumptions. These are as follows:

- A continuation of existing SLCA/IP FES contract commitments between FY 2025 and FY 2034 (no change); and

- A reduction in SLCA/IP FES contract commitments so that net firming expenses are equal to $0 between FY 2025 and FY 2034. This means, for the numbers included in the SLCA/IP power repayment study, zero dollars of firming expense and zero additional dollars of revenue from market sale or from AHP sales (resource available).

These two assumptions constitute "bookends" regarding the outcomes possible in the development of the post-2024 marketing plan.[19]

These bookends are for modeling purposes only. They represent a very broad range of possible FES obligations of electrical power in the post-2024 marketing period.

Obligations of electrical capacity under the current marketing plan were based on a 90% exceedance level (i.e., the amount of hydropower capacity available 90% of the time). This level of marketable capacity is consistent with marketing plans established by other WAPA regional offices. In establishing power obligations for the post-2024 marketing period, WAPA will consider the capacity and energy available from the SLCA/IP units including those at the Glen Canyon Dam Powerplant and will establish, through a public process, an appropriate and reasonable amount of marketable capacity and energy to provide to FES customers. The range of SLCA/IP impacts described for these bookends will almost certainly encompass the actual rate impact, once the post-2024 marketing plan is completed.

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18 There is a provision in the existing SLCA/IP contracts to modify the FES obligations upon a 5-year notice to SLCA/IP customers. However, considering the probable timing of new operating criteria for the Glen Canyon Dam following the completion of the LTEMP DEIS and the issuance of a ROD, a 5-year notice would not be significantly different than the end of the current marketing period.

19 Western could choose a post-2024 SLCA/IP FES obligation of electric power that exceeds its current obligation. However, prior to completion of the required public process it would be difficult to determine what the higher obligation would be that could be considered a reasonable bookend. Moreover, the time-frame available to complete this analysis required that the analysis be simplified. The assumption that the post-2024 SLCA/IP FES obligation continues existing commitments was easier to accomplish since much of the data related to this assumption was produced in Section K.1.

It should be noted that the establishment of these bookends is not an attempt to predict or to anticipate WAPA's choice prior to the conclusion of the required public process. This is an analysis, not a description of policy or attempt to predict WAPA's post-2024 marketing plan. This set of bookends is intended to reflect the range of reasonable possibilities. It is reasonable that WAPA would continue existing commitment levels to ensure continued customer access to the transmission associated with the energy. Moreover, it is also reasonable to believe that WAPA would establish post-2024 marketing plan commitments that exactly follow the power resource available at the SLCA/IP power system.

K.2.8 Power Repayment Studies to Determine Rate Impacts

WAPA sets rates as low as possible consistent with sound business principles to repay the federal government's investment in generation and transmission facilities in addition to specific non-power costs that power users are legislatively required by Congress to repay, such as irrigation costs that are beyond the irrigators' ability to repay. Sales of federal electric power and transmission repay all costs (including interest) associated with generating and delivering the power. WAPA prepares a PRS for each specific power project to ensure the rates are sufficient to recover expenses, including O&M, transmission, interest, replacement/upgraded equipment, purchased power, and wheeling. The PRS consists of two parts: historical data and future forecasted data. The historical data is a record of project repayment from the beginning of the project to the most recent year for which audited financial data are available. The first future year in the PRS is the first year for which forecasts, rather than actual data, are used. The last future year in the PRS must cover the final year allowed for repayment of historical investment.

Although the tool used to calculate the PRS has changed many times in the past, the principles underlying project repayment have not. These principles are summarized in U.S. Department of Energy (DOE) Order RA 6120.2 that governs project repayment and financial reporting for the DOE Power Marketing Administrations. In addition to Order RA 6120.2, WAPA's PRSs must meet the Federal Energy Regulatory Commission's rate filing requirements and procedures in 18 CFR Part 300.

K.2.8.1 PRS Expenses

All annual costs that are to be repaid by power customers must be included in the PRS. These costs include O&M, purchased power, transmission and other expenses, and interest expense. Interest expense is calculated by multiplying each investment's prior year unpaid balance by the appropriate interest rate.

Tables K.2-5 and K.2-6 show the total net purchase power costs for each year for each alternative. These tables show net purchase power expenses only. They do not include other O&M expenses, interest or principle payments. Positive numbers indicate net purchase power

TABLE K.2-5 Total Net Purchase Power Expenses (thousand 2015$) by Year and Alternative for the Continuous Current Obligations Scenario[a]

Year	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
2015	31,200	29,800	35,300	32,000	31,600	44,100	34,800
2016	96,900	95,200	93,500	98,300	96,800	104,200	98,800
2017	68,600	68,800	70,500	69,700	70,300	89,920	73,800
2018	49,500	74,100	68,320	54,200	51,500	87,930	72,020
2019	17,700	13,300	30,820	22,900	18,000	49,730	38,220
2020	34,700	33,000	48,220	37,100	35,700	69,930	53,020
2021	31,400	29,900	48,420	47,920	46,920	70,630	52,620
2022	4,350	3,650	13,020	14,750	15,400	26,780	16,570
2023	–82,550	–79,810	–63,220	–67,640	–67,550	–59,290	–66,150
2024	–36,580	–33,010	–6,710	–43,190	–41,360	–20,400	–36,130
2025	–70,810	–69,840	–55,780	–64,110	–70,420	–47,120	–59,360
2026	11,480	11,990	24,340	9,370	24,860	45,600	11,620
2027	29,400	29,900	46,320	53,320	45,120	68,830	62,320
2028	52,200	50,100	69,820	69,820	68,920	89,930	80,920
2029	75,000	60,680	76,800	77,000	76,100	99,620	97,220
2030	66,800	66,000	67,700	67,700	66,800	91,120	86,620
2031	89,100	89,900	95,300	94,600	93,400	115,420	120,720
2032	70,900	70,200	84,320	84,120	83,420	108,630	91,520
2033	67,800	66,500	84,820	84,920	84,020	107,730	91,720
2034	35,900	31,240	48,130	46,830	46,230	71,540	72,020

[a] These numbers are compared to a condition in which generation is just equal to SHP obligations. Positive numbers indicate net firming purchases. Negative numbers indicate revenues collected above a condition in which generation is just equal to SHP obligations.

expenses. Negative numbers indicate that generation from SLCA/IP power plants is sufficient to meet SHP obligations and include additional sales of electricity to FES customers (AHP) or additional sales to the market. The numbers in these tables are net purchase power expenses compared to a condition in which electrical generation is just sufficient to meet SHP obligations without firming expenses and without sales of surplus electricity to FES customers or to the market. Note that the negative numbers occur in the years 2023-2025 and carry across all the alternatives in these years. These are the wettest years of the representative trace used for this analysis.

Table K.2-5 is purchase power for the scenario in which the existing SLCA/IP commitment levels for energy and capacity are maintained. Table K.2-5 is purchase power for the scenario in which WAPA reduces its commitment levels, post-2024, to just the amount of

TABLE K.2-6 Total Net Purchase Power Expenses by Year and Alternative for the Reduced Obligations to Match Resource Scenario[a,b]

Year	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
2015	31,200	29,800	35,300	32,000	31,600	44,100	34,800
2016	96,900	95,200	93,500	98,300	96,800	104,200	98,800
2017	68,600	68,800	70,500	69,700	70,300	89,920	73,800
2018	49,500	74,100	68,320	54,200	51,500	87,930	72,020
2019	17,700	13,300	30,820	22,900	18,000	49,730	38,220
2020	34,700	33,000	48,220	37,100	35,700	69,930	53,020
2021	31,400	29,900	48,420	47,920	46,920	70,630	52,620
2022	4,350	3,650	13,020	14,750	15,400	26,780	16,570
2023	–82,550	–79,810	–63,220	–67,640	–67,550	–59,290	–66,150
2024	–36,580	–33,010	–6,710	–43,190	–41,360	–20,400	–36,130
2025	0	0	0	0	0	0	0
2026	0	0	0	0	0	0	0
2027	0	0	0	0	0	0	0
2028	0	0	0	0	0	0	0
2029	0	0	0	0	0	0	0
2030	0	0	0	0	0	0	0
2031	0	0	0	0	0	0	0
2032	0	0	0	0	0	0	0
2033	0	0	0	0	0	0	0
2034	0	0	0	0	0	0	0

[a] These numbers are compared to a condition in which generation is just equal to SHP obligations. Positive numbers indicate net firming purchases. Negative numbers indicate revenues collected above a condition in which generation is just equal to SHP obligations.

[b] Zeroes indicate that no purchase power expenses are required to firm contract obligations; however, other expense, such as operations, maintenance, repayment of investment and interest payments would continue.

energy and capacity provided by the resource. These data were developed as described above and include the following:

- Purchase power expense net of additions to revenue from the sale of AHP, and
- Cost of capacity including capital and fixed O&M expenses relative to Alternative A.

K.2.8.2 PRS Revenue Distribution

The CRSP Management Center uses a balloon payment methodology for repayment of project costs. This means that principal payments for capital costs are not due until the end of their repayment period. For example, if an investment has a repayment period of 50 years, the total principal payment can be made in the 50th year. The revenue distribution described in this section, and the PRS calculations described in the next section, pertain to the balloon payment methodology.

Within the PRS, electrical power revenues within the year must first be applied to the annual O&M costs. Interest expense is considered an operational cost, but it is the last in priority. After all annual costs are paid, capital costs must be repaid in the following order: (1) required principal payments, (2) deficits, and then (3) the highest interest-bearing investment. Required payments are payments on those investments that still have an unpaid balance at the end of their repayment period.

K.2.8.3 The SLCA/IP PRS

The SLCA/IP PRS includes the revenue requirements for the CRSP, Collbran, and Rio Grande projects, which were integrated for marketing and ratemaking purposes on October 1, 1987, in addition to two participating projects of the SLCA/IP system that have power facilities, the Dolores and the Seedskadee Projects. The CRSP Management Center forecasts 5 years of firming purchased power in the PRS. This reflects the firming purchase power requirements between projected generation and FES contract obligations. For the remaining future years, a forecast of $4 million per year is projected to cover operational purchase power costs for the EMMO located in Montrose, Colorado.

WAPA used the FY 2015 preliminary SLCA/IP PRS as the template to calculate the rate impacts for all the alternatives. The generation, project use, energy, and capacity values for each alternative were updated in the PRS, and the rate was computed for each alternative. The rate-setting period in the PRS is determined by calculating the revenue requirement from the first future year through the year with the highest revenue requirement, which is referred to as the pinch-point year. For this rate analysis, the first future year used in the template is FY 2018. The pinch point used in the template is FY 2025 and is driven by a multi-million dollar Aid-to-Participating-Projects required payment due that year. Consequently, the rate-setting period for the template, from the first future year to the pinch point, is FY 2018 through FY 2025. The revenue requirements are recovered through a 50/50 split between the energy and capacity rates. Three rates calculated in the PRS are energy, capacity, and composite.

The energy rate is the rate that sets forth the charges for energy. It is expressed in mills/kWh and is applied to each kilowatt-hour delivered to an FES customer. The energy rate is estimated by a rates specialist and manually entered in the PRS, and a study is run to determine if the rate is sufficient to cover costs without creating a deficit. If the study produces a deficit balance, a new rate is entered into the PRS and the study is run again. The estimated rate is increased until the study no longer produces a deficit.

The capacity rate is the rate that sets forth the charges for capacity. It is expressed in $/kW-month and applied to each kilowatt of the CROD. The formula for the capacity rate is linked to the energy rate and is simultaneously updated to ensure the revenue requirement is recovered through a 50/50 split between the capacity and energy rates.[20]

The composite rate is the rate for firm power, which is the total annual revenue requirement for capacity and energy divided by the total annual energy sales. It is expressed in mills/kWh and used for comparison purposes only. The composite rate is calculated after the energy rate is computed and the rate-setting period is established. The composite rate, in mills/kWh, is calculated as the ratio of the total revenue required during rate-setting period to the total projected sales during the rate-setting period.

K.2.8.4 Standard PRS Rate-Setting Method Versus the Method Used in This Analysis

In order to accurately compute the impact of each alternative in terms of energy and capacity rates, projected power purchases for the entire rate-setting period of 2015 through 2034 were used. This deviates from WAPA's normal 5-year forecast in order to accurately capture each alternative's rate impacts. Table K.2-4 shows power purchase costs, assuming that current FES obligations would continue after FY 2024, and Table K.2-5 shows results for the marketing structure that would incur zero firming expenses after 2024. Table K.2-6 shows the SLCA/IP rate impact for each alternative.

K.2.9 Results

Table K.2-6 shows the estimated SLCA/IP energy and capacity rates by alternative. This reflects WAPA's current method of billing. SLCA/IP FES customers are billed monthly for the amount of energy used and for their capacity allocation. A composite rate is an index number that includes the energy and capacity rates together and may be useful for comparison purposes.

Table K.2-7 shows that there is a significant difference between the "bookend" assumptions. Comparing the composite rate, the No Change condition results in higher SLCA/IP rates across all alternatives compared to the Resource Available condition. For the No Change condition, the highest rate occurs under Alternative G (38.75 mills/kWh). The lowest SLCA/IP

[20] The production of hydropower that Western markets requires the construction of a dam and water storage. The fuel for these hydropower facilities is water, which is costless. Under the law, Western is required to set "cost-based" rates. If Western used production costs to set capacity and energy rates, the energy rate would be zero or near zero. It has been Western's practice to set FES rates so that 50% of the revenues collected through the sale of power are through the capacity rate and 50% of the revenues collected are through the energy rate. Other Federal power marketing agencies use different rate-setting strategies, but their rates are also required to be cost-based. The "50/50 split" is not a legal requirement, but, rather, a common Western practice.

TABLE K.2-7 SLCA/IP Rate Impact by Alternative[a]

	Alternative A (No Action Alternative)		Alternative B		Alternative C		Alternative D (Preferred Alternative)		Alternative E		Alternative F		Alternative G	
	NC[b]	RA[c]	NC	RA	NC	RA	NC	RA	NC	RA	NC	RA	NC	RA
Pinch-Point FY	2031	2055	2031	2055	2031	2055	2031	2055	2031	2055	2025	2057	2031	2055
Composite (mills/kWh)	32.64	25.19	32.69	25.07	33.77	25.65	33.65	25.22	33.41	25.16	37.79	27.53	38.75	26.65
Energy (mills/kWh)	13.52	13.40	13.54	13.22	13.99	14.55	13.94	13.78	13.84	14.01	15.67	16.86	16.07	15.22
Capacity ($/kW-month)	5.74	5.69	5.75	5.62	5.94	6.18	5.92	5.85	5.88	5.95	6.66	7.16	6.83	6.50

[a] Rate impacts in this table are in part based on net purchase power costs shown in Tables K.2.5 and K.2.6 which include the impacts of LTEMP experiments

[b] NC = No change from current FES commitment levels.

[c] RA = Resource available. Commitment level equals available SLCA/IP federal hydropower resource.

rate occurs under Alternative A (32.64 mills/kWh), although Alternative B is almost the same rate (32.69 mills/kWh). The range is 6.11 mills/kWh, with Alternative G producing a rate that is 19% higher than Alternative A (the no action alternative). The Resource Available condition produces similar results. The lowest SLCA/IP rate occurs under Alternative B (25.07 mills/kWh), almost identical to Alternative A (25.19 mills/kWh). Under this condition, the highest SLCA/IP rate occurs under Alternative F (27.53 mills/kWh). The range is smaller under this condition with Alternative F producing a rate that is 2.46 mills/kWh or 10% higher than Alternative B.

It is worth noting that under either of the post-2024 "bookend" conditions, Alternatives A, B, C, D, and E produce similar SLCA/IP rates. Alternatives F and G produce significantly higher SLCA/IP rates.

As described previously, the no change and resource available bookends are used for modeling purposes only and do not represent estimates or indications of the post-2024 commitment levels that may result from the public process. Alternative impacts on SLCA/IP rates illustrated in Table K.2-7 are indications of the rank order of the alternatives and the direction of impacts (positive or negative), and they encompass a reasonable range of the actual future rate impacts once the post-2024 marketing plan has been implemented. For the final LTEMP EIS, assumptions concerning post-2024 commitment levels may be revised to duplicate the range examined in the economic analysis described in Section K.1. This would be a SLCA/IP capacity obligation based on the 99th, 90th, and 50th percentile exceedance levels. The resulting

range will likely be somewhat narrower than the results of the bookend analysis presented in this draft.

K.2.9.1 Pinch-Point Year

Table K.2-7 includes pinch-point year information. The pinch point is the year in which the largest revenue requirement occurs in the future and is influential in setting the SLCA/IP rate.

There were three common pinch points that occurred when determining alternative-specific rates:

- 2025, caused by a required Aid-to-Participating-Projects Payment (Duchesne);
- 2031, caused by purchase power expense; and
- 2055, caused by a required Aid-to-Participating-Projects Payment (Starvation Reservoir).

As described in Section K.2.3, WAPA's SLCA/IP rates are set to assure repayment of all authorized water projects. In the current PRS, repayment of existing projects and repayment of yet-to-be constructed water projects will be completed in 50 years. The pinch-point is the year in which the largest future revenue requirement occurs. These pinch-points occur when a large water project – or "block" of a large water project – requires a repayment. After this pinch-point year, revenues are sufficient to complete repayment of remaining water projects. Therefore, it is said that the pinch-point year drives the rate.

Higher purchase power requirements require increasing the revenue requirement in the pinch-point year. Because the amount of purchase power is not consistent across alternatives, neither is the revenue requirement. The pinch-point year varies among alternatives because of the variation of purchase power amounts by alternative. It is not possible to use a consistent pinch-point year because each alternative produces different annual revenue requirements, and therefore a different schedule for completing repayment. The only way to have a consistent pinch-point year is to have consistent revenue requirements across each alternative.[21] With a fixed rate, the lower the purchase power, the more revenue available for discretionary repayment of investments which reduces annual interest and ultimately the annual revenue requirements. Conversely, increases in purchase power reduce the amount available for repayment on investment which leads to higher interest payments and subsequently, higher annual revenue requirements.

[21] One could argue that the SLCA/IP rate analysis should "force" the SLCA/IP rate to have the same pinch-point year for each alternative so that the impact of the alternatives is a more "apples to apples" comparison. This was considered as an approach, but it was decided that forcing such a condition would require a significant change in the rate-setting process. Moreover, it may be useful to the reader to know how alternatives differ in terms of their effect on setting a pinch-point year.

K.2.10 Definitions Used in Section K.2

Available Hydropower (AHP): The amount of SLCA/IP electrical energy and/or capacity available to FES customers for either the summer or winter seasons. This is designated for each month of the season.

Aid to Participating Projects: This is the part of an authorized irrigation/water project that is assigned to power for repayment. There is an assigned amount in the PRS for each authorized project.

Composite Rate: This is not a rate that is used for billing purposes. It is for comparisons. One takes the capacity rate and the energy rate, assumes a load factor and calculates the average rate per kilowatt-hour.

Contract Rate of Delivery (CROD): the amount of capacity allocated to an FES customer, by season, for the marketing period. It represents the "ceiling" obligation. An FES customer can utilize AHP capacity up to this amount.

Colorado River Storage Project (CRSP): Federal hydropower facilities in the Upper Colorado River Basin including Glen Canyon, Flaming Gorge, Fontenelle and the Aspinall Units.

CRSP Management Center: WAPA's Colorado River Storage Project Management Center. This is the WAPA office that has the responsibility for marketing the SLCA/IP power resources and for setting SLCA/IP FES rates.

Federal Energy Regulatory Commission (FERC): A federal commission that regulates the interstate transmission of electricity, natural gas, and oil. FERC also reviews proposals to build liquefied natural gas terminals and interstate natural gas pipelines as well as licensing hydropower projects. The FERC has limited jurisdiction over WAPA's rates, but must ensure that WAPA's project rates are sufficient to repay authorized projects.

Load Factor: A proportion of average energy used over a specified time period compared to peak demand for the same time period.

No Change Scenario (NC): This scenario represents a post-2024 condition where WAPA continues its current obligations to provide capacity and energy from the SLCA/IP resources.

Pinch Point Year: In setting the SLCA/IP FES rate, this is the year in which the highest payment obligation exists. It is said to "drive" the rate.

Project Use: Electrical capacity and energy reserved to power authorized water projects.

Power Repayment Study (PRS): this is the name of the model used by WAPA to set rates. PRS models are project specific.

Resources Available Scenario (RA): This scenario represents a post-2024 condition where WAPA reduces its current commitment of SLCA/IP energy and capacity to exactly match the production of power from the SLCA/IP resources.

Sustainable Hydropower (SHP): The amount of SLCA/IP electrical energy and capacity available to FES customers over the course of the marketing plan. This is the "firm" commitment that WAPA, in low release conditions, must firm up. There is an SHP capacity and energy amount for each month of the season.

Salt Lake City Area Integrated Projects (SLCA/IP): The Collbran, Rio Grande, and the Colorado River Storage Projects were integrated by WAPA in 1986 for marketing and rate-setting purposes.

K.3 IMPACTS ON RETAIL ELECTRICITY RATES

This section documents the effects of LTEMP alternatives on retail electricity rates and bills. Retail rate impacts measure how LTEMP alternatives affect electricity bills paid by household and business consumers who buy electricity from utility systems that directly or indirectly receive power from the SLCA/IP through WAPA. These impacts are documented in three sections that first explain the methodological approach, then summarize results, and finally present the impacts. The measured rate impacts do not use the wholesale rate impacts described in Section K.2 as an input, meaning that there is no direct connection between Section K.2 and this section. Instead, the rate impacts are directly computed from wholesale power costs that are derived directly from the power systems analysis. The retail rates are directly impacted by the LTEMP experiments and include both capacity and energy cost impacts. The wholesale costs that are measured directly from the power systems analysis using the carrying charge analysis described below are greater than the measured wholesale rates discussed in Section K.2, with the exception of Alternative G. This implies that the rate impacts would be lower had the wholesale rates from Section K.2 been used rather than the wholesale costs explained in this section (again, with the exception of Alternative G).

K.3.1 Analysis Approach

Retail rate and residential bill impacts are derived from the power systems analysis (described in Section K.1), SLCA/IP allocations, and publicly available retail rate and sales data using various allocation formulas. The foundation of the analysis is a database of retail sales, retail rates, and SLCA/IP energy allocations for utility systems that are given preference in power allocation from the SLCA/IP (referred to here as preference power). Rate impacts are based on the assumption that the capital, operating, and administrative costs of Glen Canyon Dam do not substantively change under different LTEMP alternatives when the energy output from the dam changes. Because these operating and administrative costs are not affected by the LTEMP alternatives, rate impacts result from changes in the cost associated with replacing capacity and/or energy with changes in dam operations. The wholesale power costs associated with changes in dam operations are labeled "grid costs" and include costs of replacement

capacity, changed production costs (fuel costs, purchased power costs, and variable operation and maintenance [O&M] costs), and differential fixed O&M costs. Using the retail data along with aggregate grid costs, the retail rate impacts of the LTEMP alternatives were determined for the vast majority of municipal, cooperative, and other entities that directly or indirectly receive preference power from SLCA/IP. A separate analysis was made for American Indian Tribes using SLCA/IP allocations to the Tribes combined with contract price data for special arrangements that are made with Tribes for SLCA/IP energy and capacity. The special contract arrangements imply that rate impacts for Tribes are generally greater than the rate impacts for non-Tribal systems. This analysis is presented in Section K.4.

The primary output from the rate impact analysis is a set of figures and tables that present the percent increase or decrease in electric rates and the changes in monthly electricity bills paid by residential consumers of municipal utilities, cooperative distribution utilities, Tribal authorities, and irrigation districts. (Retail consumers include businesses households and other institutions, while residential only includes households.) The rate impacts of different LTEMP alternatives are presented relative to Alternative A (the no action alternative). Rate impacts were estimated for all of the utility systems that have available retail energy sales data published by the Energy Information Agency (EIA) and incorporated more than 90% of entities that receive power from the SLCA/IP in terms of energy allocation. Entities for which rate impacts cannot be measured directly because of a lack of publicly available data include direct retail consumers such as military bases, universities, and the DOE Albuquerque office. In addition to computing rate impacts for companies with available data from the EIA, retail rate impacts for American Indian Tribes were calculated. This calculation used data from utility systems that serve the Tribes at a retail level combined with the effects of net benefit contracts between the Tribes and wholesale utility systems that directly compensate for wholesale power. Contracts between Tribes and wholesale systems to provide benefits are termed net benefit contracts. This analysis is presented in Section K.4.

Four primary tasks were undertaken to compute the rate impacts on retail consumers. These tasks were:

1. Compiling retail energy sales ($), rate ($/MWh), and residential bill ($/month) data for each utility system directly or indirectly receiving an allocation of SLCA/IP federal preference power;

2. Computing year-by-year grid costs under LTEMP alternatives from the power systems analysis and analyzing how the capital cost of new capacity is translated into retail revenue requirements (the capital recovery factor or carrying charge rate);

3. Allocating the aggregate grid cost impacts under LTEMP alternatives to individual retail utility systems; and,

4. Presenting the disparate retail rate and residential bill impacts over time for different systems.

Three information sources, as illustrated in Figure K.3-1, were used to compute the rate impacts of LTEMP alternatives. The first set of inputs for the analysis was a database of sales, rates, and SLCA/IP allocations for utility systems that receive federal preference power from the SLCA/IP. The second set of inputs consisted of the aggregate grid cost combined data from the power systems analysis with capital recovery charge analysis that represents the wholesale power costs. The third set was macroeconomic data from the Energy Information Administration (EIA) (EIA 2015b,c). These inputs were used to determine the relative rate impacts for individual systems from different LTEMP alternatives. Varying impacts on individual systems were largely driven by (1) the amount of preference power allocated to each system relative to the total generation resources of the system, and (2) the current retail rate, which influences the percentage change calculation (a higher rate results in a smaller percent change).

Explanations of analytical methods for determining rate impacts are organized around Figure K.3-1. The next three sections explain the data input items listed on the left side of Figure K.3-1. Section K.3.1.4 describes details of the calculation process referenced in the middle of Figure K.3-1, and Sections K.3.2 and K.3.3 describe the rate impacts that are cited on the right side of the figure. Additional description of the process to compute rate impacts for American Indian Tribes appears in Section K.4.

K.3.1.1 Database of Sales, Rates, and SLCA/IP Allocation for Retail Utility Systems

The explanation of the database is separated into two parts that address: (1) how a list of utility systems that receive federal preference power from SLCA/IP and distribute power to retail

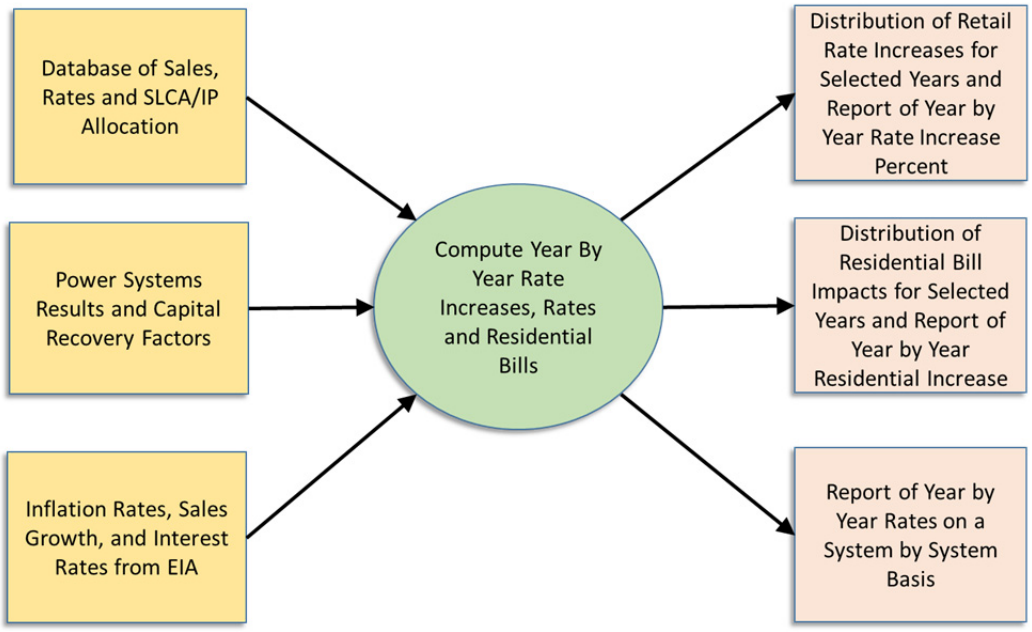

FIGURE K.3-1 Flowchart Diagram of Rate Impact Analysis Process

residential, commercial, industrial and other consumers was compiled; and (2) how retail statistics are gathered for utility distribution systems from Form EIA-861 detailed data files (EIA 2015a).

List of Utility Systems that Distribute Power to Retail Consumers

Developing the database for retail rate analysis involved arranging a list of utility systems that sell electricity on a retail basis and that directly or indirectly receive SLCA/IP federal preference power allocations. The starting point for this list is tabulating utility systems that receive federal preference power from SLCA/IP. WAPA provided this information in a spreadsheet of allocations for the period October 1, 2008, through September 30, 2024 (Osiek 2014). The allocation data included information for 154 different systems that receive separate preference power allocations.

Some of the utility systems listed in the Allocation Report do not sell power on a retail basis to residential and business retail consumers. Five systems including (1) the Wyoming Municipal Power Agency (WMPA), (2) the Utah Municipal Power Agency (UMPA), (3) the Platte River Power Authority (Platte River), (4) the Colorado River Commission of Nevada (CRCN), and (5) Tri-State Generation and Transmission Cooperative (Tri-State) receive preference power allocations from SLCA/IP and then re-allocate power to distribution systems. Table K.3-1 shows that these five indirect systems comprise 47% of the total SLCA/IP federal preference power. Deseret Generation and Transmission Cooperative and the Utah Associated Municipal Power Systems are not included in the five indirect allocation entities because for these two systems, each of their member distribution systems receives distinct direct allocations.

TABLE K.3-1 Energy Allocations for Systems Receiving Indirect SLCA/IP Allocations

System	Annual SLCA Energy Allocation (MWh)	Percent of Total Allocation
Systems Receiving Indirect Allocation		
Wyoming Municipal Power Agency	24,753	0.50%
Utah Municipal Power Agency	290,604	5.87%
Platte River Power Authority	502,467	10.15%
Colorado River Commission of Nevada	88,212	1.78%
Tri-State Generation and Transmission	1,424,012	28.76%
Subtotal Systems with Indirect Allocation	2,330,048	47.05%
Systems Receiving Direct Allocation	2,621,739	52.95%
Total Energy Allocation	4,951,787	100.00%

For the systems with indirect allocation listed in Table K.3-1, it is necessary to compile retail sales and rate data on all of the individual systems that sell power to retail consumers because the larger wholesale systems do not sell to retail consumers. A list of retail entities that are members of indirect retail systems (e.g., distribution cooperatives [co-ops] that are members of Tri-State) have been obtained from Websites for the five indirect allocation utility systems (CRCN 2015; Platte River Power Authority 2015; Tri-State 2015; UMPA 2015; WMPA 2015). After including the retail systems that are members of indirect allocation utilities, the total number of retail utility systems in the database increases from 154 to 226.

Retail Statistics for Distribution Utility Systems from the Form EIA-861 Database

Rate impact calculations for each entity required data for residential and nonresidential sales revenues and sales quantity. The primary source for the existing retail rates and retail residential, commercial, industrial, and other energy sales is the Form EIA-861 database (EIA 2015a). Data for direct retail consumers such as military bases and most American Indian Tribes are not included in the primary EIA database. After adjusting for complications associated with differences in system names, historical data availability, and systems that operate in multiple states, 91% of the preference power can be associated with retail sales data available in the EIA 861 database as shown in Table K.3-2. This table does not include additional data that has been separately gathered for the American Indian Tribes and is described in Section K.4. Additional data for American Indian Tribes is derived from utility companies that serve the Tribal Reservation along with wholesale utility systems that are the SLCA/IP benefit crediting partners (see Section K.4). Tribal entities that provide data to the EIA 861 database (representing the figure of 44.19% in Table K.3-2) included Ak-Chin, Tohono O'odham Reservation, and the Navajo Tribal Utility Authority. These three systems operate their own utilities and do not have special contracting arrangements to secure their SLCA/IP allocation. After accounting for special net benefit contracts used by Tribal Authorities combined with retail utilities that serve the Tribes, the coverage of Tribes is 100%. The 44.19% shown in Table K.3.2 does not include the additional data that is described in Section K.3.2.

K.3.1.2 Incorporation of Power Systems Analysis and Capital Recovery Factors

The second category of information input to the rate impact analysis shown in Figure K.3-1 is projected grid cost data derived from the power systems analysis and capital recovery factors. The amount of annual aggregate capacity (in MW) that is added on an annual basis, the total annual variable production cost, and the fixed O&M costs for new capacity are obtained from the power systems analysis described in Section K.1. The amount of capacity that needs to be added under each LTEMP alternative due to changes in operations is converted to revenue requirements using a carrying charge analysis combined with the projected cost of constructing new generating plants.

TABLE K.3-2 Coverage of Retail Information from EIA Database Relative to SLCA/IP Preference Power Allocation[a]

System	SLCA Annual Energy Allocation (MWh)	Percent of Total Energy Allocation	SLCA Energy with Retail Sales	Percent of Energy With Retail Sales
WMPA, UAMPS, UMPA, CRCN, Platte River	1,231,926	24.87	1,229,054	99.77
Tri-State, Deseret	1,840,470	37.15	1,840,470	100.00
Co-ops not Included in Larger Entities	210,951	4.26	210,951	100.00
Electric Districts and Irrigation Districts	123,588	2.49	108,401	87.71
Municipalities not in JAAs (including SRP)	921,408	18.60	921,408	100.00
Military Bases	70,550	1.42	0	0.00
Tribal Authorities	464,030	9.37	205,051	44.19
Universities and DOE Office	91,401	1.84	0	0.00
Total	4,954,323	100.00	4,515,334	91.14

[a] Note: CRCN = Colorado River Commission of Nevada; JAA = Joint Action Agency; SRP = Salt River Project; UAMPS = Utah Associated Municipal Power Systems; UMPA = Utah Municipal Power Agency; WMPA = Wyoming Municipal Power Agency.

To integrate power systems analysis with the rate impact calculations, selected results are summed together over the different systems that are simulated. Aggregating data from the power systems analysis across the large systems that were modeled and then allocating those costs to individual systems means that, in terms of the rate impact analysis, there is no difference in treatment between the small systems and the other eight utilities modeled in the power systems analysis. Equations used to convert the generation cost and capacity expansion data to aggregate grid cost impacts are listed below, where *t* represents the annual period, *i* represents the LTEMP alternative, and *c* represents the capacity type. The summation is over the new capacity type:

$$\text{Capacity Cost}_{t,i} = \sum \text{New Capacity}_{t,i,c} \times \text{Capacity Cost}_{t,i,c} \times \text{Carrying Charge Rate}_{t},$$

$$\text{Fixed O\&M}_{t,i} = \sum \text{Accumulated Capacity}_{t,i,c} \times \text{Fixed O\&M Cost/kW-yr}_{c}, \text{ and}$$

$$\text{Grid Cost}_{i,t} = \text{Production Cost}_{i,t} + \text{Capacity Cost}_{t,i} + \text{Fixed O\&M}_{t,i}.$$

Carrying Charge Factors Applied to New Capacity That Account for Ownership and Financing Structures of Municipal and Cooperative Systems

Rate impacts cannot be directly calculated from outputs generated by the power systems analysis because of the manner in which plants are financed. The annual cost of new capacity that is charged to consumers is established from dollar amounts that are paid to bondholders who lend money for constructing a new plant. Annual funds collected to compensate for the cost of building new capacity is termed the "capital recovery factor" or the "carrying charge rate." A detailed analysis has been made of carrying charges for individual municipal and cooperative

systems as part of the rate impact analysis. The carrying charges used data from financial reports and derived revenue requirements from changes in the quantity of generating capacity. The analysis includes effects of municipally financed debt, debt service requirements, the tenor of debt, and other assumptions including the interest rate. Some of the considerations in deriving the carrying charge analysis include:

- The carrying charge for purposes of the rate impact depends on the debt structure used to finance the investment. If the bond repayment period is not the same as the plant life and/or the bond repayment does not increase with inflation (both of which are generally true) then the capital recovery for purposes of the rate impact analysis is different than the economic carrying charge used in the power system analysis;

- The carrying charge for rate impact analysis does not reflect differences in risks associated with generating alternatives that are borne by consumers (for example, the capacity from Glen Canyon Dam already exists, while the ultimate cost of capacity from new generation plants has uncertain capital and operating costs);

- The carrying charge for rate impact analysis is affected by the debt service coverage and other specific features of bonds issued to finance construction for municipal and cooperative systems;

- The year-by-year carrying charge measured using actual interest rates relevant for measuring rate impacts is flat over the prospective tenor of the debt (by contrast, the real carrying charge used in economic analysis in the initial year of the plant life is lower than subsequent years);

- The carrying charge for generation and transmission cooperatives may be affected by patronage capital that is generally part of the financing of a new powerplant;

- The interest rate used in the calculation of carrying charges for rate impact analysis should reflect the credit rating and the tax status of entities that will finance the new construction; and

- The interest rate used for the carrying charge analysis changes over time when interest rates change (as projected by the EIA).

The carrying charge rates implemented in the rate impact analysis are shown on Figure K.3-2. The carrying charges applied in the rate impact simulation are a weighted average of the carrying charges for taxable (e.g., co-op) and municipal financing. The weighted average is derived from the energy allocations for (1) systems that issue taxable debt (co-ops and irrigation districts), and (2) systems for which the interest is exempt from federal income taxes (municipal systems). The weighted average carrying charge that converts one-time capital costs for construction of new capacity into projected annual revenue requirements begins at a level of

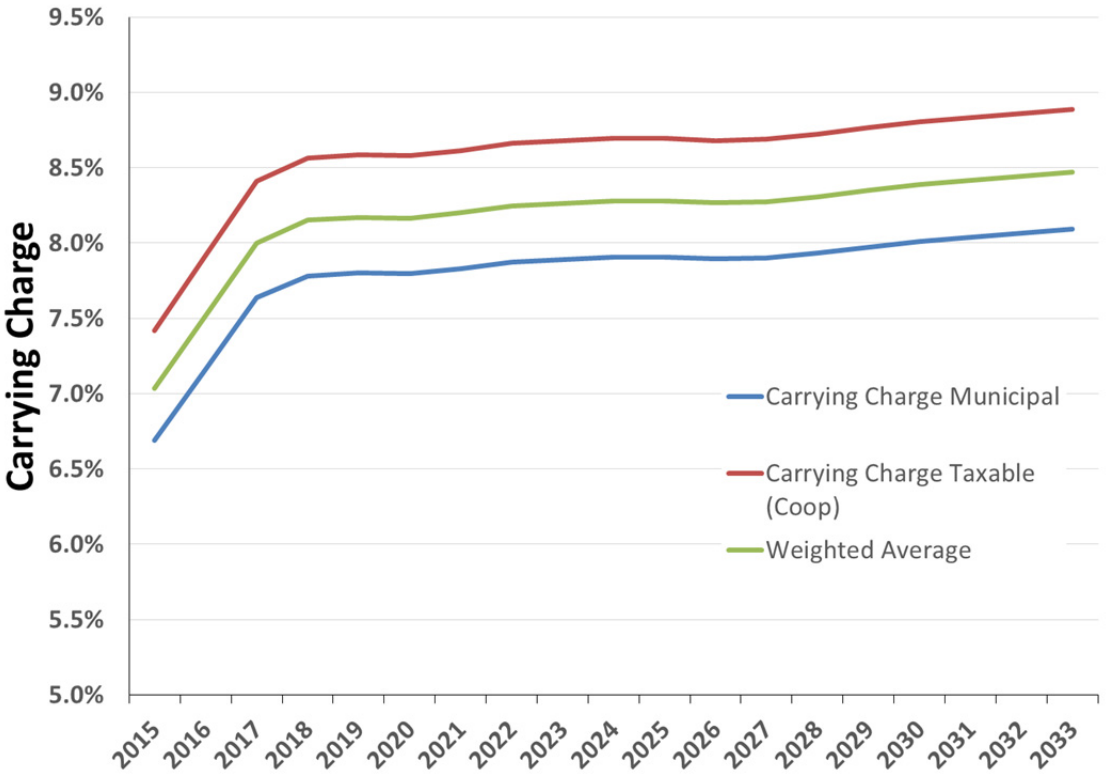

FIGURE K.3-2 Projected Carrying Charge Rates Used in Rate Impact Analysis

7.03% in 2015 and eventually increases to 8.50% (the middle line in Figure K.3-2). By contrast, if the same interest rate and inflation assumptions were applied to computing economic carrying charges, the real capital recovery factor would only be 4.38% in 2014. This higher carrying charge increases measured rate impacts.

K.3.1.3 Inflation Rates, Sales Growth, and Interest Rates from EIA

The third set of input data presented on the left side of Figure K.3-1 consists of general macroeconomic variables that drive the prospective level of base retail rates for each utility system. Macroeconomic factors include the expected level of electricity rates and the expected level of retail sales growth in the southwest region, as well as future interest rates for the municipal and cooperative systems. Data for these items has been derived from information provided in EIA regional forecasts presented in the 2015 Annual Energy Outlook (EIA 2015b). Projections from the EIA annual outlook (EIA 2015c) are also used for macroeconomic data including prospective inflation rates and interest rates.

K.3.1.4 Calculation Process for Computing Rate and Bill Impacts

The middle of Figure K.3-1 represents calculations made for computing rate impacts after the inputs are established. The computations of rate impacts for individual systems involve a series of allocations under each LTEMP alternative. Figure K.3-3 shows three allocation procedures that were part of calculating rate impacts. The first allocation involved attributing total grid cost to individual utility systems using SLCA/IP allocation data (shown in red in Figure K.3-3). For the indirect allocation systems defined in "List of Utility Systems that Distribute Power to Retail Consumers" above, a second allocation involved attributing SLCA/IP power from the Generation and Transmission Cooperative or the Joint Action Agency to individual members (shown in yellow in Figure K.3-2). These two allocations define impacts measured by the percent change in retail rates. The only allocation that involves assumptions with respect to utility-specific ratemaking processes is the computation of residential bill impacts. To compute the residential bill impact, costs must be allocated between residential and nonresidential consumers (shown in green in Figure K.3-2). For this allocation, the assumption is made that capacity and energy costs are allocated in the same proportion as existing overall rates.

Then next five sections describe the allocation process used to compute the rate impacts. The first section explains why wholesale rates were not needed in the allocation process and how

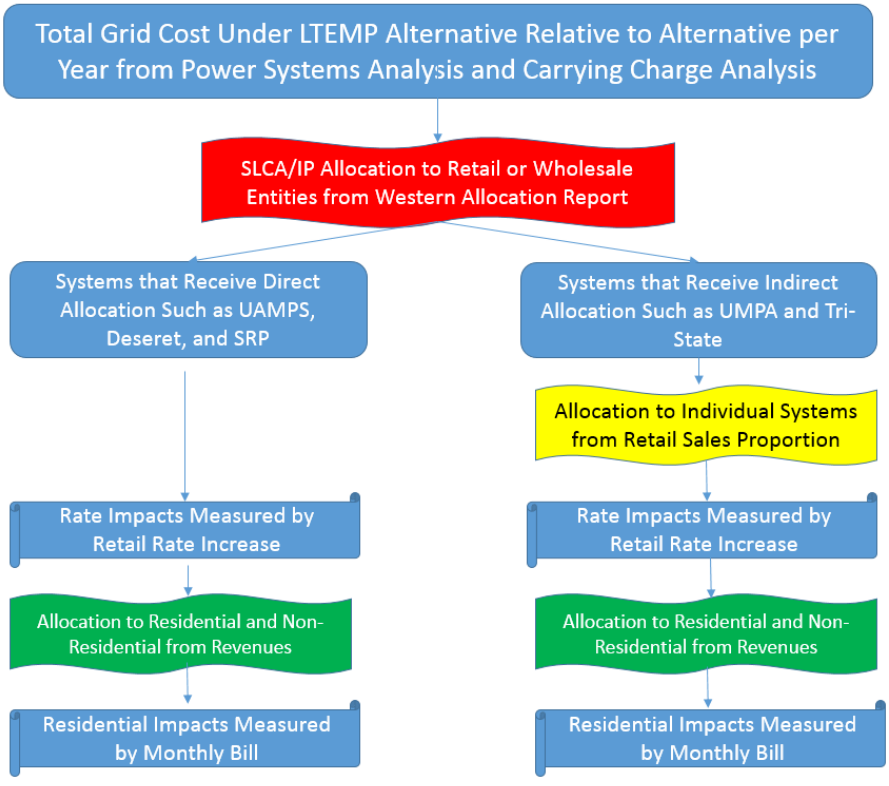

FIGURE K.3-3 Flowchart Diagram of Allocation Process

the aggregate grid cost impacts can be compared to SLCA/IP wholesale revenues. The second section describes the allocation of aggregate grid costs to different systems, and the third section describes the allocation process for indirect systems. The fourth section explains the allocation process for residential rates, and the final section demonstrates the process with a case study.

Using Grid Costs Rather than SLCA/IP Wholesale Rates for Computing Retail Rate Impacts

A fundamental concept underlying the rate impact analysis is that rate impacts of LTEMP alternatives occur because of differences in alternatives with regard to capacity that is lost and energy that must be purchased during different periods, not WAPA's cost structure. WAPA must collect the same amount of revenue to cover its costs under all of the LTEMP alternatives, even though marketable capacity has declined and timing of energy production has changed. For LTEMP alternatives that increase grid cost relative to Alternative A, retail consumers of entities that receive SLCA/IP capacity and energy in one way or another pay for replacing capacity and more expensive energy. (It is assumed that consumers who are not associated with entities that receive SLCA/IP capacity do not incur added costs.) This implies that rate impacts can be computed directly from grid costs rather than WAPA wholesale tariffs. For benchmarking purposes, the average annual production, fixed O&M, and investment costs on SLCA/IP customers are presented relative to the dollar amount of revenues collected by WAPA presented in Sections K.1 and K.3.2.2. Wholesale grid costs used as the basis for computing rate impacts have been compared to the aggregate wholesale amounts that would be paid under projected SLCA/IP rates described in Section K.2. This analysis evaluated the aggregate incremental grid cost for each alternative as compared to the aggregate wholesale power cost that would be paid under the wholesale SLCA/IP rates computed in Section K.2. The analysis demonstrates that for LTEMP alternatives other than Alternative G, the SLCA/IP wholesale rates would result in lower measured impacts than the aggregate grid costs.

The fact that retail rate impacts can be computed without separate calculations of WAPA wholesale rates can be demonstrated with a hypothetical example of three rate calculation approaches, the first of which does not include wholesale rate calculations, while the second and third apply different possible changes in wholesale tariffs that result from various LTEMP alternatives. All three of the wholesale rate techniques result in the same retail rate impact. The first method does not require measurement of SLCA/IP wholesale rates and is consistent with the approach illustrated in Figure K.3-3. Using this approach, rate impacts are computed by directly allocating grid costs under different LTEMP alternatives. The second method assumes that WAPA increases wholesale capacity charges to cover the fixed costs associated with lower amounts of capacity from changes in Glen Canyon Dam operations. This method assumes that the utility systems themselves procure the capacity and energy to make up for the changes in dam operations. The total amount of wholesale revenues received by WAPA does not change in this second method, and the utility systems themselves incur the increased grid costs in this scenario. Because WAPA's revenues do not change and utilities procure the capacity and energy deficits created from the LTEMP alternatives, the second scenario produces the same revenues as the first method, in which wholesale rates are not considered. The third approach assumes that WAPA, instead of the utility systems, procures the deficient capacity and energy. This means the

grid cost impacts are included in the WAPA wholesale rates and, from the perspective of the utility systems, the capacity quantity does not change. The same amount of capacity and energy must be procured by WAPA as would be procured by the individual utility systems. Ultimately, SLCA/IP rates change in different LTEMP alternatives to cover changes in the cost of capacity and energy.

Allocation of Aggregate Grid Costs to Retail Systems

The primary allocation formula applied to compute rate impacts involves allocating total grid costs to different systems using the annual SLCA/IP energy as reported in Osiek (2015). This allocation process, illustrated in red in Figure K.3-3, is represented by the following equation (recall that retail rates include rates to residential, business, and other consumers served by the utility system):

Retail Change for Individual System Relative to Alternative A ($) =
[SLCA/IP Energy Allocation to Individual System (MWH) /
Aggregate SLCA/IP Energy Allocation to All Systems (MWH)] ×
Aggregate Grid Cost Impact of LTEMP Alternative Relative to Alternative A ($).

SLCA/IP energy allocation in the above formula is applied by summing the summer and winter energy allocation for each system listed in Osiek (2015). The actual allocation that determines the amount each system pays for SLCA/IP power involves both energy and capacity and is differentiated by season. This raises the question of whether summer capacity, winter capacity, summer energy, and winter energy should be applied in a more complex allocation process. The question is resolved because the allocation shares to individual systems would be virtually identical if either the capacity or energy allocation were used. This is demonstrated by the fact that the annual load factor in SLCA/IP allocations is similar across different systems. If the load factor across systems is the same, then allocation of total grid costs using either capacity or energy will result in the same percentage of aggregate grid cost being attributed to each individual system. The similarity of annual load factors (average hourly energy for the winter and summer divided by the average summer and winter capacity) is illustrated in Figure K.3-4. Because the load factor is nearly identical for almost all distribution systems in Figure K.3-4, the use of capacity or energy does not influence the allocation process.

Given total retail revenues attributed to individual systems, the calculation of percent change in retail rates from LTEMP alternatives can be represented by the two formulas shown below. In these formulas, *t* is a subscript for the year and *i* represents the individual system. The term Retail $\text{Change}_{t,i}$ shown in the equation is the result of the equation presented at the beginning of this section.

$$\text{Rate Change Percent}_{t,i} = \text{Retail Change}_{t,i} / \text{Retail \$ Revenue under Alternative A}_{t,i}$$

Retail Revenue under Alternative $A_{t,i}$ comes from retail revenue for each individual system that is part of the database. Increases in retail revenues from sales growth and from price increases

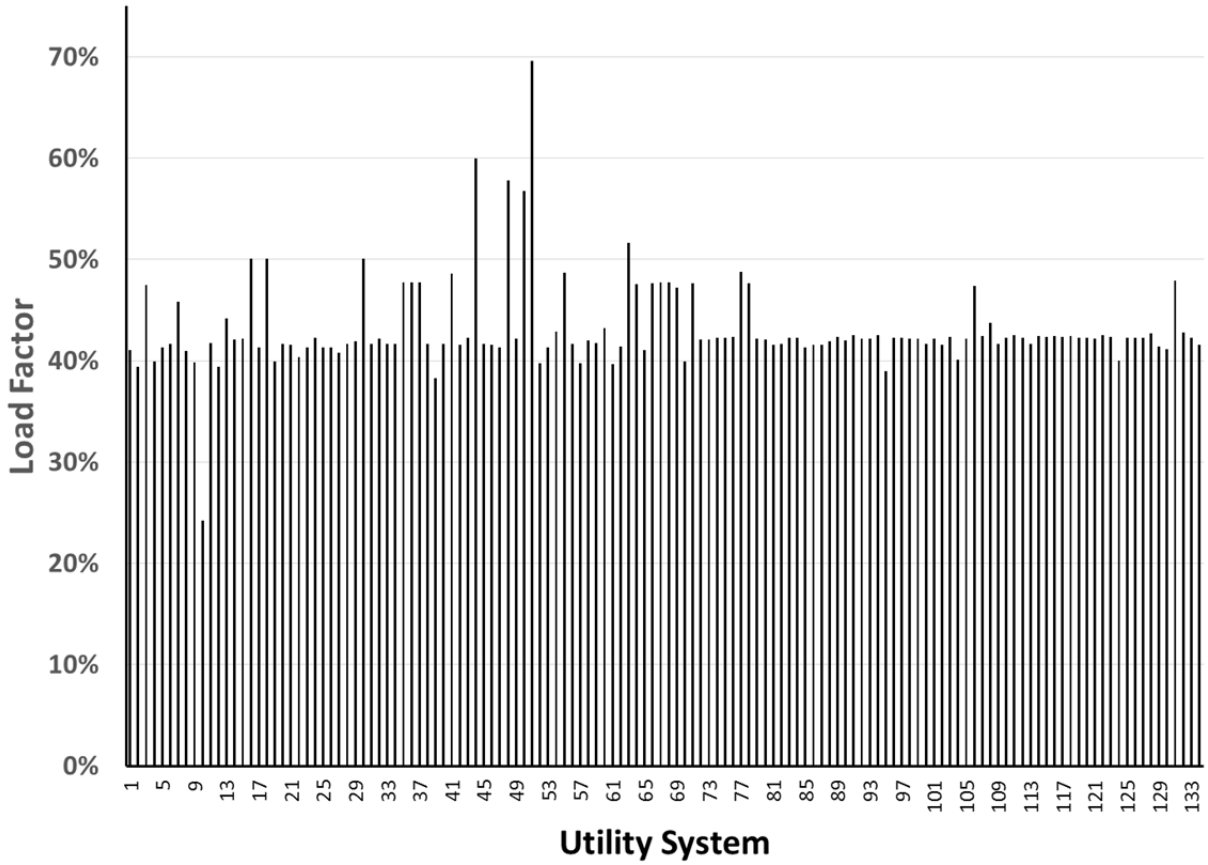

FIGURE K.3-4 Load Factors of SLCA/IP Power (Source: Osiek 2015)

after the base period are calculated from the EIA energy outlook for the Southwest region as represented by the following equation:

Retail Rate ($/MWh) under Alternative $A_{t,i}$ = Retail Rate under Alternative $A_{t-1,i}$ × (1 + Electricity Price Inflation from EIA_t) × (1+1 + Sales Growth from EIA_t).

SLCA/IP Energy for Indirect Allocation Systems

The second allocation issue highlighted in Figure K.3-3 involves allocation of SLCA/IP energy and capacity to individual retail entities from systems that receive indirect allocations. For the indirect allocation systems other than Tri-State (WMPA, UMPA, Platte River, and CRCN), the allocation of SLCA/IP energy to individual member utility systems is made on the basis of the retail sales proportion. Retail sales of the individual member system are divided by aggregate retail sales accumulated for the wholesale system (e.g., WMPA). The percentage of retail sales is multiplied by the aggregate SLCA/IP allocation to the large system reported in Osiek (2015). For Tri-State, the same general process was used, with the exception that

distribution cooperatives in Nebraska are not assumed to receive any SLCA/IP preference power and are not included in the aggregate sales calculation. The method for allocating SLCA/IP energy to individual distribution systems that are part of the larger indirect allocation systems can be represented by the following equation:

Allocation of SLCA/IP to Distribution Entity (MWh) =
[Annual Retail Sales of Distribution Entity (MWh) /
Total Aggregate Retail Sales of Distribution Systems in Group (MWh)] ×
Total SLCA/IP Allocation to Group (MWh).

Allocation Process from Computing Residential Bill Impacts

The final allocation process illustrated in Figure K.3-3 is the allocation of overall retail revenues (residential and non-residential revenues) to residential consumers and computation of residential bills. Calculation of residential bills involves two steps. The first step is to allocate a portion of the total retail increase for the system to residential consumers. This allocation is made with the ratio of residential revenues to total retail revenues for each system. Using the residential revenue percent, the dollar amount of change in residential revenue under LTEMP alternatives relative to Alternative A can be represented by the following equation:

$$\text{Residential Revenue Change } \$_{t,i} = \text{Change in Grid Cost}_{t,i} \times \text{Residential Percent}_{i}.$$

The second step is computing the monthly residential bill change from residential revenue change. The change in monthly residential bill relative to Alternative A is computed by dividing the total residential revenue change by projected residential consumers and then by 12. The number of residential consumers is projected through dividing the overall sales growth by 2 (implicitly assuming half of the growth is from increased use per customer). Calculation of monthly residential bills relative to the Alternative A is demonstrated in the equations below:

$$\text{Residential \$ Bill Increase}_{t,i} = \text{Residential \$ Increase}_{t,i} / \text{Residential Customers}_{it} / 12,$$

where:

$$\text{Residential Customers}_{it} = \text{Residential Customers}_{i,t-1} \times (1+\text{Sales Growth EIA}_{t}/2).$$

Case Study Illustration of the Allocation Process

The process of calculating rate impacts can be demonstrated by considering a case study. Tri-State is used to show how aggregate grid costs are allocated to determine rate impacts and why wholesale rates are not necessary in computing retail rate impacts. To demonstrate how rate changes are established, the grid cost impact under Alternative F in the highest impact year is used. On an aggregate basis, grid costs in this case increase by $41 million (in real 2015 dollars) relative to Alternative A. Tri-State members had retail revenues of $1.476 billion (computed from aggregating revenues for the Tri-State systems excluding the Nebraska members using the

database).[22] Tri-State energy allocations represent 29.0% of the total SLCA/IP (derived from the allocation report and recorded in the database). The amount of grid cost increase allocated to Tri-State can be computed as 29.0% multiplied by the aggregate grid cost change of $41 million, or $11.89 million. Note this calculation is made without any wholesale rate calculations. This calculation implies that the increase in average retail rates for Alternative F in the high-impact year across Tri-State member systems is $11.89 million/$1,476 billion = 0.81%.

The same retail rate calculation can be made by first computing impacts on SLCA/IP wholesale rates. Using the current capacity and energy allocations, WAPA revenues collected from SLCA/IP power are current published rates multiplied by aggregate allocations. Total revenues from multiplying capacity charges by total SLCA/IP capacity and energy charges by total SLCA/IP energy, sum to approximately $143 million. The total increase in wholesale rates would then be 28.67%, or $41 million/$143 million, if WAPA did not change capacity and energy allocations in the SLCA/IP tariff. Tri-State payments for wholesale power without the increase are the Tri-State allocation percent multiplied by total SLCA/IP revenues or 29.0% × $143 million = $41.47 million. For Tri-State, the increase in wholesale costs is 28.67% × $41.47 million = $11.89 million. Thus, the wholesale cost increase is the same whether it is calculated directly from aggregate grid costs as in the last paragraph or whether it is computed using wholesale rates as in this paragraph, and the $143 million of revenues collected from wholesale rates is not necessary for computing retail rate impacts. The wholesale impact of $11.89 million translates into the same retail impact of 0.81% discussed above. The example demonstrates that a large wholesale rate increase of 28.87% translates to a much smaller retail rate impact.

Rate Impact Measurement for American Indian Tribes

A detailed retail rate impact analysis has been prepared for American Indian Tribes. The analytical approach and results are described in Section K.4.

K.3.2 Results

Retail rate and residential bill changes are affected by the aggregate grid costs that occur under the various LTEMP alternatives relative to Alternative A. Once grid cost changes are established (that correspond to SLCA/IP wholesale rate changes), differential retail rate changes experienced by individual systems are affected by the amount of power that a system receives from SLCA/IP relative to total generation resource requirements of the system. The ratio of SLCA/IP allocation to retail sales for a particular system is termed the "preference ratio." Measurement of aggregate grid cost and the effect of SLCA/IP allocation guide presentation of the rate analysis in this section. The first part measures the aggregate grid cost change relative to

[22] By comparison, Tri-State's wholesale revenues were $1.019 billion in 2013, as reported in its Financial Report (Tri-State 2015).

wholesale revenues that are currently collected for SLCA/IP capacity and energy. Second, differential retail rates for individual systems are explained in the context of the preference ratio.

K.3.2.1 Grid Cost Changes Relative to WAPA Wholesale Revenues

Retail rate impacts of LTEMP alternatives relative to Alternative A are relatively small for individual utility systems. This is because grid cost impacts are spread over a wide consumer base and because SLCA/IP is only one out of a multitude of generating resources for the retail utility systems. Given the small rate impacts on retail systems, changes in annual grid costs relative to the total SLCA/IP revenues are introduced to provide a benchmark for comparing LTEMP alternatives. Table K.3-3 presents the average annual real grid cost increases per year from 2015 through 2035 (the LTEMP period) for LTEMP alternatives relative to Alternative A. (Grid costs that include capacity costs and production costs are defined in Section K.3.1.) Table K.3-3 shows that using the benchmark of wholesale revenues collected for SLCA/IP federal preference power, the increase in annual real grid costs divided by current wholesale revenues is as much as 20% for Alternative F. The grid cost increase is between 4% and 5% of current SLCA/IP wholesale revenues for Alternatives E and D. Capacity differences between the respective LTEMP alternatives and Alternative A, presented as the capital recovery of capacity costs, are the most important drivers of grid cost changes. The average annual capacity that is constructed under Alternative A that corresponds to the two right-most columns in Table K.3-3 is 2,701 MW.

TABLE K.3-3 Average Annual Grid Cost Relative to SLCA/IP Wholesale Revenues Relative to Alternative A

Alternative	Average Annual Grid Cost Increase Relative to Alternative A (in thousands of 2015$)	WAPA Revenues from SLCA/IP Capacity and Energy Charges (in thousands of 2015$)	Percentage Change Relative to WAPA Revenues	Average Capacity Differential Relative to Alternative A After 2017 (MW)	Maximum Capacity Differential in Single Year Relative to Alternative A (MW)
A		143,000	0.00%		-
B	(976)	143,000	–0.68%	(13.53)	(230.00)
C	9,820	143,000	6.87%	189.41	230.00
D	6,831	143,000	4.78%	121.76	230.00
E	6,392	143,000	4.47%	135.29	230.00
F	28,751	143,000	20.11%	392.35	460.00
G	17,218	143,000	12.04%	230.00	230.00

K.3.2.2 Retail Rate Changes for Individual Systems and SLCA/IP Power Relative to Total Resources

Variation among retail rate changes for individual utility systems under different LTEMP alternatives are driven in large part by the ratio of SLCA/IP energy allocation compared to the total generation resources required for the system. Using the database described in Section K.2.1.2, the proportion of SLCA/IP power to total resources can be measured by computing the ratio of SLCA/IP annual energy allocation to total retail sales. If this preference ratio is low for a retail utility system, then even a relatively large increase in SLCA/IP costs will probably have a small rate impact. Figure K.3-5 displays the range in preference ratios for individual systems, together with the size of the systems, in a scatter plot. The size of the system on the x-axis is represented by annual retail sales. The y-axis of the graph demonstrates that the range in preference ratio varies from less than 1% to more than 60% for different systems in the database. Points in the upper left corner of Figure K.3-5 demonstrate that most of the systems with high preference ratios are small. This is likely due to the history of allocations for preference power. If a system was small when it originally received a preference power allocation, but has subsequently grown large, it will have a relatively lower ratio of SLCA/IP allocation to retail sales (sales have increased and the SLCA/IP allocation has remained the same). On the other hand, if a system has not grown much since the original allocation was made (i.e., it is a small system with relatively low retail sales), the preference ratio could remain relatively high.

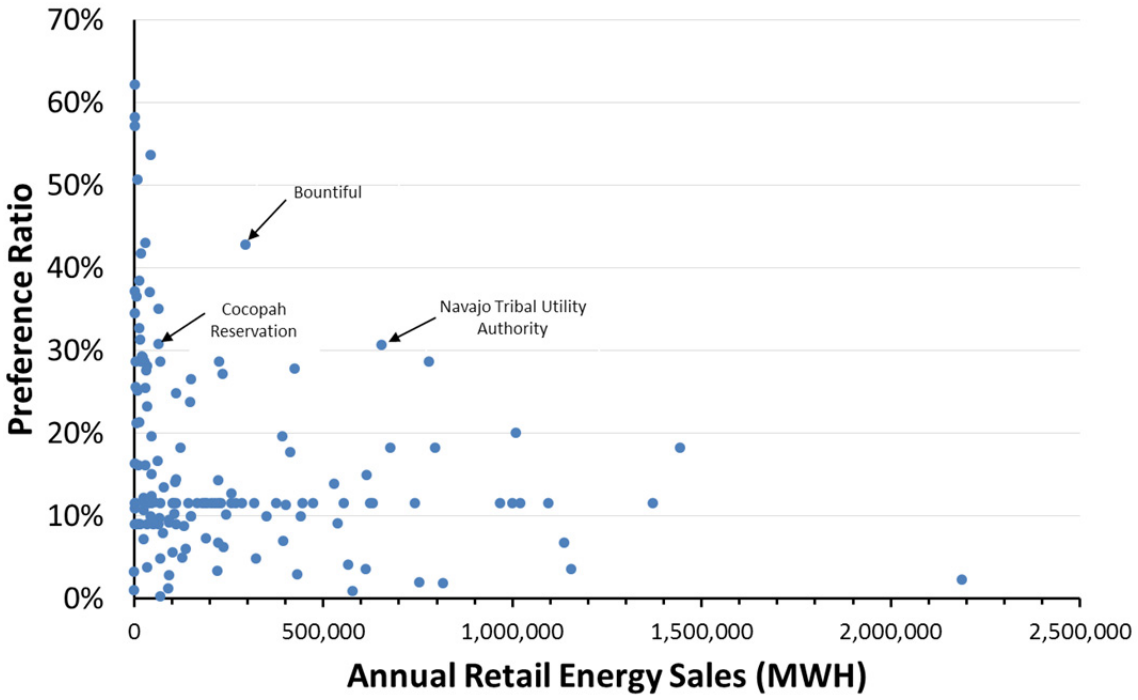

FIGURE K.3-5 Scatter Plot of Preference Ratio and Annual Retail Sales

Two of the Tribes that provide data to the EIA 861 database are highlighted in Figure K.3-5 as background for the rate impacts that are discussed in Section K.3.4.[23] The Navajo Tribal Utility Authority represents a large proportion (about 40%) of the SLCA/IP allocation to Tribes.[24] Figure K.3-5 shows that the Tribes with EIA data do have relatively high preference ratios. The only other utility system with a relatively high preference ratio that is not a very small system is the City of Bountiful, a member of UAMPS (highlighted in Figure K.3-5).

The relationship between the preference ratio and rate changes for individual systems is demonstrated by scatter plots of the percentage retail rate change and the preference ratio. In the scatter plots, the retail rate change is measured relative to Alternative A, implying that a scatter plot for Alternative A is not meaningful. Figure K.3-6 presents scatter plots of the preference ratio and the percent rate change relative to Alternative A for Alternatives B through G. In displaying the scatter plots for each LTEMP alternative relative to Alternative A, a single year is selected so that each system represents a single point. In each panel of Figure K.3-6, the year shown is the year with the highest rate impact for the respective LTEMP scenario. Because the highest rate changes do not occur in the same year for the various LTEMP alternatives, as explained in Section K.3.3.2, the scatter plots use different years.

The scatter plots shown in Figure K.3-6 demonstrate that much of the rate impact on individual systems is driven by the preference ratio. For each of the panels in Figure K.3-6, a regression equation of the percent retail rate change versus the preference ratio is displayed. The R^2 statistic displayed on each of the panels is 0.87. This indicates that 87% of the variation in percentage rate change can be explained by variation in the preference ratio. The 13% of variation in percentage retail rate changes that is not explained by the preference ratio represents other factors that include the level of retail rates, the load factor of the system, distribution costs, and the capacity and energy costs paid for non SLCA/IP power.

Scatter plots displayed in Figure K.3-6 have differently scaled y-axes. The y-axes represent the range in possible rate changes for the respective LTEMP alternative in the year with the highest (absolute value) percent change. The upper end of the y-axis therefore represents the absolute maximum retail rate percent increase for the LTEMP alternative across systems. Finally, regression equations are presented in each panel of Figure K.3-6 that shows the relationship between the preference ratio and the percent retail rate change in the year with the maximum change for each LTEMP alternative. These regression equations can be used to approximate rate impacts for systems that are not included in the database, as explained in the next section.

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23 Fifty-three different Tribal entities receive capacity and energy allocations from SLCA/IP, representing 8.85% of the total energy allocation. Because the Tribes do not report sales and revenues as part of Form EIA-861 database, accessing sufficient data to make individual rate impact assessments was not possible. Instead, the analysis focused on two Tribal systems: Navajo Tribal Utility Authority and the Cocopah Reservation.

24 Retail data for the Navajo Tribal Utility Authority was derived from its Integrated Resource Plant (IRP) and Website (https://ww2.wapa.gov/sites/western/es/irp/Documents/NTUA2012.pdf) rather than from the EIA-861.

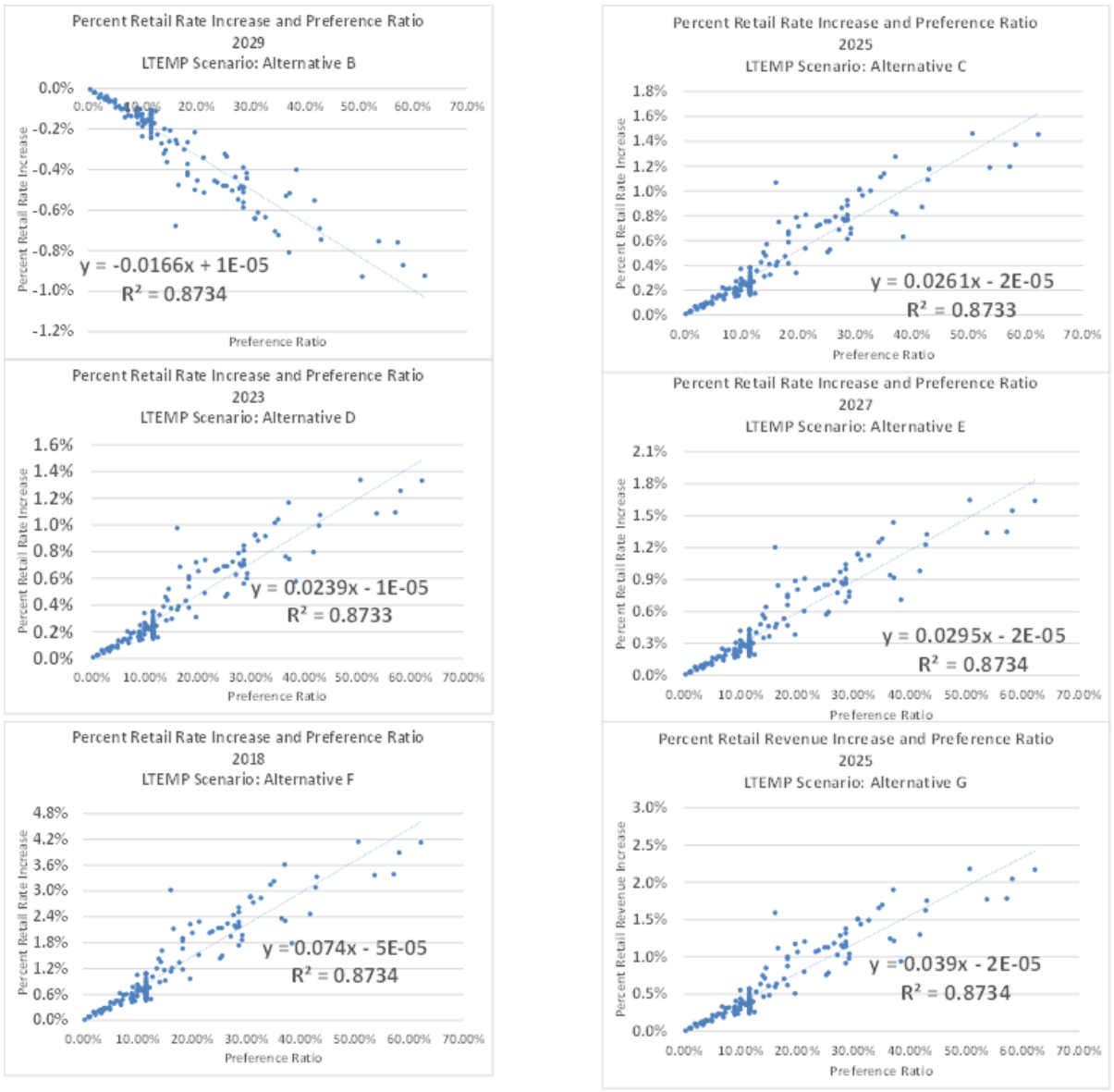

FIGURE K.3-6 Scatter Plots of Percent Retail Rate Change and the Preference Ratio

K.3.2.3 Using Regression Equations to Approximate Retail Rate Changes for Systems Not Included in the Database

For small Tribal systems and other entities that do provide retail sales and rate data to the EIA, the rate impacts can be approximated using the regression equations shown in Figure K.3-6. To compute rate impacts for systems that are not directly evaluated in the database, the preference ratio should be computed first through dividing annual SLCA/IP energy allocations by the retail electricity usage of consumers for the system. This preference ratio can then be multiplied by the coefficient shown in each of the panels of Figure K.3-6. For example, under Alternative F in the high-impact year, the coefficient is 0.074. If the ratio of SLCA/IP energy to

total energy consumption is 50% for an entity such as a U.S. Air Force base or for a Tribe that does not report to the EIA, the estimated rate increase would be 3.7% (0.074 × 50%).

K.3.3 Summary of Impacts

Retail rate and residential bill impacts under the LTEMP alternatives were compiled for 147 different utility systems during the LTEMP period, 2015 to 2035, on an annual basis. The retail rate impacts and the residential bill impacts under Alternatives B–G are presented relative to Alternative A. Due to the large number of retail utility systems that receive federal preference power and the number of LTEMP alternatives, various different techniques were used to summarize the rate impact results.

Rate and bill impacts are presented in four parts. First, the aggregate impacts are averaged across all systems and across the entire LTEMP period. Second, the impacts of LTEMP alternatives are presented on a year-by-year basis averaged across all systems. This section also includes a summary comparison of maximum-impact-year rate and bill impacts across different LTEMP alternatives. Third, rate and bill impacts for specific utility systems are listed under different LTEMP alternatives and the impacts under each LTEMP alternative are discussed. Fourth, the rate impacts on small systems and Tribes are explained.

K.3.3.1 Average Rate Impacts under LTEMP Alternatives over the 20-Year LTEMP Period

To demonstrate the general magnitude of rate impacts and evaluate the relative impact of different LTEMP alternatives on retail electricity rates, impacts are presented in terms of average impacts across utility systems and the LTEMP period. Before introducing the rate and bill impacts for Alternatives B, C, D, E, F, and G relative to Alternative A, retail rates and residential bills for Alternative A are described. The retail rates and residential bills under Alternative A provide a benchmark for gauging impacts of other alternatives. For example, a monthly residential bill increase of $1.00 under a particular LTEMP alternative relative to Alternative A can be evaluated relative to the average and median monthly residential bills in Alternative A.

Figures K.3-7 and K.3-8 display retail rates in $/MWh and residential bills in $/month under Alternative A. Note that none of the tables and figures in this section include the impacts on Tribes that have special net benefit contracts. Rate impacts for Tribes with net benefit contracts are addressed in Section K.3.4.2. Figure K.3-7 shows the distribution of retail rates across the utility systems. Retail rates are computed by dividing retail revenues collected from residential, business and other consumers by retail sales for the consumers. Rates and bills are represented in Figures K.3-7 and K.3-8 with distribution analyses. The increments on the x-axes demonstrate the highest and lowest ranges for rates and bills across different systems. The average and the median statistics, as well as the ranges, are shown in the graph titles. The range in retail rates under Alternative A varies from $55/MWh to $177/MWh, with an average rate of $104/MWh. The level of retail rates influences the reported rate increase percent in subsequent

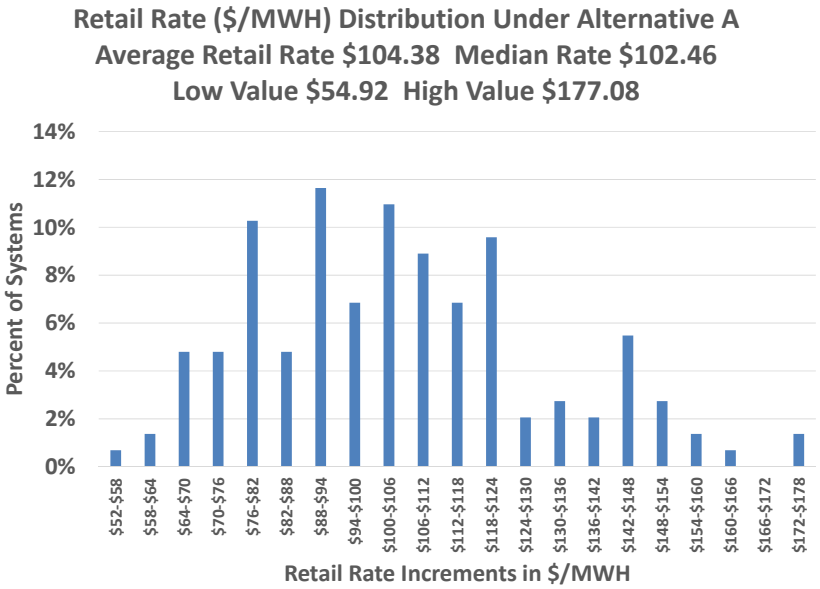

FIGURE K.3-7 Retail Rate Distribution under Alternative A

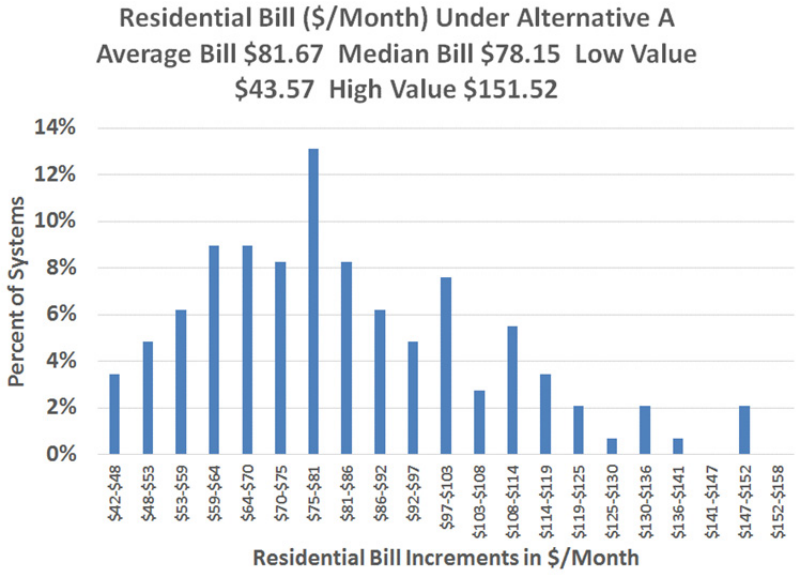

FIGURE K.3-8 Monthly Residential Bill Distribution under Alternative A

presentation of rate impacts. For example, a lower retail rate for a particular system results in a higher percent increase, all else being equal, because the allocated aggregated cost increase is divided by the retail rate. On the other hand, a lower retail rate does not influence the residential bill calculation because bill impacts are measured on an absolute basis.

Figure K.3-8 presents monthly residential bills that are calculated by dividing annual residential revenues of a system by the number of residential consumers and then dividing the product by 12. Average monthly bills under Alternative A range between $44 and $151 per month, with an average of $82 per month. This implies that an increase of $1 from an LTEMP alternative other than Alternative A results in a typical percent increase in monthly bills of somewhat more than 1%.

Figures K.3-9 and K.3-10 illustrate the average impacts on retail rate changes and on monthly residential bills across different systems relative to Alternative A. Residential bill impacts in Figure K.3-10 and in the rest of the subsequent rate impact presentation are measured in real 2015 dollars. The graphs in Figures K.3-9 and K.3-10 display averages across systems that are not weighted by the size of the systems. This means that a small system with less than 1,000 consumers is given the same weight as a large system with hundreds of thousands of customers (such as SRP). Because rate impacts tend to be greater for small systems, evaluating impacts using averages weighted by the sales size results in lower increases (about half of the unweighted average). Weighted average impacts are discussed in Section K.3.3.3 and presented in Table K.3-4. Figure K.3-9 demonstrates that even the most extreme LTEMP alternative in terms of changing dam operations (Alternative F) results in rate changes for retail consumers below 1%. Under Alternative F, there is an average rate increase of 0.75% relative to Alternative A. Figure K.3-10 shows that the highest average residential bill impact is 69 cents per month. Alternatives E and D have much lower retail rate impacts that are approximately 20% of the rate impact under Alternative F. (Note that individual rate impacts on particular systems can be higher than the average impacts.)

K.3.3.2 Average Year-by-Year Rate Impacts

Rate impacts presented in the previous paragraphs, which average rate and bill changes across the entire LTEMP period, mask the year-to-year rate impacts. Impacts in a single year can be different than average impacts across years because of the manner in which capacity changes occur and the effects of dam operations on production costs. Maximum rate impacts in a single year may be of concern to stakeholders. Therefore, the average annual retail rate and bill impacts from year to year are presented in this section. Figures K.3-11 and K.3-12 show the year-by-year averages for the overall retail percent changes and residential bill changes under different LTEMP alternatives. Year-by-year impacts for LTEMP alternatives are measured relative to Alternative A and the averages are not weighted by system size. Figure K.3-11 demonstrates that in terms of average percent changes in retail rates across all of the utility systems, the changes are not constant from year to year. Retail rate impacts from Alternative F are above the other alternatives, except in 2 of the years. The largest percent changes other than under Alternative F are under Alternative G, which has relatively constant changes over the LTEMP period. The

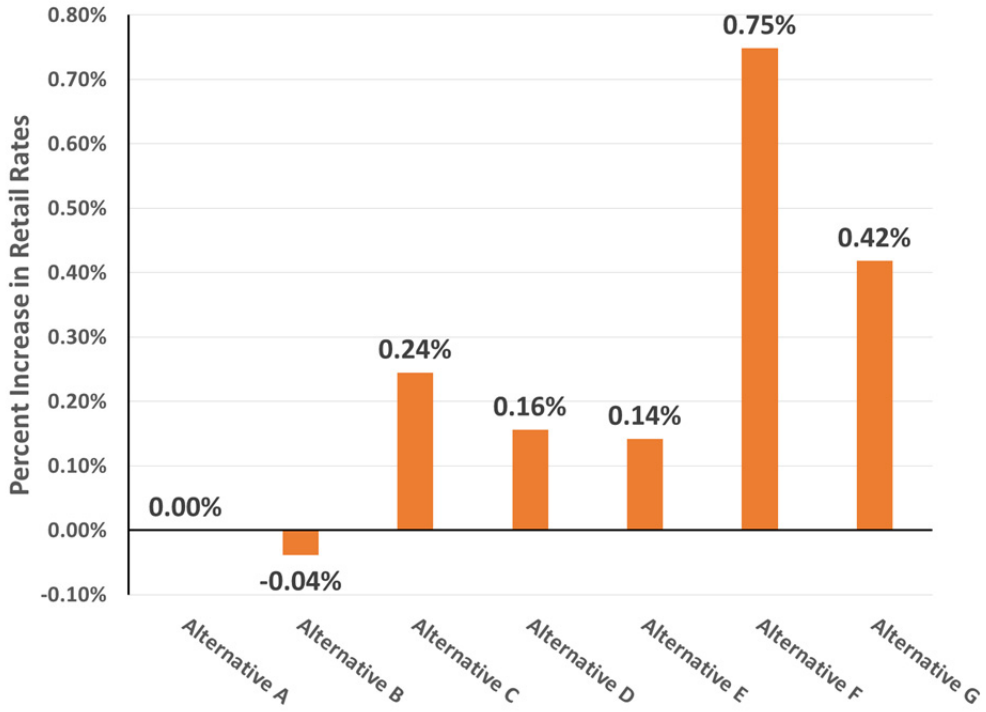

FIGURE K.3-9 Average Retail Rate Impacts under LTEMP Alternatives Relative to Alternative A

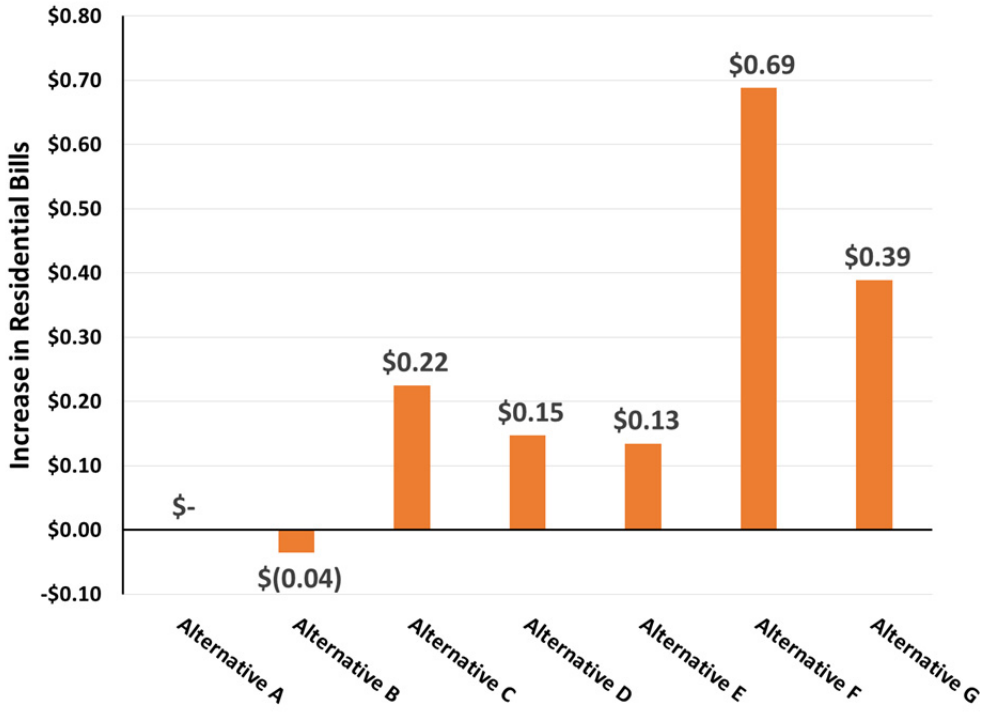

FIGURE K.3-10 Average Residential Bill Impacts under LTEMP Alternatives Relative to Alternative A

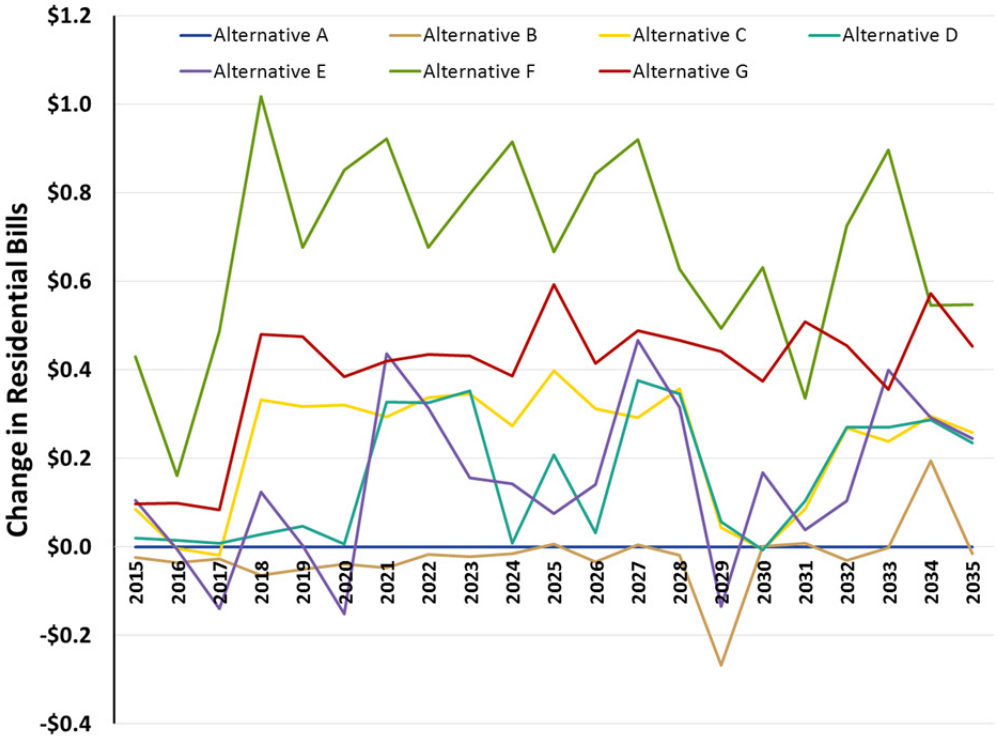

FIGURE K.3-11 Average Retail Percent Revenue Increase Relative to Alternative A

third-highest rate impacts are from Alternative C; these are constant until 2028, after which the impacts decline. Alternatives D and E have varying impacts from year to year that are driven by differences in construction of new capacity. Alternative B has impacts below zero (bill reductions relative to Alternative A), except in 2034, when construction of new capacity is accelerated relative to Alternative A. All of the tables and figures in this section include the Ak-Chin, Tohono O'odham Reservation, and Navajo Tribal Utility Authority Tribes but do not include the impacts on Tribes that have special net benefit contracts. Rate impacts for Tribes with net benefit contracts are addressed in Section K.3.4.2.

Figure K.3-12 shows that in terms of monthly bill changes from year to year, the annual patterns are similar to the trends in retail bill changes. The highest monthly bill impact in a single year is just above $1.00 per month under Alternative F, relative to Alternative A in 2018. The year 2018 for Alternative F is termed the maximum impact year. For Alternative G, the maximum residential monthly impact is just below 60 cents per month in the year 2025. Impacts for the maximum year are presented in Table K.3-4. Figure K.3-11 also demonstrates that monthly bill impacts are more variable from year to year under Alternative E than other LTEMP alternatives. Alternative E has bill changes below zero in the years 2017, 2020, and 2029. The bill impacts are higher for Alternative E than Alternative D, but Alternative D does not have any impacts that are below zero.

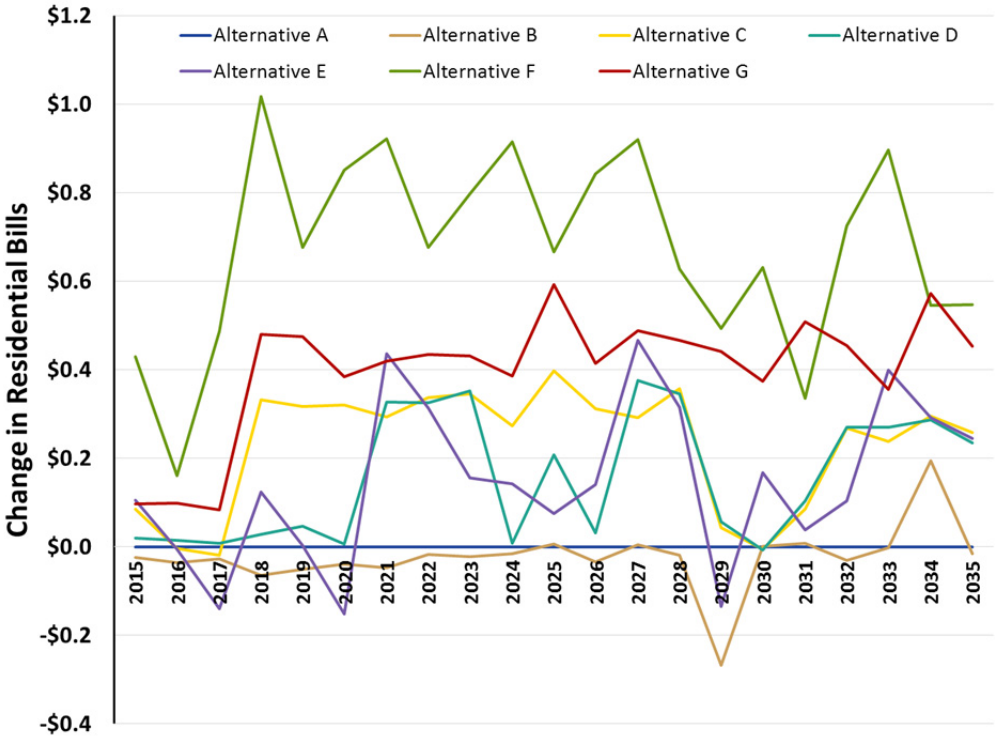

FIGURE K.3-12 Average Monthly Residential Bill Changes Relative to Alternative A

Maximum and average rate and bill impacts are recorded in Table K.3-4, which summarizes the average impacts across systems in the maximum impact year and over the LTEMP period. Unlike the impacts presented up to this point, Table K.3-4 also presents the averages and maximum impacts using an alternative weighting method where the size of different systems is considered. The weighting method places a higher weight on larger systems by multiplying all of the impacts by the ratio of retail sales for a system to aggregate retail sales across all systems. When averages are weighted by sales, the rate and bill impacts are approximately half of the amount without weighting. For example, the maximum monthly bill impact of $1.02 per month under Alternative F in 2018 is reduced to 50 cents when small systems are given lower weight and larger systems are given higher weight. The large reduction in impacts from weighting by sales comes about in part because SRP and the City of Colorado Springs have low rate impacts and a very high level of sales relative to other systems. The sales of these two systems alone represent 45% of the total sales for all systems in the analysis. When weighting by sales, the weighting calculation shown in Table K.3-4 excludes SRP and the City of Colorado Springs in the aggregate sales tabulation.

In addition to displaying average impacts across years and average rate impacts in the maximum change year, median impacts are also shown in Table K.3-4. Median statistics show the rate or bill change for which 50% of companies are above the value and 50% are below the value. The median values are less affected by extreme high values or low values and result in

TABLE K.3-4 Summary Table of Comparative Values

Impact	Alternative A (No Action Alternative	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Percent change in average grid cost relative to WAPA revenues	No Change	–0.68	6.87	4.78	4.47	20.11	12.04
No Weighting by size							
Percent change in retail rates (average across years)	No Change	–0.04	0.25	0.15	0.14	0.75	0.42
Average percent change in retail rates (maximum impact year)	No Change	–0.27	0.43	0.39	0.50	1.21	0.64
Median percent change in retail rates (maximum impact year)	No Change	–0.20	0.27	0.25	0.30	0.76	0.40
Change in monthly residential bill (average across years)	No Change	–$0.04	$0.22	$0.15	$0.13	$0.69	$0.39
Average change in monthly residential bill (maximum impact year)	No Change	–$0.27	$0.40	$0.38	$0.47	$1.02	$0.59
Median change in monthly residential bill (maximum impact year)	No Change	–$0.23	$0.31	$0.27	$0.09	$0.78	$0.46
Weighting by size with adjustments for SRP and Colorado Springs							
Percent change in retail rates (average across years)	No Change	–0.03	0.19	0.12	0.11	0.59	0.33
Percent change in retail rates (maximum impact year)	No Change	–0.21	0.34	0.31	0.39	0.96	0.50
Median percent change in retail rates (maximum impact year)	No Change	–0.19	0.26	0.24	0.30	0.75	0.39
Change in monthly residential bill (average across years)	No Change	–$0.03	$0.18	$0.12	$0.11	$0.56	$0.32
Change in monthly residential bill (maximum impact year)	No Change	–$0.25	$0.32	$0.31	$0.38	$0.83	$0.48
Change in monthly residential bill (average across years)	No Change	–$0.22	$0.31	$0.27	$0.10	$0.79	$0.46

lower observed impacts because a few systems with high rate impacts skew the averages. The top half of Table K.3-4 shows data on an unweighted basis that have been shown above. The lower half shows weighted averages, including the median. The top part of Table K.3-4 demonstrates that the maximum impact is lower when measured by the median instead of the average. For example, under Alternative F, the maximum residential bill impact of $1.02 that is averaged for all systems is more than 20% less (78 cents) when the median is used to measure the typical impact. The impact is further reduced when the impacts are weighted by sales size, as shown at the bottom of the table. Weighting by sales reduces the measured rate impact. For example, under Alternative G, the average retail rate increase is reduced from 0.64% to 0.50% when the average is weighted by adjusted sales size. When the median sales weighted statistic is measured, the number for the maximum year under Alternative G falls to 0.39%.

K.3.3.3 Individual System Impacts and Summary Descriptions of LTEMP Alternatives

This section addresses individual rate and bill impacts on particular systems rather than presenting results in terms of averages. Detailed rate impacts on selected individual utilities are presented separately for systems that experience relatively large and relatively small impacts. Four tables, Table K.3-5 through Table K.3-8, demonstrate the large and small individual impacts on different systems. The tables show the year with the maximum retail rate and monthly bill impact for each alternative relative to Alternative A. Using the lists of systems with the highest rate impacts and the graphs and tables from previous sections, each alternative is summarized.

Lists of Individual Systems with Largest and Smallest Impacts

Table K.3-5 lists the 30 systems with the largest percentage retail rate impact (in absolute value) for the LTEMP alternatives. Given the aggregate grid cost change from an LTEMP alternative, the retail rate impact for a particular system depends on the SLCA/IP energy allocation, the preference ratio, and the current retail rate. None of these three items change with different operations of the dam. This means the ranking of systems does not change under different alternatives and lists of systems with the largest and smallest impact can be presented on a single table. The percentage rate impact is shown under the letter of the respective alternative. The year of the maximum impact for which the retail rate impact is displayed is shown below the alternative title. Table K.3-6 displays the 30 systems with the smallest percentage retail rate impact in a similar format. The size of systems as measured by the number of residential consumers and the preference ratio is presented for each system. The year for which the impact is measured is also shown on Table K.3-5.

Many of the entities that experience the largest impacts are part of the UAMPS system and have a high ratio of preference power to sales. The systems with the highest rate impacts generally are relatively small, such as the City of Enterprise (with 517 consumers). The systems that experience the smallest impact are often large systems and have relatively low preference power ratios.

TABLE K.3-5 Individual Systems with the Largest Percent Retail Rate Impacts Relative to Alternative A

Number	Utility System	Preference Ratio	Number of Residential Consumers	Percent Rate Impact Relative to Alternative A					
				Alternative B 2029	Alternative C 2025	Alternative D 2023	Alternative E 2027	Alternative F 2020	Alternative G 2025
1	Beaver (UAMPS)	25.51	1,500	–0.48	0.76	0.69	0.85	2.14	1.13
2	Ephraim (UAMPS)	28.19	1,731	–0.48	0.76	0.70	0.86	2.15	1.13
3	Manti (UMPA)	28.65	1,274	–0.49	0.77	0.70	0.86	2.17	1.14
4	Murray (UAMPS)	27.89	13,977	–0.49	0.78	0.71	0.88	2.20	1.16
5	Spanish Fork (UMPA)	28.65	9,712	–0.49	0.78	0.71	0.88	2.20	1.16
6	Dixie Escalante R.E.A.	19.68	13,831	–0.50	0.79	0.72	0.89	2.23	1.17
7	Brigham City	26.57	6,643	–0.50	0.79	0.73	0.89	2.25	1.18
8	Provo (UMPA)	28.65	31,204	–0.51	0.81	0.74	0.91	2.29	1.20
9	Ocotillo I.D.	21.36	19	–0.51	0.81	0.74	0.91	2.29	1.21
10	Paragonah (UAMPS)	37.22	250	–0.52	0.82	0.75	0.92	2.31	1.22
11	Fairview (UAMPS)	36.53	714	–0.53	0.84	0.76	0.94	2.37	1.25
12	Flowell E.A., Inc. (Deseret)	27.66	194	–0.55	0.86	0.79	0.97	2.44	1.29
13	Morgan (UAMPS)	41.79	1,429	–0.55	0.87	0.80	0.98	2.47	1.30
14	Levan (UMPA)	28.65	317	–0.56	0.89	0.81	1.00	2.51	1.32
15	Nephi (UMPA)	28.65	1,890	–0.59	0.93	0.85	1.04	2.62	1.38
16	Parowan (UAMPS)	31.33	1,237	–0.61	0.97	0.88	1.09	2.73	1.44
17	Monroe (UAMPS)	32.73	916	–0.63	1.00	0.92	1.13	2.84	1.49
18	Navajo Tribal Authority	30.75	32,727	–0.64	1.01	0.92	1.14	2.86	1.51
19	Cocopah Reservation	30.83	3,334	–0.64	1.01	0.93	1.14	2.87	1.51
20	Helper	16.10	1,020	–0.68	1.07	0.98	1.20	3.03	1.59
21	Bountiful (UAMPS)	42.82	15,295	–0.69	1.09	1.00	1.23	3.09	1.62
22	Oak City (UAMPS)	34.51	260	–0.70	1.11	1.02	1.25	3.15	1.66
23	Gunnison	35.12	3,348	–0.72	1.14	1.04	1.29	3.23	1.70
24	Ak-Chin Municipal	43.03	282	–0.75	1.18	1.08	1.33	3.33	1.75
25	Truth or Consequences	53.69	3,572	–0.75	1.19	1.09	1.34	3.37	1.77
26	Holden (UAMPS)	57.22	215	–0.76	1.20	1.09	1.35	3.39	1.78
27	Maricopa MWCD	37.09	NA[a]	–0.81	1.28	1.17	1.44	3.62	1.90

TABLE K.3-5 (Cont.)

Number	Utility System	Preference Ratio	Number of Residential Consumers	Percent Rate Impact Relative to Alternative A					
				Alternative B 2029	Alternative C 2025	Alternative D 2023	Alternative E 2027	Alternative F 2020	Alternative G 2025
28	Kanosh (UAMPS)	58.20	284	–0.87	1.37	1.26	1.55	3.89	2.05
29	Meadow (UAMPS)	62.22	158	–0.92	1.46	1.33	1.64	4.13	2.17
30	Enterprise (UAMPS)	50.65	517	–0.93	1.46	1.34	1.65	4.14	2.18

[a] NA = Not applicable (i.e., the system does not sell to residential consumers).

TABLE K.3-6 Individual Systems with the Smallest Percent Retail Rate Impacts Relative to Alternative A

No	Utility System	Preference Ratio	Number of Residential Consumers	Percent Rate Impact Relative to Alternative A					
				Alternative B 2029	Alternative C 2025	Alternative D 2023	Alternative E 2027	Alternative F 2020	Alternative G 2025
1	Frederick	0.26	3,453	0.00	0.01	0.01	0.01	0.01	0.01
2	Salt River Project	1.09	867,846	–0.02	0.03	0.02	0.03	0.08	0.04
3	Los Alamos County	0.98	7,792	–0.02	0.03	0.03	0.03	0.09	0.05
4	Wellton-Mohawk I.D.	1.24	2,768	–0.02	0.03	0.03	0.04	0.09	0.05
5	Intermountain R.E.A.	2.27	130,075	–0.03	0.05	0.04	0.05	0.13	0.07
6	Grand Valley E.C.	3.33	14,021	–0.04	0.06	0.05	0.07	0.17	0.09
7	Central Valley E.C., Inc.	2.04	5,180	–0.04	0.07	0.06	0.07	0.19	0.10
8	Lea County E.C., Inc.	1.89	6,759	–0.04	0.07	0.06	0.08	0.20	0.10
9	ELECTRICAL DISTRICT 3	3.54	19,561	–0.05	0.07	0.07	0.08	0.21	0.11
10	Washington (UAMPS)	2.89	5,578	–0.05	0.07	0.07	0.08	0.21	0.11
11	Farmers E.C., Inc.	2.93	9,739	–0.05	0.08	0.07	0.09	0.23	0.12
12	Colorado Springs Utilities	3.29	180,928	–0.05	0.09	0.08	0.10	0.24	0.13
13	Holy Cross E.A.	3.59	45,196	–0.06	0.09	0.08	0.10	0.25	0.13
14	Safford	4.91	3,378	–0.06	0.09	0.08	0.10	0.25	0.13
15	Yampa Valley Rural	4.15	21,670	–0.06	0.10	0.09	0.11	0.27	0.14
16	Santa Clara (UAMPS)	3.84	1,973	–0.06	0.10	0.09	0.11	0.29	0.15
17	Mesa (APPA)	4.85	13,257	–0.07	0.11	0.10	0.12	0.31	0.16
18	Navopache E.C., Inc.	6.96	34,867	–0.08	0.13	0.12	0.14	0.36	0.19
19	Torrington (WMPA)	5.66	3,163	–0.09	0.14	0.12	0.15	0.39	0.20
20	Glenwood Springs	5.00	4,779	–0.09	0.15	0.13	0.17	0.42	0.22
21	Fort Laramie (WMPA)	8.98	210	–0.10	0.15	0.14	0.17	0.43	0.22
22	Gallup	6.83	8,509	–0.10	0.15	0.14	0.17	0.43	0.23
23	Lamar Utilities Board	9.53	4,219	–0.10	0.16	0.14	0.18	0.45	0.24
24	Lehi (UAMPS)	6.26	14,146	–0.10	0.16	0.15	0.18	0.45	0.24
25	Kaysville (UAMPS)	6.01	7,929	–0.10	0.16	0.15	0.18	0.45	0.24
26	Sierra Electric Cooperative	11.56	3,595	–0.10	0.16	0.15	0.18	0.46	0.24
27	Tohono O'odham	9.20	3,036	–0.11	0.17	0.15	0.19	0.47	0.25
28	Thatcher	7.26	1,072	–0.11	0.17	0.15	0.19	0.48	0.25
29	Raton	12.46	3,645	–0.11	0.17	0.16	0.20	0.49	0.26
30	Sangre de Cristo Electric	11.56	10,756	–0.11	0.18	0.16	0.20	0.50	0.26

TABLE K.3-7 Individual Systems with the Largest Monthly Residential Bill Impacts Relative to Alternative A

No	Utility System	Preference Ratio	Number of Residential Consumers	Monthly Bill Impact (2015 $) Relative to Alternative A					
				Alternative B 2029	Alternative C 2025	Alternative D 2023	Alternative E 2027	Alternative F 2020	Alternative G 2025
1	Bridger Valley E.A., Inc.	23.82	5,262	–0.43	0.63	0.56	0.74	1.62	0.94
2	Murray (UAMPS)	27.89	13,977	–0.43	0.63	0.56	0.74	1.62	0.95
3	Paragonah (UAMPS)	37.22	250	–0.43	0.64	0.56	0.75	1.63	0.95
4	Provo (UMPA)	28.65	31,204	–0.43	0.64	0.57	0.75	1.63	0.95
5	Gunnison	35.12	3,348	–0.46	0.69	0.61	0.81	1.76	1.03
6	Monroe (UAMPS)	32.73	916	–0.46	0.69	0.61	0.81	1.76	1.03
7	Salem (UMPA)	28.65	1,793	–0.47	0.70	0.62	0.82	1.79	1.04
8	Parowan (UAMPS)	31.33	1,237	–0.47	0.70	0.62	0.82	1.79	1.04
9	Nephi (UMPA)	28.65	1,890	–0.49	0.73	0.65	0.85	1.86	1.09
10	Spanish Fork (UMPA)	28.65	9,712	–0.49	0.73	0.65	0.86	1.88	1.10
11	Truth or Consequences	53.69	3,572	–0.50	0.74	0.66	0.87	1.90	1.11
12	Garkane Power Assn., Inc.	27.18	10,520	–0.50	0.75	0.66	0.87	1.91	1.11
13	Manti (UMPA)	28.65	1,274	–0.50	0.75	0.66	0.88	1.92	1.12
14	Page (AZ) +	24.91	3,492	–0.51	0.76	0.67	0.89	1.94	1.13
15	Morgan (UAMPS)	41.79	1,429	–0.52	0.78	0.69	0.91	1.99	1.16
16	Dixie Escalante R.E.A., Inc.	19.68	13,831	–0.53	0.79	0.70	0.93	2.02	1.18
17	Willwood	16.37	49	–0.55	0.81	0.72	0.95	2.07	1.21
18	Levan (UMPA)	28.65	317	–0.55	0.82	0.72	0.96	2.09	1.22
19	Holyoke	29.24	937	–0.55	0.82	0.73	0.96	2.09	1.22
20	Electrical District 3 (APPA)	14.49	975	–0.56	0.82	0.73	0.97	2.11	1.23
21	Oak City (UAMPS)	34.51	260	–0.57	0.84	0.74	0.98	2.15	1.25
22	Kanosh (UAMPS)	58.20	284	–0.61	0.90	0.80	1.05	2.30	1.34
23	Ocotillo I.D.	21.36	19	–0.66	0.98	0.87	1.15	2.52	1.47
24	Electrical District 3, Maricopa County	16.62	93	–0.71	1.05	0.93	1.23	2.69	1.57
25	Bountiful (UAMPS)	42.82	15,295	–0.76	1.13	1.01	1.33	2.90	1.69
26	Meadow (UAMPS)	62.22	158	–0.78	1.15	1.02	1.35	2.95	1.72
27	Holden (UAMPS)	57.22	215	–0.78	1.16	1.03	1.36	2.96	1.72
28	Enterprise (UAMPS)	50.65	517	–0.84	1.24	1.10	1.46	3.18	1.86
29	Flowell E.A., Inc. (Deseret)	27.66	194	–0.92	1.37	1.22	1.61	3.51	2.05
30	Ak-Chin Municipal	43.03	282	–1.39	2.07	1.83	2.42	5.29	3.08

TABLE K.3-8 Individual Systems with the Smallest Monthly Residential Bill Impacts Relative to Alternative A

				Monthly Bill Impact (2015 $) Relative to Alternative A					
No	Utility System	Preference Ratio	Number of Residential Consumers	Alternative B 2029	Alternative C 2025	Alternative D 2023	Alternative E 2027	Alternative F 2020	Alternative G 2025
1	Maricopa County	37.09	NA[a]	0.00	0.00	0.00	0.00	0.00	0.00
2	Frederick	0.26	3,453	0.00	0.01	0.01	0.01	0.02	0.01
3	Los Alamos County	0.98	7,792	–0.02	0.02	0.02	0.03	0.06	0.03
4	Wellton-Mohawk I.D.	1.24	2,768	–0.03	0.04	0.03	0.05	0.10	0.06
5	Salt River Project	1.09	867,846	–0.03	0.04	0.04	0.05	0.11	0.06
6	Intermountain R.E.A.	2.27	130,075	–0.04	0.06	0.05	0.07	0.16	0.09
7	Washington (UAMPS)	2.89	5,578	–0.04	0.07	0.06	0.08	0.17	0.10
8	Lea County E.C., Inc.	1.89	6,759	–0.05	0.07	0.06	0.08	0.17	0.10
9	Central Valley E.C., Inc.	2.04	5,180	–0.05	0.07	0.06	0.08	0.18	0.11
10	Farmers E.C., Inc.	2.93	9,739	–0.05	0.08	0.07	0.09	0.20	0.12
11	Colorado Springs Utilities	3.29	180,928	–0.06	0.08	0.07	0.10	0.21	0.12
12	Grand Valley E.C.	3.33	14,021	–0.06	0.09	0.08	0.10	0.22	0.13
13	Glenwood Springs	5.00	4,779	–0.07	0.10	0.09	0.11	0.25	0.15
14	Yampa Valley Rural	4.15	21,670	–0.07	0.10	0.09	0.12	0.25	0.15
15	Gallup	6.83	8,509	–0.07	0.10	0.09	0.12	0.27	0.16
16	Navopache E.C., Inc.	6.96	34,867	–0.08	0.11	0.10	0.13	0.29	0.17
17	Safford	4.91	3,378	–0.08	0.12	0.10	0.14	0.30	0.17
18	Torrington (WMPA)	5.66	3,163	–0.08	0.12	0.11	0.14	0.31	0.18
19	Holy Cross E.A.	3.59	45,196	–0.08	0.12	0.11	0.14	0.31	0.18
20	Fort Laramie (WMPA)	8.98	210	–0.09	0.13	0.11	0.15	0.33	0.19
21	Price	7.93	4,460	–0.09	0.13	0.11	0.15	0.33	0.19
22	Mesa (APPA)	4.85	13,257	–0.09	0.13	0.12	0.15	0.33	0.19
23	Santa Clara (UAMPS)	3.84	1,973	–0.09	0.14	0.12	0.16	0.35	0.20
24	ELECTRICAL DISTRICT 3	3.54	19,561	–0.09	0.14	0.12	0.16	0.36	0.21
25	Lusk (WMPA)	8.98	931	–0.09	0.14	0.12	0.16	0.36	0.21
26	Mora-San Miguel	11.56	10,575	–0.10	0.15	0.13	0.18	0.38	0.22
27	Lehi (UAMPS)	6.26	14,146	–0.10	0.15	0.13	0.18	0.38	0.22
28	Farmington	6.73	34,037	–0.10	0.15	0.14	0.18	0.39	0.23
29	Cody (WMPA)	8.98	5,894	–0.10	0.15	0.14	0.18	0.39	0.23
30	Kit Carson Electric	11.56	24,309	–0.11	0.17	0.15	0.19	0.42	0.25

[a] NA = Not applicable.

Tables K.3-7 and K.3-8 list the systems with the highest and lowest residential monthly retail bill impacts in a similar format to the percent retail rate change tables. As with Tables K.3-5 and K.3-6, the impacts are shown for Alternatives B–G relative to Alternative A. The ranking of residential bill impacts is not the same as the rank of the retail percent increase. One of the reasons for differences in ranking is due to residential use variation among individual systems. Systems with lower residential use have a higher bill impact because grid costs are spread over a smaller base, all else being equal. Differences in residential usage are evidenced by the fact that the median average usage across the different systems is 730 kWh per month, while the maximum use for a single system is 1,680 kWh per month, and the system with the lowest annual residential usage is 391 kWh per month.[25] The ranking of retail percent impacts and monthly residential bill impacts also differs because residential bills are measured in absolute rather than in percentage terms. If two utility systems have the same overall percentage rate increase, but one system has a higher level of prices and higher residential bills, that system will have a higher residential bill impact relative to the percentage impact. For example, Ak-Chin has a higher ranking for bill impacts than for retail rate change impacts. This utility system has a small number of residential customers and a relatively high level of consumer bills. In 2012, the average monthly bill of Ak-Chin was about $140, which is 69% higher than the average bill across all systems of $84 per month.

K.3.4 Impacts on Small Systems

Two groups of utilities that are allocated a large fraction of their generation resources from SLCA/IP projects are Tribes and some small utilities, implying that the rate and bill impacts on these two groups tend to be relatively large. Impacts on small systems are presented separately in this section. Impacts on Tribes are presented in Section K.4.

To demonstrate the effect of system size on rate impacts, statistics were computed for the 20 systems with the largest impact and the 20 systems with the smallest impacts. Table K.3-9 demonstrates that, as measured by the number of residential consumers, the average size of systems with the largest rate impacts (1,680 consumers) is much smaller than the typical size of utility systems. Without adjusting for SRP and Colorado Springs, utilities with the smallest rate impacts are on average 38 times the size of the systems that have the largest rate impacts. When the two large systems are removed, the systems with the smallest impacts are still about 10 times larger than the systems with the largest percent rate increases.

The comparatively high retail rate increases on some small utility systems under the LTEMP alternatives are shown in Table K.3-10. This table shows average retail rate impacts under different alternatives relative to Alternative A for the selected groups of utility systems. In comparing rate impacts, the maximum impact year is used. The 20 systems with the largest impact have an average rate increase that is 2.52 times the average rate increase percent across all systems. On the other hand, the 20 systems with the smallest impact have an average rate

25 These figures are averages for a system and do not account for the distribution of usage within the systems.

TABLE K.3-9 Size and Preference Ratio for Utility Systems with Large Rate Impacts

Statistics for Impact Analysis on Small Systems					
Group of System	Rate Impact Relative to Average	Residential Customers	Size Relative to Large Impact Systems	Preference Ratio	Preference Ratio Relative to Average
Utilities with Largest Rate Impact[a]	2.52	1,680	1.00	38.83%	2.36
Utilities with Smallest Impact[b]	0.18	69,099	41.13	3.24%	0.20
Utilities with Smallest Impact Excluding SRP and CS	0.20	17,096	10.18	3.81%	0.23
Average of All Systems	1.00	16,567.69	9.86	16.43%	1.00

[a] Includes 20 systems with largest impact except Tribes.

[b] Includes 20 systems with smallest rate impact.

TABLE K.3-10 Rate Impacts for Selected Groups in Maximum Impact Year

Alternative	Largest Retail Rate Change Group in Maximum Impact Year (%)	Smallest Retail Rate Change Group in Maximum Impact Year (%)	Average Retail Rate Change Across All Systems in Maximum Impact Year (%)	Rate Impact for Largest Group/ Average Rate Impact ($)
A	0.00	0.00	0.00	–
B	–0.56	–0.09	–0.27	2.08
C	1.08	0.09	0.43	2.52
D	0.98	0.07	0.39	2.52
E	1.21	0.09	0.50	2.44
F	3.05	0.22	1.21	2.52
G	1.60	0.12	0.64	2.52

increase that is a small fraction of the average rate increase for the entire population of systems. Finally, Table K.3-10 illustrates that the preference ratio is highly correlated to the rate increase.

K.3.5 Alternative-Specific Impacts

K.3.5.1 Alternative A

Under Alternative A, SLCA/IP marketable capacity is 737.2 MW using an assumed water flow rate that is low enough that one can be 90% confident that the rate will be exceeded. Average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity would not change under Alternative A. Rate impacts for each LTEMP alternative are computed relative to this alternative, meaning that the difference between two cases must be used to evaluate the change in rates.

Retail rates and residential bills are computed for Alternative A using inflation rates and sales growth from EIA forecasts (Figure K.3-13). Production costs, fixed O&M costs associated with new capacity, and the cost of new capacity from Alternative A are used as the basis for evaluating aggregate grid cost impacts for the other LTEMP scenarios.

K.3.5.2 Alternative B

Under Alternative B, rates and bills would be lower than under all other alternatives. Production costs are lower under Alternative B than under Alternative A, and there is a minor difference in the amount of capacity added for 1 year. Although the total amount of capacity added over the 20-year LTEMP period is the same as in Alternative A, a 1-year delay in constructing a new natural-gas-fired combustion turbine is projected in the power systems analysis for the year 2029. This delay in capacity additions and the difference in production cost accounts for the slightly lower annual average grid cost for Alternative B compared to Alternative A. The difference in annual grid costs averages $976 thousand per year (real 2015$).

When the annual grid cost reduction is translated to impacts on electric bills, the average retail rate decrease over the LTEMP period is -0.039%. The maximum rate decrease occurs in the year of the capacity deferral, 2029. The percent decrease in this year with the deferred capacity (the maximum impact year) is -0.27%. Table K.3-5 shows that the individual systems with the maximum impact have decreases that range between -0.48% and -0.93%. The average decrease in monthly residential bills over the LTEMP period is 4 cents per month, while the decrease in 2029 is 27 cents per month.

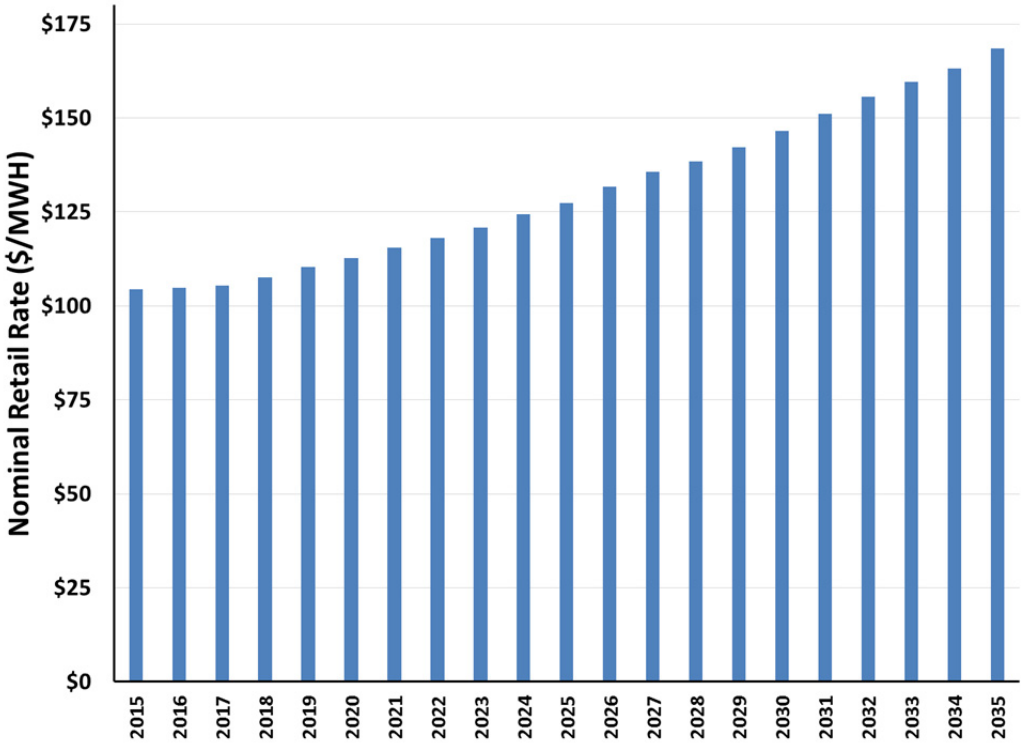

FIGURE K.3-13 Retail Rates under Alternative A

K.3.5.3 Alternative C

Retail rate increases under Alternative C relative to Alternative A are primarily driven by an increase in capacity of 230 MW that occurs for most years after 2018. This capacity increase is more than the reduction in marketable capacity of 129.1 MW. Replacement of the lost capacity and increased production costs results in varying grid cost impacts over the LTEMP period. Average grid impacts in real 2015 dollars are $9.8 million per year relative to Alternative A. These impacts are less than under Alternative F and Alternative G, but more than under Alternatives D, E, or B. The increase of $9.8 million in grid costs represents an increase of 6.87% relative to the annual wholesale revenues currently collected from SLCA/IP capacity and energy charges. When the wholesale grid cost of 6.87% is converted into retail rates, the averages across all systems and years range from a low of 0% to a high of 0.428% in 2025. The average percent retail rate increase across all systems for the LTEMP period is 0.245%. For the year 2025, which is the year with the maximum percent rate impact shown in Table K.3-5, individual systems experience percentage impacts ranging from less than 0% up to 1.46%.

Monthly residential bill impacts under Alternative C relative to Alternative A range from 0 to 40 cents for the LTEMP period. The average increase in residential bills is 22 cents per month. Detailed residential bill impacts under Alternative C for the maximum year are shown in Table K.3-6. Residential bill impacts in the highest impact year (2025) are not much higher than the results from Alternative D discussed in the next section. However, the average impacts under

Alternative C are 43% greater than the impacts under Alternative D. For the maximum impact year 2025, the range in residential bill impacts ranges between approximately $0 (4 cents for SRP consumers) and $2.07 per month (Ak-Chin Electric Municipal).

K.3.5.4 Alternative D

Retail rate increases under Alternative D relative to Alternative A are primarily driven by a reduction in capacity of 230 MW in most years. Replacement of capacity and increased production costs result in varying grid cost impacts on a year-by-year basis. Average grid impacts in real 2015 dollars are $6.8 million per year. When translated to retail rates, the impacts as an unweighted average across all systems range from 0% to a high of 0.391% in 2023. The average retail rate increase across all systems for the LTEMP period is 0.156%. For the maximum impact year 2023, individual systems experience percentage impacts ranging from 0% to 1.38%, as shown in Tables K.3-5 and K.3-6. The maximum impact retail rate increase is lower for Alternative D than for any other alternative analyzed except Alternatives B and A.

The impacts measured in terms of residential bills for individual systems in the maximum impact year are shown in Tables K.3-6 and K.3-7. Residential bill impacts under Alternative D relative to Alternative A, measured in 2015 dollars per month, range from 0 to 38 cents over the LTEMP period. The bill increase of 38 cents per month in the high-impact year is less than the bill increase in the high-impact year of 47 cents under Alternative E. The average increase in residential bills over the LTEMP period is 15 cents per month. For the year 2023, with the maximum bill impact, the range in residential bill impacts is between 0 and $1.83 per month.

K.3.5.5 Alternative E

Retail rate increases under Alternative E relative to Alternative A are primarily driven by an increase in capacity of 230 MW that occurs in 10 out of the 20 years of the evaluation, the average of which is more than the reduction in marketable capacity change of 90.21 MW. Replacement of the lost capacity and increased production costs results in varying grid cost impacts over the LTEMP period, some of which are lower than rates and bills under Alternative A. Average grid impacts are $6.4 million per year, which is lower than any of the LTEMP alternatives except Alternatives A and B. When the grid cost is converted into retail rates, the average across all systems and years range from changes that are below zero in years with no capacity change, to a high of 0.497% in 2027. The average percent retail rate increase across all systems for the years 2015 to 2035 is 0.142%. When compared to Alternative D, the average increase across the LTEMP period is slightly less, but the impact in the maximum year is slightly more. For the year 2027, which is the year with the highest rate impact, individual systems experience percentage impacts ranging from 0.03% (SRP) to 1.65% (City of Enterprise).

Residential bill impacts under Alternative E relative to Alternative A range from amounts that are below zero to 47 cents over the LTEMP period. The average increase is 13 cents per month. For the year 2027 with the maximum bill impact, the range in residential bill impacts is between 5 (SRP) and $2.42 per month (Ak-Chin Municipal Electric).

K.3.5.6 Alternative F

Retail rate increases under Alternative F relative to Alternative A are driven by increases in capacity of either 230 MW or 460 MW in various years, as well as varying amounts of production cost increases. The increase in capacity compares to the reduction in marketable capacity of 314 MW. The average grid cost increase under Alternative F is $28.7 million per year. This is much higher than any of the other LTEMP alternatives and equates to 20.11% of the $143 million in SLCA/IP wholesale revenues. The average retail rate increase reaches a high of 1.21% in 2018 and the average percent retail rate increase over the LTEMP period is 0.75%. When compared to the next highest impact scenario, Alternative G, the average impact is almost double. For the year 2018, the year with the maximum rate impact, individual systems experience percentage impacts ranging from 0.08% (SRP) to 4.14% (City of Enterprise, a member of UAMPS), as shown in Tables K.3-5 and K.3-6.

Residential bills under Alternative F that result from the grid cost increases are higher than bills under Alternative A in all years and are $1.02 in the maximum impact year. The average increase in residential bills over the LTEMP period is 69 cents per month. For the year 2018, with the maximum bill impact, the range in residential bill impacts is between 11 cents (SRP) and $5.29 (Ak-Chin Municipal Electric) per month.

K.3.5.7 Alternative G

Retail rate increases under Alternative G relative to the Alternative A are driven by an increase in capacity of 230 MW that occurs from the year 2018 forward, as well as production cost increases. The increase in capacity of 230 MW is more than the reduction in marketable capacity of 179 MW. Average grid cost increases by $17.2 million per year, which is higher than any of the LTEMP alternatives except Alternative F. The average retail rate increase across all systems and years is above zero in all years and reaches a high of 0.638% in 2025. Across the LTEMP period and all systems, the rate increase is 0.418%. When compared to Alternative C, the average increase is almost double and the impact in the maximum year is also higher because of higher production costs. For the year 2025, which is the year with the highest rate impact in this scenario, individual systems experience percentage impacts ranging from 0.04% (SRP) to 2.18% (City of Enterprise).

Residential bill impacts under Alternative G have a high of 59 cents, while the average increase in residential bills is 39 cents per month over the LTEMP period. For the year 2025, with the maximum bill impact, the range in residential bill impacts is between 6 cents (SRP) and $3.08 (Ak-Chin Municipal Electric) per month as shown in Tables K.3-7 and K.3-8.

K.4 FINANCIAL IMPACTS OF LTEMP ALTERNATIVES ON AMERICAN INDIAN TRIBES

The purpose of this section is to estimate the financial impact of LTEMP alternatives on American Indian Tribes that receive an allocation of SLCA/IP electrical power. This section also

compares the estimated financial impacts on these Tribes to the estimated financial impacts on other WAPA FES customers in the SLCA/IP marketing area to see how Tribal financial impacts compare with the financial impacts on others.

WAPA's post-2004 marketing plan purposely provided SLCA/IP power allocations to over 50 Tribes in its marketing area who historically had not been able to receive the financial benefits of federal hydropower. WAPA normally requires its customers to operate electric utilities, and most Tribes do not meet that requirement. Tribes are preference power customers. In order to encourage widespread use of federal hydropower, WAPA made administrative changes to allow numerous Tribes to receive an allocation of power and the associated financial benefits. There are 57 Tribes or Tribal entities who currently receive an allocation of SLCA/IP power (directly or indirectly) from WAPA.

The impact of the alternatives ranges from almost no impact to over $3 million in financial costs for the Tribes, with the average financial impact of all the alternatives being $1.345 million per year. Tribes may be financially impacted in three ways by the LTEMP alternatives:

- Tribes that operate their own utilities may see a change in the rate they pay for SLCA/IP power.

- Tribes that do not operate their own electric utility and have entered into benefit crediting arrangements with another utility to take their allocation, and instead receive an economic benefit from that utility, may see a change in the economic benefit, essentially a change in payment received from that other utility.

- Tribes that have entered into an economic benefit with a utility that also receives SLCA/IP power may see their economic benefit crediting payments change and may experience changes in the retail rates charged to Tribal members.

There are currently 57 Tribes and Tribal entities that received a power allocation from the SLCA/IP resources. The analysis in this report assumes that each of these Tribes will continue to receive its current allocation under each alternative of the LTEMP EIS. Nine of these Tribes operate electric utilities and receive power directly from WAPA. The remaining 48 Tribes are not electrical utilities but still receive the benefits of federal hydropower through benefit crediting arrangements with SLCA/IP customers or other electric utilities.

The purpose of benefit crediting is to provide a Tribe with the financial benefits associated with SLCA/IP power—a low-cost capacity and energy resource. This benefit is usually provided to the Tribe by an electrical service provider (supplier) that serves the area in which the Tribe is located. The benefit received by the Tribe is in lieu of a direct delivery of power by WAPA. It is intended to be the financial equivalent of a direct delivery. Because the SLCA/IP rate is generally lower than the supplier's production cost of electrical power, the difference between these costs is considered the benefit per megawatt-hour received by the

Tribe. This cost difference is multiplied by the Tribe's megawatt-hour allocation of SLCA/IP power. The product of these two numbers is the dollar benefit to the Tribe for an SLCA/IP allocation. The supplier provides the Tribe with a dollar benefit. The equation used to determine the benefit is similar to the following:

$$Benefit = SLCA/IP\ Allocation \times (Supplier\ rate - SLCA/IP\ rate) \quad \text{(Eq. 1)}$$

Where:

Benefit	=	the financial benefit received by the Tribe from the electric service provider ($),
SLCA/IP Allocation	=	SLCA/IP allocation to the Tribe in the post-2004 marketing period (MWh),
Supplier rate	=	average production cost (i.e., large customer retail rate) or purchase cost of the electrical supplier ($/MWh), and
SLCA/IP rate	=	the composite SLCA/IP FES rate ($/MWh).

K.4.1 Contractual Requirements for Calculating and Delivering Benefits to Tribes

In order to accommodate the post-2004 allocations of SLCA/IP electrical power to Tribes, WAPA contracted with seven electrical wholesale utility customers (suppliers) to establish benefit crediting arrangements, which would allow the Tribes that did not operate electric utilities to benefit from a federal hydropower allocation. WAPA and the individual Tribes made arrangements with one of the following entities:

- Public Service Company of New Mexico,
- Navajo Tribal Utility Authority,
- Page Electric Utility,
- Tri-State Generation and Transmission Association,
- Salt River Project,
- Ak-Chin Indian Community
- Deseret Generation and Transmission.

Each of these suppliers calculates the financial benefit of a Tribe's SLCA/IP power allocation according to language in three-party contracts among WAPA, the supplier, and the Tribe. The contractual language varies somewhat for each supplier. The contract for Tribal payment is typically based on the economic cost savings for the primary load serving entity. These savings are based on formulas in contracts between WAPA and the entities that compute the avoided cost of supplying the Tribal load that is ultimately served by WAPA. Essentially, the benefit each Tribe receives is the difference between the supplier's value of electrical energy and the SLCA/IP wholesale rate multiplied by the Tribe's SLCA/IP allocation. These benefit crediting arrangements are intended to capture the approximate benefit a Tribe would receive from an allocation of SLCA/IP power if it were able to receive it directly to serve its own electric load.

K.4.2 Calculation of Tribal Benefit Baseline under Alternative A (No Action Alternative)

Attachment K.11 lists the Tribes that receive an allocation of SLCA/IP electrical power, the amount of electrical capacity and energy the Tribe is currently allocated (by season), and the utility that serves the Tribal reservation or Tribal lands.

The Tribal benefit was calculated for Alternative A. Note that this benefit calculation differs somewhat from the benefit currently received by the Tribe for two reasons:

- The SLCA/IP rate developed by WAPA for Alternative A is marginally higher than the actual current SLCA/IP rate.

- The electrical rate of the supplier is estimated in several cases. WAPA's contracts may refer to "average generation cost" or to the "Class A rate," but the rate of the supplier is typically not quantitatively specified in the contract language. Therefore, the published rates for the seven suppliers that best conformed to the current contract description were used.

With these data, the calculation of the Tribal economic benefit was determined by inputting the relevant rates and Tribal allocations into Equation 1. It includes both capacity and energy components. This calculation was performed for each Tribe that has entered into a benefit crediting contract. This was not done for the nine Tribes that operate utilities; they do not receive a benefit credit because they directly receive an SLCA/IP allocation.

K.4.3 Calculation of Change in Tribal Benefit as a Result of LTEMP EIS Alternatives

Figure K.4-1 illustrates the method that was used for evaluating the impacts of LTEMP alternatives on the benefit for each Tribe.

The power economic impacts for the EIS are described in Section K.1. WAPA used these data to estimate the SLCA/IP FES rate for each alternative. The method used the results that are described in Section K.2. The financial benefit was computed for each Tribe for each alternative using the estimated SLCA/IP rate for each alternative, the estimated supplier's rate, and the Tribal allocations listed in Attachment K.11.

A simplifying assumption was used in this analysis. The Tribal allocations used for the analysis (and listed in Attachment K.11) are SLCA/IP commitment levels from the current marketing plan. This plan expires at the end of FY 2024. It was assumed that these commitment levels would continue through the LTEMP period, which extends through 2035. It should be emphasized that this is an analysis, not a description of policy or attempt to predict WAPA's post-2024 marketing plan. Although it is a reasonable assumption for the purposes of this analysis that WAPA will continue existing commitment levels after 2024, the reader should not assume that WAPA will or will not maintain these levels when the new marketing plan is finalized.

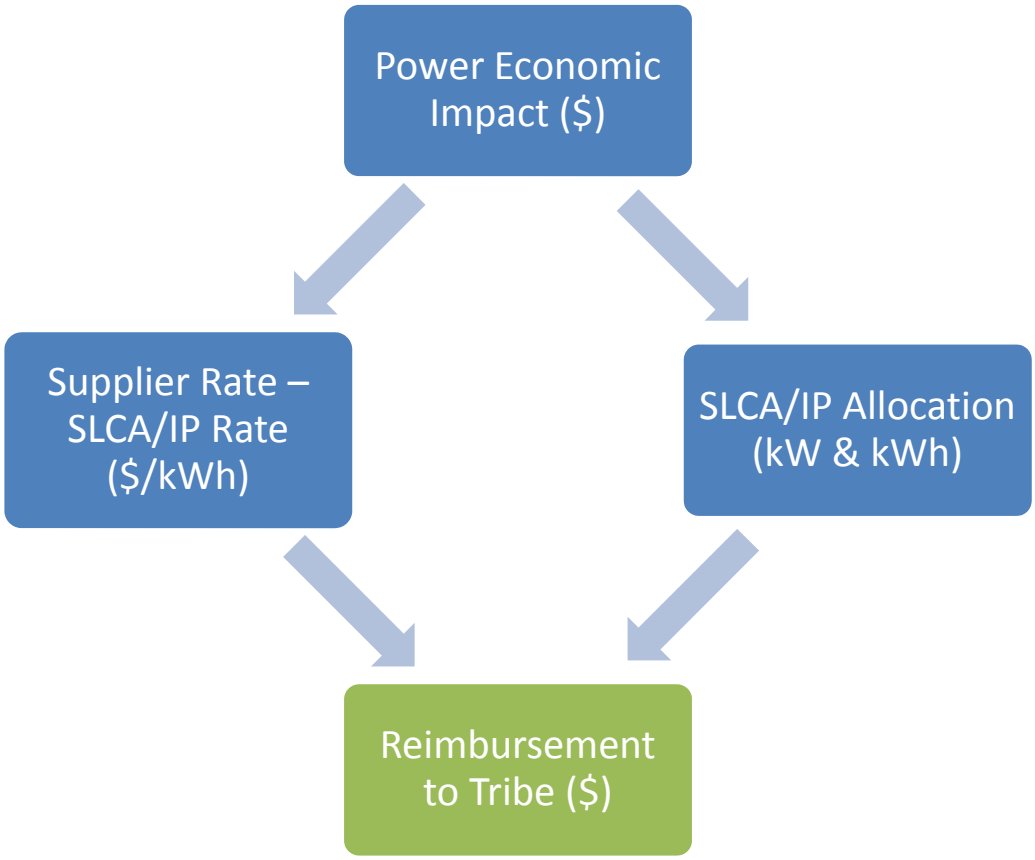

FIGURE K.4-1 Calculation of Change in Tribal Benefit Resulting from LTEMP EIS Alternatives

K.4.4 Impacts on Tribes through a Change in the Retail Rate of the Electrical Supplier to Tribal Lands

In addition to the economic impact of the LTEMP alternatives on Tribal benefits, some Tribes receive retail electric service from suppliers (such as rural cooperatives) that are SLCA/IP customers themselves. This means that Tribal households and commercial establishments on Tribal lands could pay a different retail rate for their electricity. If an alternative operating criterion at Glen Canyon Dam causes a change in the SLCA/IP rate, a utility supplying retail service to a Tribe could change its retail rate for electricity as a result of that alternative. Tribal members and commercial establishments on Tribal lands (households and businesses) could incur a change in their electrical utility bills as a result.

Attachment K.11 includes the list of the Tribes receiving their SLCA/IP allocation from a supplier along with the name of the electrical supplier that serves the Tribal reservation or Tribal lands. Section K.3 includes the estimated retail rate change for SLCA/IP customers by alternative. The financial impacts on the Tribes based on changes in the SLCA/IP rate were calculated using the following equation:

$$\textit{Financial Loss/Gain} = \textit{Total Reservation Electricity Consumption}^{26} \times \textit{Change in Retail Rate}^{27} \quad \text{(Eq. 2)}$$

Attachment K.12 is a list of Tribes receiving SLCA/IP allocations and the estimated total electrical use by Tribe. These data were partly gathered and required by WAPA as part of the development of the post-2004 marketing plan. They are referred to as applicant profile data.

These applicant profile data are believed to be out of date because they are based on electrical use by Tribes in 1998. However, more current data on Tribal electrical use were not readily available or published. Therefore, the amounts of electrical energy shown in Attachment K.12 were escalated by 2.5% per year to 2015.[28] The estimated Tribal electricity use calculated with Equation 2 is therefore an escalated amount and represents an estimate of the current electrical use by Tribes.

The estimated 2015 total electrical use by Tribal households and commercial establishments on Tribal lands was multiplied by the change in the retail rate estimated for the electrical service supplier—which is an SLCA/IP FES customer—as derived from the analysis described in Section K.3. This results in an estimated increase (or decrease) in the retail electrical utility costs paid by each Tribe annually under each alternative (via the Tribal members who live on Tribal lands).

K.4.5 Calculation of Tribal Impacts for Tribes That Are Direct SLCA/IP Recipients

For the Tribes that operate electrical utilities and receive SLCA/IP power directly from WAPA, the impacts of LTEMP alternatives were calculated. This calculation is the difference in the SLCA/IP FES rate between each of the action alternatives and the No Action alternative multiplied by the total escalated electrical use for each Tribe. Multiplying the change in SLCA/IP rate (from Section K.2) by the escalated Tribal electrical use yields the estimated financial impacts for each of the LTEMP EIS alternatives on each of the nine Tribes that receive SLCA/IP allocations directly from WAPA.

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26 This estimate is for the year 2015. It is therefore an annual amount of electrical energy used. The financial loss or gain should be interpreted as an annual financial impact.

27 These estimated changes in retail rates by alternative are taken directly from Section K.3.

28 Based on data reported by the EIA, 2.5% is the approximate average annual increase in electrical energy use over the last decade in states where Tribal entities reside.

Table K.4-1 is the result of the retail-rate impact analysis for the average household on a Tribal reservation or on Tribal lands. The estimates, by Tribe, presented in Table K.4-1 describe how a residential household might be impacted by the LTEMP EIS alternatives due to a changed retail rate. The numbers in Table K.4-1 are taken from the retail rate impact analysis described in Appendix K.3. That analysis computed the monthly change in an electric utility bill for an average residence across the SLCA/IP market footprint. Table K.4-2 shows this change. It is extracted from similar information in Section K.3. It assumes that residences on Tribal lands incur the same change in residential monthly electrical utility bills as other residences in the same electrical service area.

For example, the reservation of the Ute Tribe is electrically served by Moon Lake Electric. According to the estimate in Section K.3, Moon Lake Electric residences will pay slightly over a dollar a month more for electricity under Alternative F. It was assumed that the residences of the Ute Tribe on the Ute reservation, served by Moon Lake Electric, will also pay slightly over a dollar a month more for electricity under Alternative F. Remember that the information in Table K.4-1 is one of two financial impacts on the Tribes caused by the alternatives. The total financial impact on Tribes is presented in Table K.4-2.

K.4.6 Total Impact of LTEMP EIS Alternatives: Benefit Change and Rate Effect

Table K.4-2 lists the estimated Tribal financial impact by alternative relative to the impact under Alternative A. Table K.4-2 lists the total annual financial impact, which is (1) the change in Tribal benefit plus (2) the increase in the electrical utility bill of Tribal households and businesses due to a change in the SLCA/IP FES customers' retail rate.[29] Negative numbers indicate a positive financial benefit (this only occurs under Alternative B). Note that:

- Tribes whose electrical service is provided by a non-SLCA/IP FES customer have no retail rate change, but do experience a change in Tribal benefits;
- The Tribes that operate their own utility have no change in Tribal benefits, but do experience a change in retail rates; and
- Tribes whose lands are served by SLCA/IP customers are impacted by both a change in retail rate and a change in Tribal benefits.

[29] Table K.4-2 shows the total financial impact. The separate financial impacts from a change in Tribal benefits and from a change in the electrical utility payments made by Tribal households and businesses were calculated but not shown here because of space limitations.

TABLE K.4-1 Monthly Change in Residential Electric Utility Bill for Tribes by Alternative

	Difference from Alternative A					
Tribal Entity	Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribes that Operate Their Own Utility						
Navajo Tribal Utility Authority	–0.035	0.339	0.234	0.211	1.011	0.591
Navajo Agricultural Products Industries	NA	NA	NA	NA	NA	NA
Ak-Chin Indian Community	–0.123	1.187	0.820	0.740	3.539	2.069
Tohono O'Odham Utility Authority	–0.013	0.122	0.084	0.076	0.362	0.212
Fort Mojave Indian Tribe	–0.032	0.309	0.214	0.193	0.922	0.539
Bureau of Indian Affairs Colorado River Agency	NA	NA	NA	NA	NA	NA
San Carlos Irrigation Project	NA	NA	NA	NA	NA	NA
Jicarilla Apache Tribe	NA	NA	NA	NA	NA	NA
Gila River Indian Community	NA	NA	NA	NA	NA	NA
Tribes That Have a Benefit Contracting Arrangement						
Alamo Navajo Chapter	–0.012	0.115	0.080	0.072	0.344	0.201
Canoncito Navajo Chapter	–0.014	0.134	0.092	0.083	0.399	0.233
Cocopah Indian Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Colorado River Indian Tribes	0.000	0.000	0.000	0.000	0.000	0.000
Confederated Tribes of the Goshute Reservation	–0.015	0.145	0.100	0.091	0.433	0.253
Duckwater Shoshone Tribe	–0.015	0.145	0.100	0.091	0.433	0.253
Ely Shoshone Tribe	–0.015	0.145	0.100	0.091	0.433	0.253
Ft. McDowell Mojave-Apache Indian Community	–0.016	0.158	0.109	0.099	0.471	0.275
Havasupai Tribe	–0.123	1.187	0.820	0.740	3.539	2.069
Hopi Tribe	–0.007	0.065	0.045	0.041	0.195	0.114
Hualapai Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Las Vegas Paiute Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Mescalero Apache Tribe	–0.021	0.206	0.142	0.128	0.614	0.359
Nambe Pueblo	–0.026	0.246	0.170	0.153	0.733	0.429
Paiute Indian Tribe of Utah	0.000	0.000	0.000	0.000	0.000	0.000
Pascua Yaqui Tribe	–0.123	1.187	0.820	0.740	3.539	2.069
Picuris Pueblo	–0.018	0.170	0.118	0.106	0.508	0.297
Pueblo De Cochiti	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of Acoma	–0.014	0.134	0.092	0.083	0.399	0.233
Pueblo of Isleta	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of Jemez	–0.026	0.246	0.170	0.153	0.733	0.429
Pueblo of Laguna	–0.014	0.134	0.092	0.083	0.399	0.233
Pueblo of Pojoaque	–0.026	0.246	0.170	0.153	0.733	0.429
Pueblo of San Felipe	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of San Ildefonso	–0.026	0.246	0.170	0.153	0.733	0.429
Pueblo of San Juan	–0.026	0.246	0.170	0.153	0.733	0.429

TABLE K.4-1 (Cont.)

Tribal Entity	Difference from Alternative A					
	Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribes That Have a Benefit Contracting Arrangement						
Pueblo of Sandia	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of Santa Clara	–0.026	0.246	0.170	0.153	0.733	0.429
Pueblo of Santo Domingo	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of Taos	–0.018	0.170	0.118	0.106	0.508	0.297
Pueblo of Tesuque	0.000	0.000	0.000	0.000	0.000	0.000
Pueblo of Zia	–0.026	0.246	0.170	0.153	0.733	0.429
Pueblo of Zuni	–0.014	0.134	0.092	0.083	0.399	0.233
Quechan Indian Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Ramah Navajo Chapter	–0.014	0.134	0.092	0.083	0.399	0.233
Salt River Pima-Maricopa Indian Community	–0.016	0.158	0.109	0.099	0.471	0.275
San Carlos Apache Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Santa Ana Pueblo	0.000	0.000	0.000	0.000	0.000	0.000
Skull Valley Band of Goshute Indians	0.000	0.000	0.000	0.000	0.000	0.000
Southern Ute Indian Tribe	–0.011	0.106	0.073	0.066	0.317	0.185
Tonto Apache Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Ute Indian Tribe	–0.009	0.086	0.059	0.054	0.256	0.150
Ute Mountain Ute Tribe	–0.035	0.338	0.234	0.211	1.009	0.590
White Mountain Apache Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Wind River Reservation	–0.020	0.189	0.130	0.118	0.562	0.329
Yavapai Apache Nation	0.000	0.000	0.000	0.000	0.000	0.000
Yavapai Prescott Indian Tribe	0.000	0.000	0.000	0.000	0.000	0.000
Yomba Shoshone Tribe	0.000	0.000	0.000	0.000	0.000	0.000

Alternative impacts listed in Table K.4-2 include the sum of both types of financial impacts.[30] Alternative impacts included in Table K.4-2 are indications of the rank order of the alternatives and the direction of impacts (positive or negative), and they describe an estimated financial impact under current contractual obligations. These financial impacts would continue beyond 2024 if contract commitments to all FES customers including Tribes and Tribal entities do not change. They represent one possible outcome of the post-2024 marketing plan. For the final EIS, assumptions concerning post-2024 commitment levels may be revised to duplicate the range examined in the economic analysis described in Section K.1.

30 The Tribal benefit calculation is the difference the Supplier's average production cost and the SLCA/IP rate multiplied by the Tribe's SLCA/IP allocation. For simplicity, the authors assume that the supplier's average production cost does not change as a result of an LTEMP DEIS alternative. It is more likely that an increase in a SLCA/IP rate will result in a lesser increase in the average production cost of a SLCA/IP FES customer. Therefore, the calculations of Tribal benefit change are overestimates for those Tribes that are served by SLCA/IP FES customers.

TABLE K.4-2 Total Dollar Annual Impact on Tribes under LTEMP Alternatives Relative to Alternative A

Tribal Entity	SLCA/IP Allocation (MWh)	Difference from Alternative A ($)					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribes That Operate Their Own Utility							
Navajo Tribal Utility Authority	183,625	9,090	205,442	183,625	139,991	936,304	1,110,839
Navajo Agricultural Products Industries	49,046	2,452	55,422	49,536	37,765	252,587	299,671
Ak-Chin Indian Community	11,356	562	12,705	11,356	8,658	57,905	68,699
Tohono O'Odham Utility Authority	7,765	384	8,687	7,765	5,920	39,592	46,973
Fort Mojave Indian Tribe	1,036	51	1,159	1,036	790	5,282	6,266
Bureau of Indian Affairs Colorado River Agency	2,451	121	2,742	2,451	1,868	12,497	14,826
San Carlos Irrigation Project	5,919	293	6,622	5,919	4,512	30,179	35,805
Gila River Indian Community	148,828	–13,860	206,171	148,828	128,785	705,437	564,644
Jicarilla Apache Tribe	2,464	122	2,757	2,464	1,879	12,566	14,909
Tribes That Have a Benefit Contracting Arrangement							
Alamo Navajo Chapter	1,222	–50	1,575	1,222	1,012	5,954	5,640
Canoncito Navajo Chapter	900	–37	1,159	900	745	4,382	4,151
Cocopah Indian Tribe	4,355	216	4,873	4,355	3,321	22,209	26,348
Colorado River Indian Tribes	18,072	895	20,219	18,072	13,778	92,150	109,327
Confederated Tribes of the Goshute Reservation	292	–7	367	292	238	1,432	1,418
Duckwater Shoshone Tribe	389	–10	490	389	318	1,912	1,892
Ely Shoshone Tribe	595	–15	749	595	486	2,923	2,895
Ft. McDowell Mojave-Apache Indian Community	8,895	380	10,065	8,895	6,825	45,202	52,851
Havasupai Tribe	887	29	1,021	887	687	4,484	5,124
Hopi Tribe	22,836	(1,580)	30,613	22,836	19,366	109,616	95,282
Hualapai Tribe	2,304	114	2,578	2,304	1,757	11,748	13,938

TABLE K.4-2 (Cont.)

Tribal Entity	SLCA/IP Allocation (MWh)	Difference from Alternative A ($)					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Las Vegas Paiute Tribe	2,310	114	2,585	2,310	1,761	11,780	13,976
Mescalero Apache Tribe	6,322	–261	8,147	6,322	5,235	30,792	29,163
Nambe Pueblo	399	–16	514	399	330	1,942	1,840
Paiute Indian Tribe of Utah	583	29	652	583	445	2,973	3,527
Pascua Yaqui Tribe	4,754	153	5,472	4,754	3,684	24,035	27,463
Picuris Pueblo	312	–13	402	312	258	1,518	1,432
Pueblo De Cochiti	767	38	858	767	585	3,912	4,641
Pueblo of Acoma	2,669	–110	3,439	2,669	2,210	12,999	12,310
Pueblo of Isleta	4,123	204	4,612	4,123	3,143	21,021	24,940
Pueblo of Jemez	1,542	–63	1,986	1,542	1,276	7,510	7,117
Pueblo of Laguna	4,809	–199	6,197	4,809	3,982	23,422	22,183
Pueblo of Pojoaque	1,544	–63	1,989	1,544	1,278	7,523	7,130
Pueblo of San Felipe	1,406	70	1,573	1,406	1,072	7,168	8,504
Pueblo of San Ildefonso	409	–17	527	409	338	1,990	1,885
Pueblo of San Juan	1,935	–80	2,494	1,935	1,602	9,425	8,926
Pueblo of Sandia	3,278	162	3,668	3,278	2,499	16,717	19,833
Pueblo of Santa Clara	1,541	–63	1,986	1,541	1,276	7,507	7,115
Pueblo of Santo Domingo	1,662	82	1,859	1,662	1,267	8,472	10,051
Pueblo of Taos	1,811	–74	2,332	1,811	1,499	8,823	8,367
Pueblo of Tesuque	2,288	113	2,560	2,288	1,744	11,666	13,841
Pueblo of Zia	493	–20	635	493	408	2,402	2,277
Pueblo of Zuni	7,101	–293	9,148	7,101	5,879	34,587	32,771
Quechan Indian Tribe	2,319	115	2,595	2,319	1,768	11,825	14,029
Ramah Navajo Chapter	2,295	–94	2,956	2,295	1,899	11,178	10,597
Salt River Pima-Maricopa Indian Community	56,758	2,423	64,225	56,758	43,551	288,436	337,237

TABLE K.4-2 (Cont.)

Tribal Entity	SLCA/IP Allocation (MWh)	Difference from Alternative A ($)					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
San Carlos Apache Tribe	14,791	732	16,549	14,791	11,277	75,421	89,480
Santa Ana Pueblo	1,622	80	1,814	1,622	1,236	8,269	9,810
Skull Valley Band of Goshute Indians	56	3	63	56	43	286	339
Southern Ute Indian Tribe	7,391	–305	9,523	7,391	6,119	35,996	34,095
Tonto Apache Tribe	1,364	68	1,527	1,364	1,040	6,957	8,254
Ute Indian Tribe	4,835	(342)	6,495	4,835	4,105	23,190	20,060
Ute Mountain Ute Tribe	3,169	(131)	4,083	3,169	2,623	15,432	14,618
White Mountain Apache Tribe	22,090	1,094	24,715	22,090	16,841	112,639	133,636
Wind River Reservation	7,284	(823)	10,361	7,284	6,408	34,163	25,349
Yavapai Apache Nation	6,246	309	6,988	6,246	4,762	31,848	37,784
Yavapai Prescott Indian Tribe	2,877	142	3,219	2,877	2,193	14,670	17,404
Yomba Shoshone Tribe	116	6	129	116	88	589	699
Total	658,509	–336	738,872	609,463	486,660	3,030,857	3,204,513
Total for Systems that Operate Utility		10,503	237,357	212,151	161,739	1,081,759	1,283,408
Total for Systems with Benefit Contracts		–10,839	501,515	397,312	324,921	1,949,098	1,921,105

K.4.7 Total Impact on Tribes and Tribal Members Versus Retail Rate Changes to Households

Figures K.4-2 through K.4-7 illustrate the difference between the total financial impact of the alternatives on Tribes as compared to the financial impact on non-Tribal households and businesses that receive retail service from utilities that are SLCA/IP customers.

The financial impacts on non-Tribal households and businesses are, for illustrative purposes in this analysis, the percentage change in the electrical retail rate for the SLCA/IP FES customer (or their utility system member that provides retail electrical service in a service area). This information is a duplication of the analysis included in Appendix K.3, which is the retail rate analysis of the alternatives. In Figures K.4-2 through K.4-7, the blue lines illustrate non-Tribal SLCA/IP FES customers or member systems and are the same data that are included in Section K.3.

An increase (decrease) in the retail rates of an SLCA/IP FES customer or member system causes a financial effect (positive or negative) on households and businesses in the utilities' service area by increasing (decreasing) the electrical utility cost paid. This change in the utility bill and the resulting financial effect at the household/business level is approximately equivalent to the financial impact on Tribes and Tribal members.

Figures K.4-2 through K.4-7 present the percentage difference (compared to Alternative A) of financial impacts on Tribes and non-Tribes[31] for each alternative. Alternative B is the only alternative that results in a reduction in impacts relative to Alternative A (Figure K.4-3). The financial impacts of Alternatives C, D, and E are relatively similar (Figures K.4-3 through K.4-5), but greater than under either Alternative A or Alternative B. The financial impacts of Alternatives F and G are relatively similar to each other (Figure K.4-3), and higher than under any of the other alternatives. Alternative F has the highest financial impacts of any alternative.

K.4.8 Conclusions

Several conclusions can be drawn from this analysis:

- LTEMP alternatives are estimated to have a financial effect on Tribes that receive an SLCA/IP allocation. Compared to Alternative A, the impact is negative for Alternatives C, D, E, F, and G. These impacts are larger for Alternatives F and G. The financial impact on Tribes under Alternative B is largely positive.

[31] The total percentage change is measured on the y-axis. For Tribal entities, this percentage change is the sum of the retail rate impact and the Tribal benefit impact. For non-Tribal SLCA/IP customers or members systems, it is the percentage change from the retail rate impact.

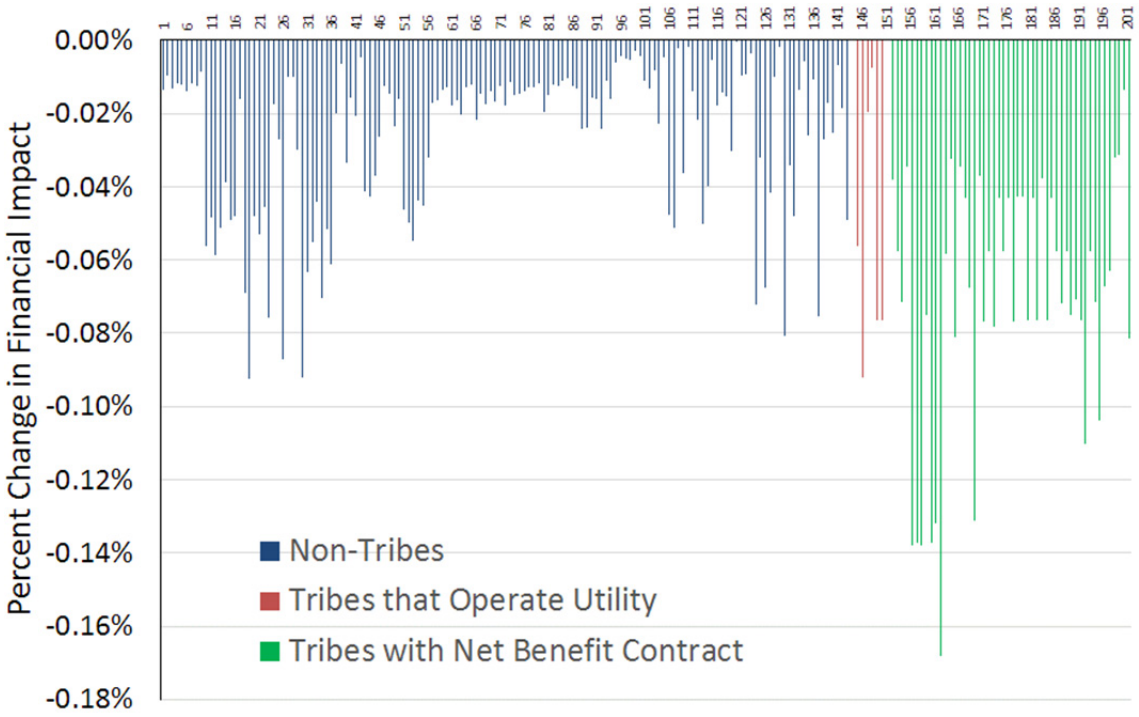

FIGURE K.4-2 Financial Impacts under Alternative B Relative to Alternative A for Tribal and Non-Tribal Entities

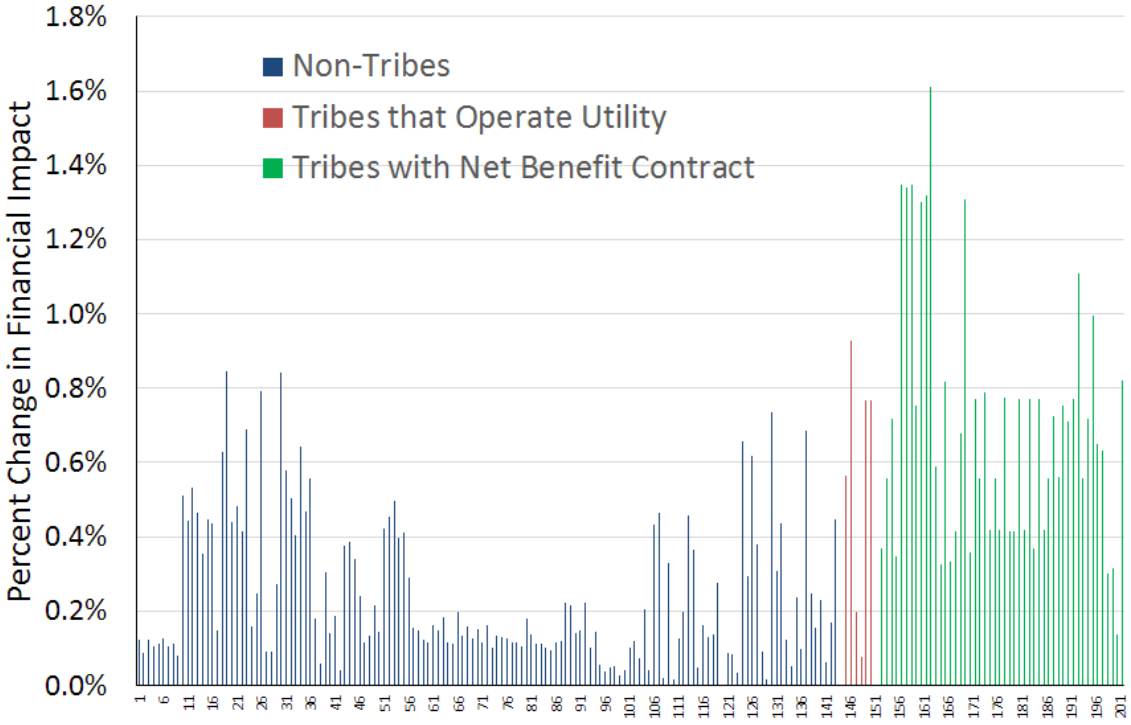

FIGURE K.4-3 Financial Impacts under Alternative C Relative to Alternative A for Tribal and Non-Tribal Entities

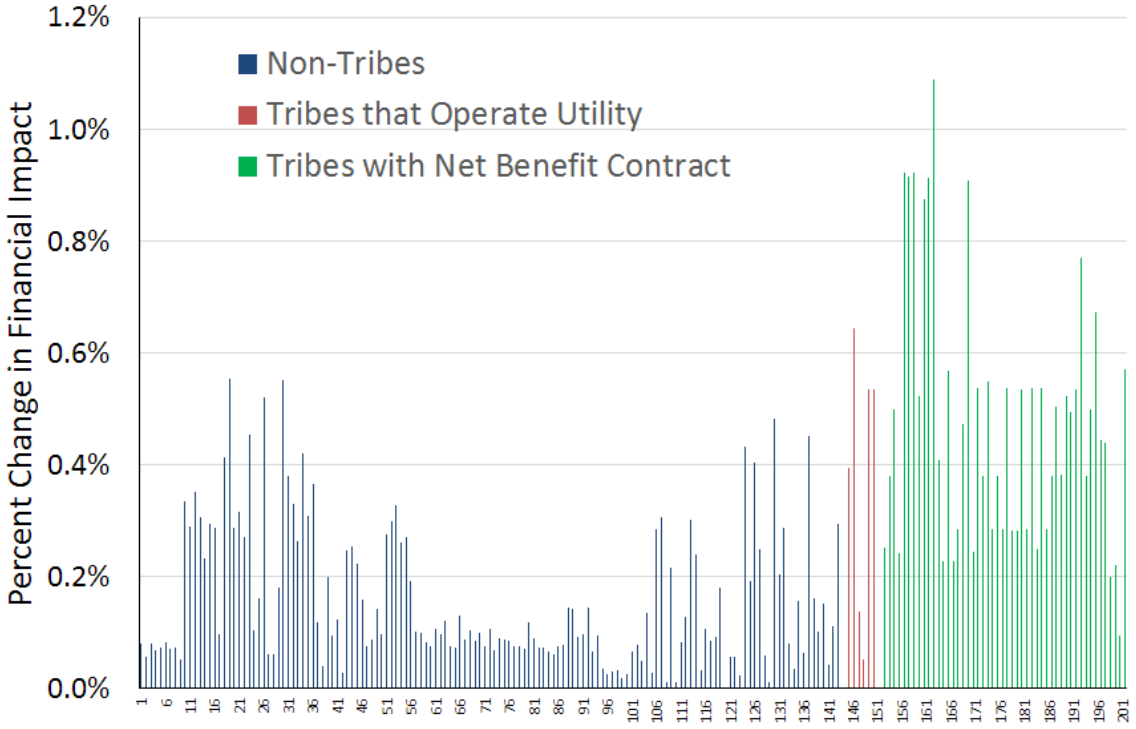

FIGURE K.4-4 Financial Impacts under Alternative D Relative to Alternative A for Tribal and Non-Tribal Entities

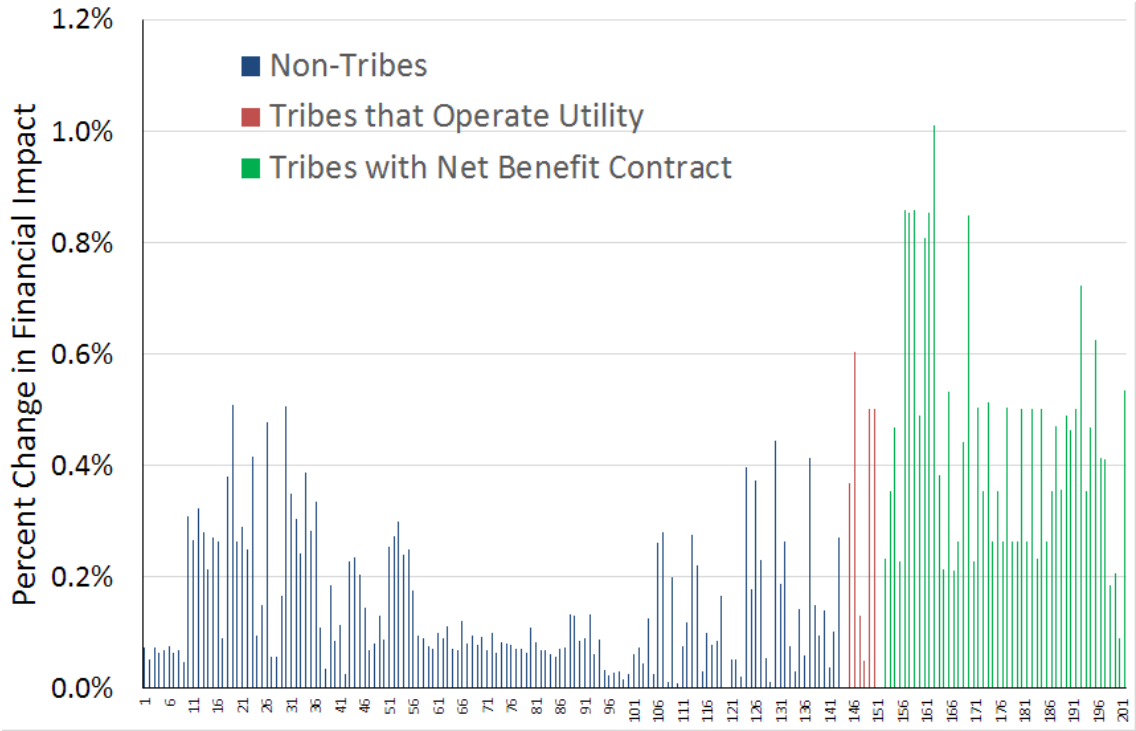

FIGURE K.4-5 Financial Impacts under Alternative E Relative to Alternative A for Tribal and Non-Tribal Entities

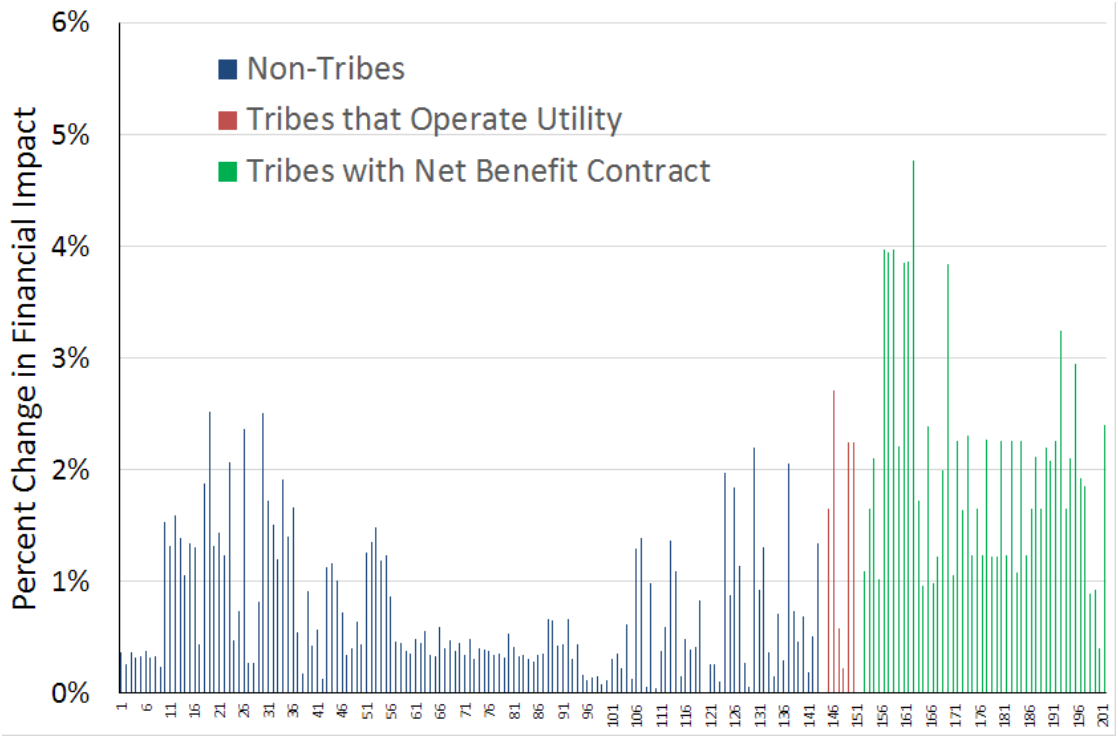

FIGURE K.4-6 Financial Impacts under Alternative F Relative to Alternative A for Tribal and Non-Tribal Entities

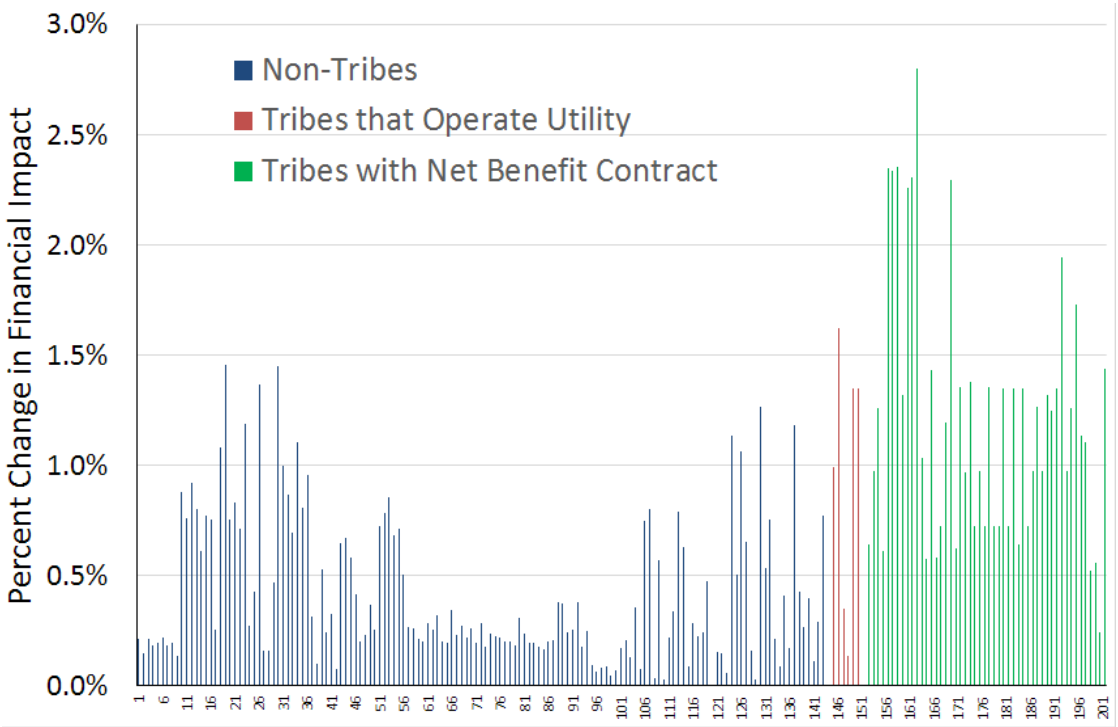

FIGURE K.4-7 Financial Impacts under Alternative G Relative to Alternative A for Tribal and Non-Tribal Entities

- The financial impacts on Tribes are from two sources:
  - A change in the Tribal benefits provided to the Tribes under benefit crediting contracts; and
  - A change in the electrical utility bills paid by Tribal members and businesses that receive retail service from a supplier that receives an SLCA/IP allocation.

- These two sources of financial impact are additive for some Tribes—those who receive Tribal benefits and whose reservation or Tribal land is served by electrical utilities that are SLCA/IP FES customers.

- Tribal financial impacts for Alternatives C, D, E, F, and G, relative to Alternative A, are larger than the financial impacts on non-Tribes.

K.5 IMPACTS OF LTEMP ALTERNATIVES ON LAKE MEAD AND THE HOOVER DAM POWERPLANT

The Hoover Dam Powerhouse has 17 turbines that have a combined hydropower nameplate capacity of 2,074 MW (https://www.wapa.gov/About/Pages/power-projects.aspx). Both the energy production and operating capacity of this large hydropower resource is affected by LTEMP EIS alternatives. Released water from Lake Powell through the Glen Canyon Dam travels down the Colorado River through the GCNP and then into the Lake Mead Reservoir. Monthly water release volumes from Lake Powell, however, differ by LTEMP alternative and will therefore impact pool elevations in Lake Mead, and, in some rare situations water releases from Hoover Dam, when Lake Mead's operating condition is changed as a result of differences in projected December month-end elevations. Alternatives B, D, and E have the same Glen Canyon Dam October through December total release volumes as Alternative A, and therefore do not affect the Lake Mead operating condition, and thus the release volumes from Hoover Dam.

For example, Figures K.5-1 and K.5-2 show that under Alternative F, Lake Powell monthly water releases from late winter through spring are higher than for Alternative A (dotted orange line), thereby raising the pool elevation (solid orange line) at Lake Mead above levels projected under Alternative A from April through November. Because Glen Canyon Dam annual release volumes under all alternatives are nearly identical, the impacts of changed operations are within an annual time frame. Note that all alternatives, except for Alternative F, have very similar pool elevations when comparing end of the water year values.

Monthly differences in Lake Mead reservoir elevations among alternatives may impact Hoover Dam's generation economic value. The primary factors include changes in (1) the

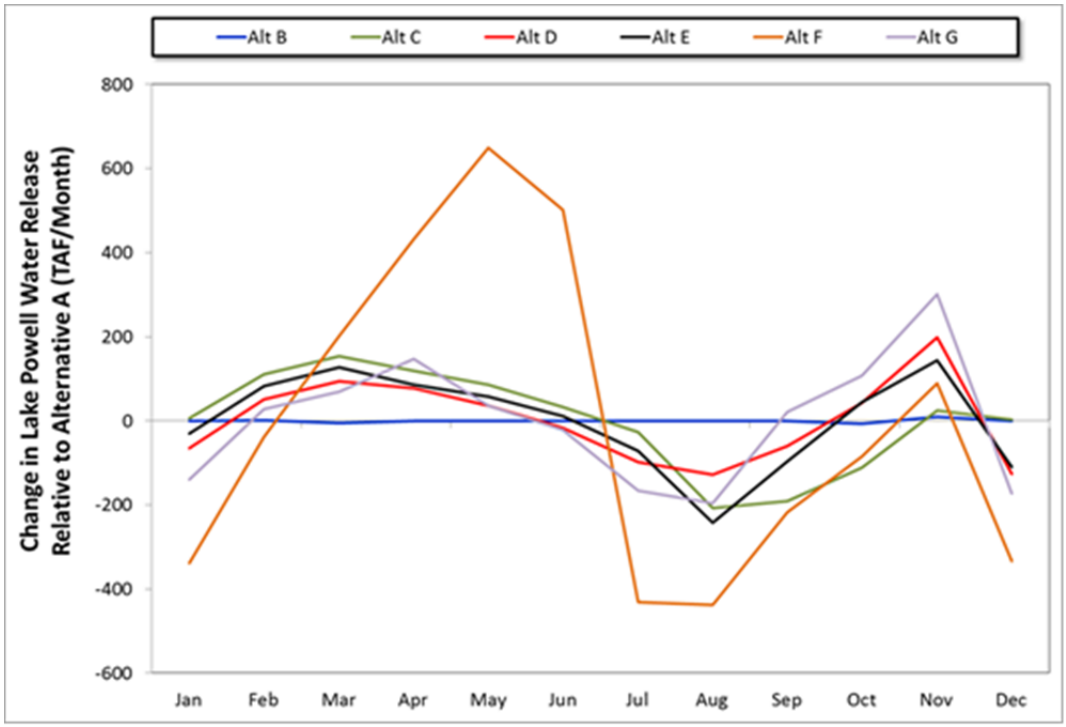

FIGURE K.5-1 Change in Lake Powell Monthly Water Release Volumes under LTEMP Alternatives

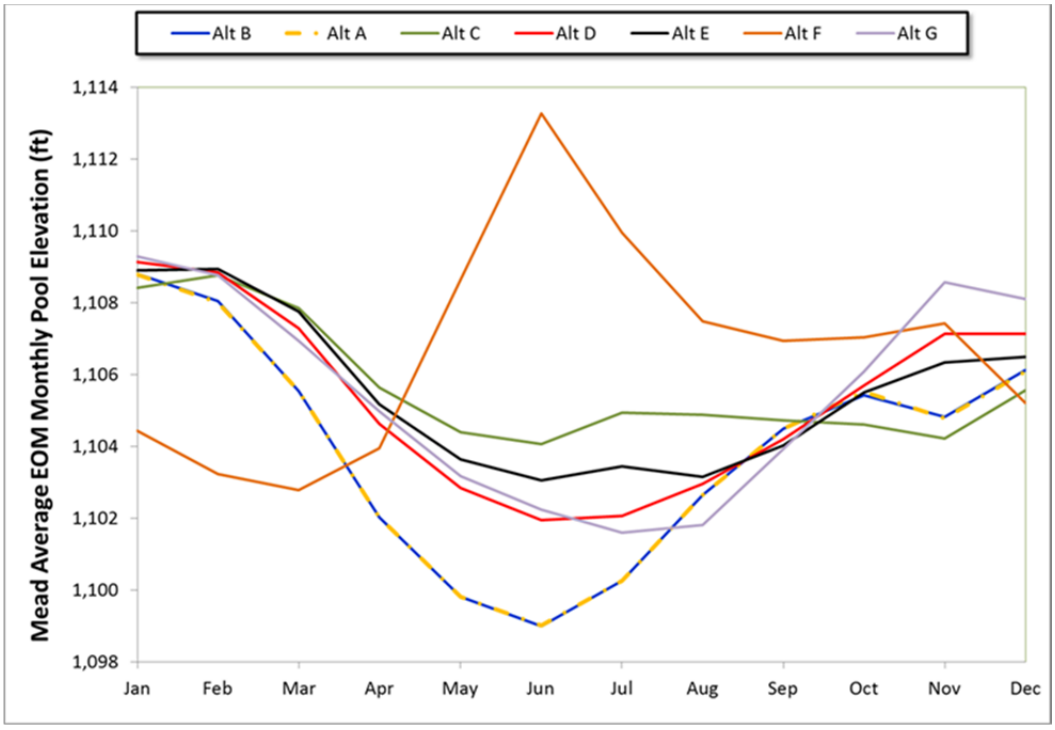

FIGURE K.5-2 Average Lake Mead EOM Pool Elevations under LTEMP Alternatives

percentage of time Lake Mead elevation is below minimum power pool[32]; (2) monthly differences in power head and resulting electricity (i.e., energy) production[33]; (3) maximum operating capacity; and (4) in some infrequent situations, but only for Alternatives C, F and G, differences in water release volumes from Lake Mead. In terms of the economic impacts of alternatives on the Hoover Powerplant, the first two are much larger than the latter two.

Hoover powerplant economics are composed of firm capacity and energy components. For the purpose of evaluating the economic value of the Hoover Powerplant, a distinction is made between the powerplant's nameplate capacity and its maximum operational capacity, which varies as a function of power head. This maximum operational capacity is referred to in this section as the Hoover derated capacity.

This study also refers to firm capacity, which is distinctly different from both nameplate and derated capacities. Firm capacity in this report is defined as the Hoover Powerplant derated capacity level (output potential) during the time of the regional peak electricity demand (load) at a specified probability level of occurrence. To be consistent with the definition of firm capacity used elsewhere in this EIS, Hoover firm capacity is set equal to the Hoover derated capacity at a 90% exceedance level during August. It is based on numerous forecasts of derated capacity using an ensemble of future hydrology and Lake Mead pool conditions. Note that the 90% exceedance level means that the derated capacity is lower than the firm capacity only 10% of the time, and is therefore based on a very low hydropower condition. Firm capacity is assumed to be the capacity level that would be used in either regional or utility-specific studies of current and future capacity needs such as an IRP.

At Hoover Dam, power is scheduled by WAPA's Desert Southwest Office customers, each of which is allocated a portion of the available real-time derated capacity of the Hoover powerplant. It is therefore at the discretion of each entity that receives Hoover capacity how it utilizes this capacity for long-term planning purposes; that is, how it credits Hoover as "firm" capacity. Under these contracts, the utility customer bears the risk of not meeting its firm capacity targets and system reliability goals. The utility may therefore need to acquire additional firm capacity. Marketed capacity levels are rooted in the amount that is projected to be physically available.

Hoover economic metrics for both firm capacity and energy are measured in terms of NPV and are computed for each alternative. The following sections describe the methods, model, and comparative impacts of LTEMP alternatives on Lake Mead, Hoover Powerplant operations, and power system economics.

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32 For this analysis, a distinction is made between water that is routed through the powerplant turbines and water that bypasses the dam and powerplant.

33 Turbine water releases convert the kinetic energy of falling water into mechanical energy which is then converted to electricity by a generator. The volume of water needed to generate 1 MWh of electricity is a function of several factors.

K.5.1 Hoover Analysis Methods, Model, and Supporting Data

The purpose of this analysis is to determine if impacts to Hoover Dam hydropower exist, the direction of impact, and some sense of the magnitude of that impact. A model of Hoover Powerplant operations was developed to analyze potential LTEMP impacts on Hoover Powerplant economics. Compared to the modeling of Glen Canyon Dam hydropower resources, it is a simpler representation of dam and hydropower operations because it is less detailed and it operates on monthly time steps instead of hourly. *Its purpose is to provide rough estimates of the direction, magnitude, and ranking of LTEMP alternative impacts on the Hoover Powerplant under a given set of assumptions.* As will be discussed in more detail later, model results are highly sensitive to assumptions, some of which are not yet precisely known. Because of the uncertainties of the assumptions, the magnitude of these estimates for Hoover Dam hydropower resources is not directly comparable to the results for Glen Canyon Dam hydropower resources. The above factors should be taken into consideration when interpreting model results.

The Hoover Powerplant Model utilizes monthly Lake Mead water release volumes projected by the CRSS model for 21 hydrology traces over the 20-year LTEMP study period. These water releases sometimes vary by alternative. Releases are primarily driven by the operating criteria that were established under the *Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* ROD that was signed on December 13, 2007 (Reclamation 2007b). Under Alternatives C, F, and G, changes in Lake Mead monthly releases may, in rare occasions, occur when Lake Mead's operating condition is changed as a result of differences in projected December end of month (EOM) elevations. Because monthly water release decisions for the upcoming year are made at the beginning of the calendar year and forecasts of the future are uncertain, Hoover releases sometimes differ from the ones that would have occurred had the future been known with perfect foresight.

Lake Mead EOM reservoir elevations projected by the Sand Budget Model (SBM) are also input into the Hoover Powerplant Model. For each alternative and 21 hydrology traces over the 20-year study period, the SBM schedules HFEs at Glen Canyon Dam. Scheduling is based on CRSS model results for Glen Canyon Dam and initial results from the GTMax-lite model. Because an experiment typically requires a large water release volume, the SBM reallocates CRSS Glen Canyon Dam monthly water releases within a WY in order to provide the HFE with a sufficient amount of water. Based on this reallocated monthly water and a water mass-balance equation, Lake Mead pool elevations are computed. The SBM primarily reallocates water within the same WY, not among WYs.

The SBM does <u>not</u> alter CRSS Hoover Dam monthly water releases, allowing the Hoover Powerplant Model to directly use CRSS water releases. The SBM does, however, change CRSS monthly inflows into Lake Mead and thus projected, water storage volumes, and reservoir elevations.

AURORA model monthly average market on-peak and off-peak prices projected for the Palo Verde hub are used by the Hoover Powerplant Model to compute economic energy values. These are the same hourly prices used elsewhere in this EIS. Also identical to the GTMax-Lite

methodology, firm hydropower capacity is based on a 90th percentile exceedance level during the month of August. Other factors such as unscheduled unit outage probabilities and unit maintenance schedules can also factor into powerplant maximum operational capacity and firm capacity computations, but were not included in this relatively simple model.

The economic value of Hoover firm capacity is based on the same replacement costs as those used for GTMax-lite and very similar to the average costs used in the power systems economic analysis. It is based on the levelized cost of capital plus annual fixed O&M costs to construct a new advanced combustion turbine (CT), which amounts to $51,300/MW-yr. As discussed later, these capacity replacement costs are irrelevant to the final economic cost computation. The time series of Hoover economic costs are discounted at the same 3.375% annual rate used in GTMax-Lite and the power systems analysis.

K.5.2 Hoover Monthly Energy Production and Water-to-Power Conversion

The Hoover Powerplant Model projects powerplant monthly energy production over the 20-year LTEMP study period based on SBM monthly projections of Lake Mead EOM pool elevation and CRSS-projected Hoover Dam monthly water releases for each of the 21 hydrology traces. A model-derived water-to-power conversion factor[34] is multiplied by the monthly turbine water release volumes to project Hoover Powerplant energy production. The operating characteristics of the Hoover Powerplant were based on and derived from information provided by Reclamation.

Argonne derived a water-to-power conversion equation and its coefficients based on historical Lake Mead pool elevations and Hoover generation data, as recorded in Form PO&M-59. The equation has two components. The first component is a linear relationship between historical conversion factors and the pool elevations. The second component relates the conversion factor to monthly water release volumes in the form of a third-order polynomial function. Due to the implementation and application of new software at Hoover Dam that optimizes the powerplant unit dispatch to increase plant-level power conversion efficiency, equation coefficients in the period prior to March 2011 differ from the coefficients used after this date.[35]

To assess the accuracy of the derived equation, a back-casting exercise was conducted. Lake Mead pool elevation and water-to-power conversion factors have a similar pattern and can be used to explain most, but not all, of the changes in power conversion over time. Monthly turbine releases yield additional accuracy to the Argonne power conversion equations, but relatively small inaccuracies remain. Average absolute conversion errors during both the

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34 The water-to-power conversion factor, expressed in terms of MWh/ac-ft equals the monthly turbine water release (ac-ft) divided by monthly generation. Note that this conversion factor only includes turbine releases; that is, bypass water is excluded.

35 McManes (2014) discusses the change in Hoover Powerplant efficiency (3.4% improvement) that results from using unit dispatch software to guide power operations.

historical pre- and post-2011 periods are less than 0.005 ac-ft/MWh; that is, the equation estimated power conversion factors are on average within 1.2% of the actual values. The simple average of the errors equals zero. For comparative analyses such as this one, this level of accuracy was judged to be sufficient.

Projections of future monthly water-to-power conversion factors use equation coefficients derived for the post-2011 time period. In reality, conversion efficiencies (and therefore water-to-power conversion factors) will change in the future as equipment ages and changes are made to the powerplant. One such change that is partially implemented involves the replacement of old turbines with ones that can be operated over a wider range of hydraulic heads and have a narrower operating rough zone.

When the SBM projects that the Lake Mead elevation is below the minimum power pool, the Hoover Powerplant Model assumes the entire projected monthly water volume bypasses the Hoover Powerplant. Therefore, both the monthly derated capacity and generation of the Hoover Powerplant are set equal to zero. These non-power water releases are referred to in this report as "bypass" water.

Based on information and guidance from Reclamation, at the time this analysis was conducted, it was conservatively assumed that the minimum pool elevation for energy production at the Hoover Powerplant was 1,050 ft above sea level. It should be noted that at the time the final LTEMP EIS was being written, the official minimum power pool required to generate power was being revised. It appears that Hoover turbines will be capable of operating below a 1,050-ft pool elevation. This is in part supported by turbine performance curves for new wide-head turbines that are installed at some of the units. Since none of the Hoover turbines have actually been operated below this level, derated capacities and power conversion factors below 1,050 ft are somewhat speculative.

The monthly average turbine water release at Hoover Dam over the 21 traces and 20-year study period differ by alternative. As shown in Figure K.5-3, the greatest difference in turbine releases among alternatives relative to Alternative A is about 81 thousand acre-feet (kaf) (roughly 11.7% more) in June under Alternative F. In almost all cases, the difference in turbine water release among alternatives is nearly counterbalanced by differences in bypass water releases. In the example above, 69 kaf more water is bypassed under Alternative A than under Alternative F. This is due to a higher occurrence of reservoir elevations below the minimum power pool elevations under Alternative A. There is also a greater average total water release (turbine and bypass); about 12 kaf, in June under Alternative F due to the differences in the frequency of Lower Basin shortages that are projected to occur in the future. The greater water release in June is offset by lower water releases in the winter and early spring. Also note in Figure K.5-3 that on average Lake Mead turbine water releases are nearly identical in Alternatives A and B, and Alternative D has the next smallest deviations from Alterative A.

Multiplying monthly turbine water releases by the water-to-power conversion factor yields an estimate of the generation produced by the Hoover Powerplant. As shown in Figure K.5-4, Alternatives A and B have the lowest generation levels, while Alternative F typically has the most generation. The range of generation among alternatives is the largest from

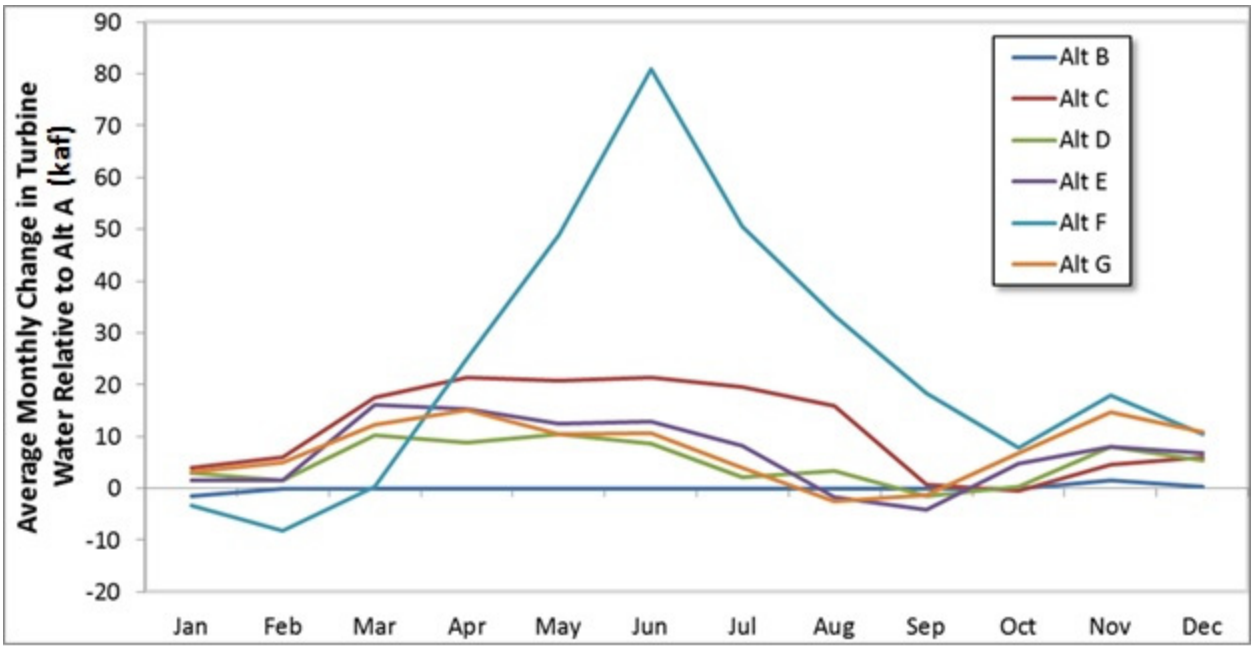

FIGURE K.5-3 Average Monthly Difference in Turbine Water Releases Relative to Alternative A

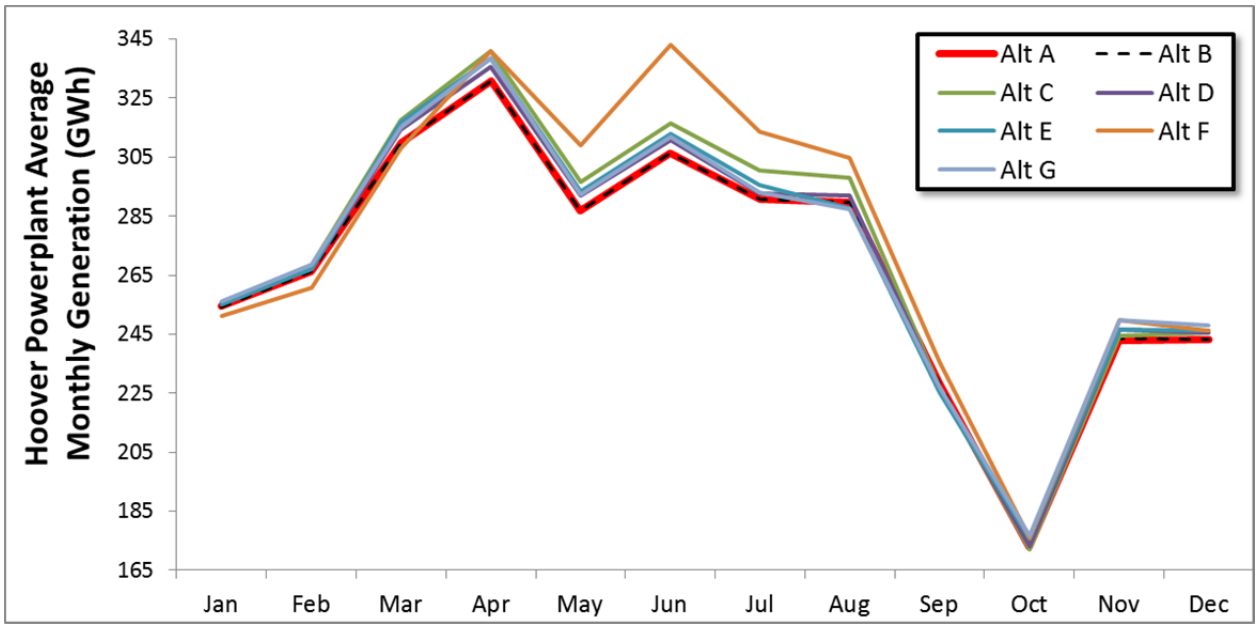

FIGURE K.5-4 Average Monthly Hoover Powerplant Generation for All Power Systems under Primary LTEMP EIS Alternatives

late spring through the end of summer, while the range in autumn and winter tends to be relatively small.

K.5.3 Hoover Maximum Operational Capacity and Firm Capacity

In addition to water-to-power conversion factors discussed in the preceding section, the derated capacity of the Hoover Dam Powerplant is also affected by the pool elevation of Lake Mead. Argonne derived a curve of derated capacity as a function of pool elevation based on information provided by Reclamation. Historically, at pool elevations of 1,205 ft and above, the maximum net output is 2,074 MW. It decreases as the pool elevations drops below the 1,205-ft level. As discussed previously, below the minimum power pool elevation of 1,050 ft, the derated capacity is zero.

This analysis assumed that the firm hydropower capacity of Hoover is based on a 90th percentile exceedance. Results of this analysis, however, show that under all alternatives, Lake Mead's elevation in August is projected to be below the minimum power pool level (where no generation is assumed to be possible) more than 10% of the time. Because the maximum operational capacity is zero under all alternatives, the powerplant is credited with no firm capacity despite projections that indicate that the derated capacity for the Hoover Powerplant is expected to be greater than zero most of the time. It therefore follows that LTEMP alternatives have no impact on Hoover Powerplant's firm capacity and economic value.

K.5.4 Economic Value of Hoover Powerplant Energy

The change in the economic value of Hoover Powerplant energy production under each alternative is computed by multiplying the change in monthly energy production by monthly market prices of energy as projected by the AURORA model. Estimates are made for each month of the 20-year LTEMP period for all 21 hydrology traces. For this analysis, it was assumed that the powerplant generates 95% of its total energy production during hours of the week that have relatively high market prices.[36] The remaining 5% is generated during times when prices are lower.

To compare the economic impact of alternatives on a consistent basis, the net present value (NPV) of Hoover Powerplant economic benefits were computed using a 3.375% annual discount rate, the same rate used for computing the NPV elsewhere in this EIS. The result of NPV calculations for the Hoover Powerplant is shown for each alternative in Figure K.5-5. The NPV benefit for Hoover ranges from nearly zero for Alternative B to about $89 million for Alternative F.

[36] The 95% assumption is based on discussions with Reclamation staff.

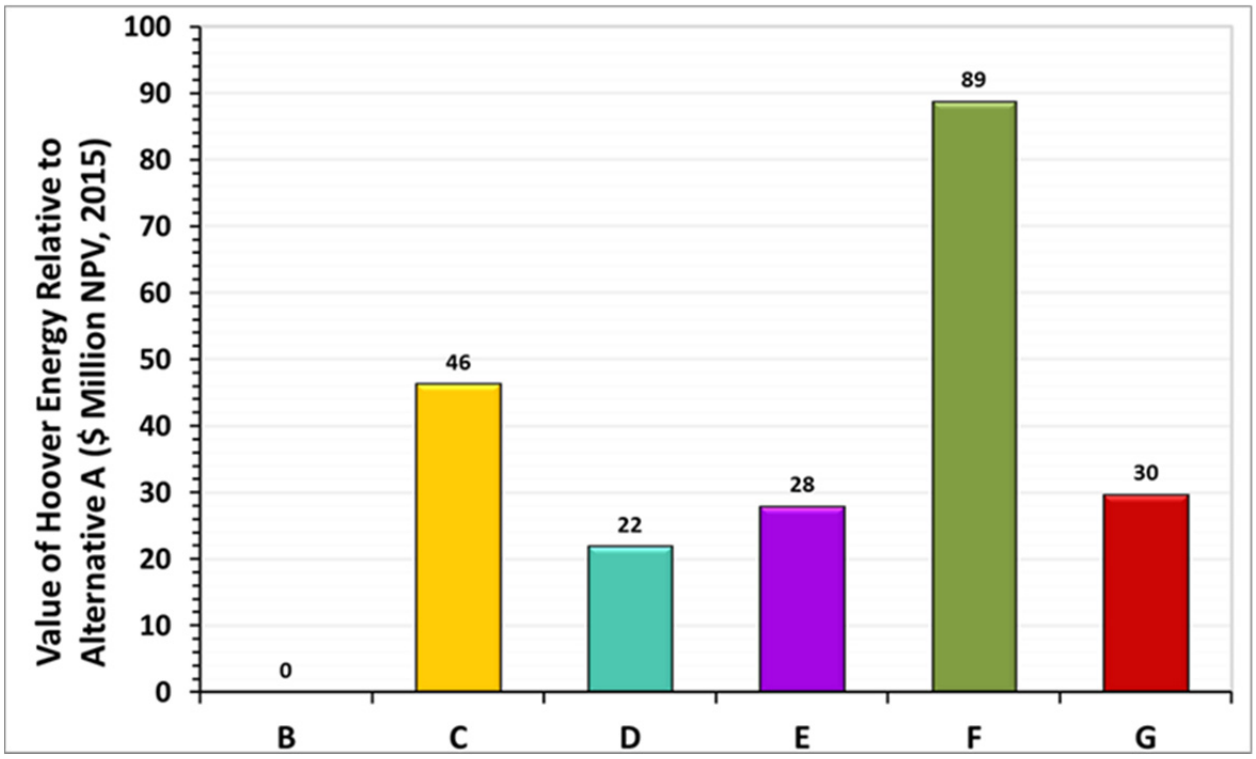

FIGURE K.5-5 NPV of Hoover Powerplant Benefits Relative to Alternative A Resulting from LTEMP Alternatives

K.5.5 Sensitivity of Model Results

Model results are highly sensitive to assumptions, some of which are not yet precisely known. In particular, the assumption regarding minimum power pool elevation has a large bearing on the results discussed above because most of the estimated benefits are due to lower bypass releases under LTEMP alternatives. If a lower minimum pool elevation was assumed, results would be significantly different. For example, at an assumed minimum power pool of 950 ft the Hoover Powerplant Model projects zero bypass releases because SBM pool elevations are always above that level. Energy economics would therefore be significantly different.

On the other hand, the economic impacts of firm capacity discussed above are zero because pool elevations are lower than 1,050 ft more than 10% of the time under all alternatives. If a 950-ft minimum power pool had been assumed. Firm capacity levels and economic values would always be greater than zero and most likely vary among alternatives. This lack of precise information about Hoover should be taken into consideration when interpreting model results.

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ATTACHMENT K.1:

GEOGRAPHIC SCOPE OF THE ANALYSIS

The geographic scope of the economic effects of the operations of Glen Canyon Dam has long been a topic of discussion among staff at the Western Area Power Administration (WAPA), Bureau of Reclamation (Reclamation), National Park Service (NPS), Grand Canyon Monitoring and Research Center (GCMRC), and Argonne National Laboratory (Argonne). The method described herein assumes that the effect of changes to the operation of the Glen Canyon Dam is limited to the Salt Lake City Area Integrated Projects (SLCA/IP) system; that is, SLCA/IP federal hydropower resources and WAPA's SLCA/IP long-term firm (LTF) customers. Figure 1 shows the extent of the study area considered in this analysis. This assumption became essential when the scope and timing of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) power systems analysis were re-evaluated in June 2014 as a result of funding and schedule considerations. Several proposed options for proceeding were developed at that time to offer different levels of analytical detail, costs, and completion dates. The option selected (middle ground relative to detail, funding, and timing) defined the geographic scope as WAPA's SLCA/IP marketing area with ties to the rest of the Western Interconnection for market transaction at the Palo Verde hub. Budget and timing factors have determined the scope of this initial analysis.

This analysis assumes that there is little, if any, economic effect at electricity hubs outside the SLCA/IP system of hydropower plants and WAPA's firm customers in terms of changes in locational marginal prices (LMPs) as a result of alternative operations at Glen Canyon Dam. Argonne undertook a study that verified this limited regional influence. A report documenting this study will be written and peer reviewed. A final, peer-reviewed version of this report will not be available until sometime after the final LTEMP Environmental Impact Statement (EIS) has been published. Therefore, when simulating the operation of Glen Canyon Dam, the region of detailed modeling is restricted to the SLCA/IP system. Spot market transactions conducted at points between this system and the rest of the Western Interconnection will be represented as a static set of market prices for the Palo Verde hub.

Western Interconnection Energy Transactions

The SLCA/IP system is directly connected with other private or invest-owned electric utilities (IOUs) in the geographic area. Among these are Rocky Mountain Power, Excel Energy, and Public Service Company of New Mexico. An electrical market exists such that the SLCA/IP system can exchange with these utilities and others to which they are indirectly connected in order to lower operating costs. To approximate these economic energy exchanges, the AURORA model was run to simulate the dispatch of the entire Western Interconnection. Resulting prices from this run are then input into the more geographically limited, but more detailed, model of the SLCA/IP powerplants and its firm customers. It is assumed that these prices are static and do not change as a result of alternative operating criteria at Glen Canyon Dam. Glen Canyon Dam is a

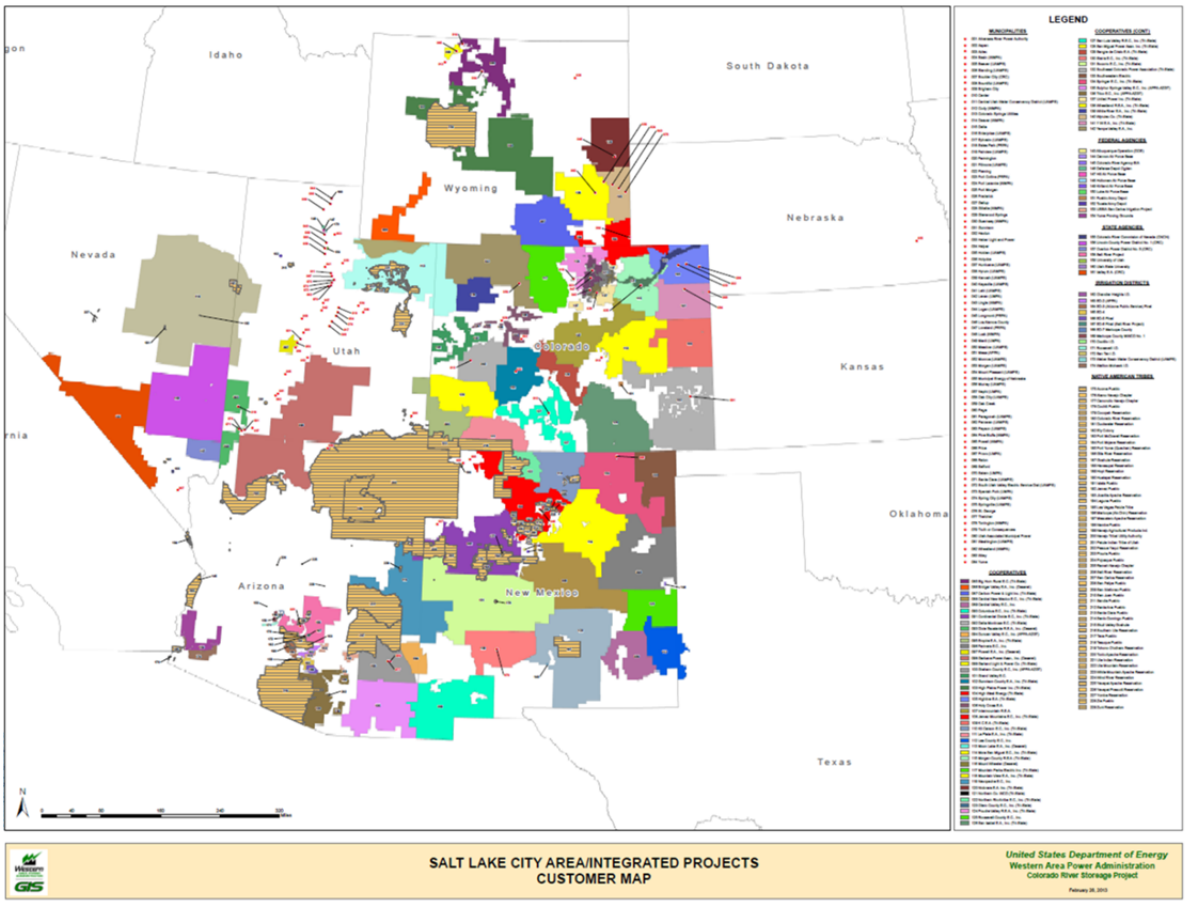

FIGURE 1 Study Area Considered in the LTEMP Power Systems Analysis

very small resource compared to the total Western Interconnection generating capacity and is thought to have only a miniscule impact on Western Interconnection market prices.

Western Interconnection Capacity Transactions

For this analysis, we make the simplifying assumption that no capacity exchange or joint expansion planning occurs—economic impacts of changes in Glen Canyon Dam capacity are limited to WAPA's eight large SLCA/IP LTF customers. Note that smaller customers do not have significant supply resources. It is therefore assumed that small customers will not build capacity in the future. All lost Glen Canyon Dam capacity as a result of operational changes at Glen Canyon Dam would be replaced by the eight larger utility systems, and any resulting capacity losses for the small customers would be replaced via LTF capacity agreements with the larger utilities.

This assumption that the SLCA/IP system will replace lost capacity through its own initiatives can be justified if there is no accessible excess capacity in the larger region. Therefore,

a capacity loss at Glen Canyon Dam cannot be replaced via the purchase of excess capacity from a surrounding utility; for example, from IOUs with whom they are connected. If this assumption is true, the methodology described here will provide a very good approximation of the true economic impact, since the loss of Glen Canyon Dam capacity will require the construction of new capacity somewhere in the grid.

In order to properly assess the strength of this assumption, an examination of relevant regional data, such as integrated resource plans (IRPs) of WAPA's large customers that own generating facilities and large IOUs in the geographic and "electrical" area was conducted. In general, all IRPs examined revealed that utilities are expanding capacity with both renewable and thermal technologies in the near future. In addition, some utilities are increasing Demand Side Management programs to reduce the need for expanding capacity. It was also discovered that the loss of capacity in one large IOU (namely, NVEnergy) from a mandated shutdown of coal-fired powerplants will be replaced with natural gas-fired generation about a year after the first group of coal-fired units are shut down (see Figure 7 in Attachment K.9). Summaries of key IRPs are provided in Attachment K.9. The conclusion drawn from the review of the IRPs is that there is very little, if any, excess capacity in the Balancing Authorities in which WAPA's customers are located and in the broader power pool areas that are defined in the AURORA "out-of-the-box" model configuration. Therefore, loss in capacity at Glen Canyon Dam would need to be replaced soon after the loss was incurred. This loss could be replaced by new capacity that is either built by WAPA's customers or alternatively by another utility and sold via LTF capacity contracts. In this analysis, it is assumed that the replacement capacity would be directly built by the customers. From a purely economic viewpoint, there is little difference if the pool of eight large customers builds the capacity or if it is built by another utility.

Analysis Fidelity

Although in reality WAPA and its customers operate in the Western Interconnection, the approach used by Argonne power system analysts emphasizes performing high-fidelity analyses on a smaller network topology as opposed to analyzing system response of the entire Western Interconnection to changes in operating criteria dictated by LTEMP EIS alternatives. By accurately modeling a smaller system, it is possible to track and explain with a relatively high level of confidence both system- and component-level reactions to alternative operating criteria and to trout management flow (TMF) and HFE operation schedules. SLCA/IP system interactions with the broader Western Interconnection are also represented, but in far less detail. As described in this attachment, power systems analysts were able to fairly closely match historical 2013 generation levels for the eight large utility systems.

It should also be noted that unit commitments, system dispatch, and capacity expansion decisions are not made by a single entity that makes decisions for the entire interconnect. Instead autonomous decisions under uncertainty are made by many entries in the Western Interconnection using market price signals such as the ones reported by the Intercontinental Exchange (ICE) to take unit commitment, dispatch, and energy market transaction decisions. Therefore, the AURORA model of the Western Interconnection tends to "over optimize" system operations. Low 2012 Palo Verde market prices computed by AURORA may be in part due to

the "single decision maker" approach that is employed. Another difficulty in modeling Western Interconnection operations is that hydropower operating constraints for the multitude of hydropower plants within the interconnection are extremely challenging. The approach used in this analysis represents a middle ground between simulating each utility individually and optimizing Western Interconnection operations. It also allows the modeler to represent hydropower operations at a level of detail that cannot be simulated at an adequate level of fidelity by AURORA.

ATTACHMENT K.2:

AURORA WESTERN INTERCONNECTION SPOT MARKET ENERGY PRICES ADJUSTMENTS

The power systems analysis uses a representation of the spot market at the Palo Verde hub where SLCA/IP market system participants buy and sell energy at a set of given hourly prices. The methodology applied in this study uses this price set to represent the economic value of energy; that is, the marginal cost to produce energy that serves the last megawatt of load. This includes both fuel costs and variable operation and maintenance (O&M) expenses. Historical economic values are extremely difficult to accurately estimate because the Western Interconnection is composed of numerous independent entities that operate in a geographically large and very complex grid. Difficulties associated with modeling the Western Interconnection for long-term analyses consist of but certainly not limited to the following (http://www.ipd.anl.gov/anlpubs/2012/04/73032.pdf):

1. The interconnection includes multiple U.S. states and three countries;

2. Part of the system operates in an organized central market (i.e., CAISO) and other portions operate in a bilateral market;

3. A large fraction of Western Interconnection loads are supplied by hydropower plants, many of which are subject to complicated and difficult to model environmental operating criteria (even on a site-specific level);

4. A lack of unit-specific information on fuel prices and heat rate curves ;

5. Insufficient data on bus-level loads;

6. A large and complicated transmission system;

7. Lack of information on resource availability (e.g., unit outage and transmission line outages);

8. Forecast errors associated with loads, hydropower inflows, and variable resource (wind/solar) output; and

9. Complex interactions among entities that make decisions under uncertainty based on limited information about the interconnection.

All power systems models, including AURORA, must therefore make many simplifying assumptions about the grid and the mathematical representation of each grid component. These assumptions lead to an imperfect representation of reality.

In the study, spot market prices modeled for 2013 by the default Western Interconnection AURORA model were significantly different from day-ahead market (DAM) prices published by the ICE and the CAISO. The Palo Verde hub was chosen to represent prices for the spot market in the AURORA network topology for the LTEMP analysis because it is the hub closest to Glen Canyon Dam and is often used as the benchmark price for Western Area Power Administration (WAPA) energy transactions.

The ICE publishes day-ahead weighted average peak, off-peak, and Sunday off-peak electricity price for every day each year. Sunday off-peak hours are the 16 daytime hours that have the highest loads; they correspond to the 16 hr classified as peak in the other 6 days of the week. Hourly prices generated by the AURORA model were subdivided into 7 categories; namely, holiday, Sunday daytime, Sunday nighttime, Saturday peak, Saturday off-peak, weekday peak, and weekday off-peak. The monthly averages were computed for each category and compared against the monthly average of the ICE prices in these categories.

In order to bring AURORA model hourly prices in line with these ICE prices, AURORA model results were scaled to match ICE averages. A scalar (ratio of the ICE to AURORA prices) was generated for each month and each category. In this preliminary investigation, it was discovered that prices generated by the AURORA model were generally lower than the ICE prices. Prices in off-peak hours were lower by about 5 to 15% and prices in peak hours were lower by as much as 20 to 50%. To adjust for this discrepancy in prices, future AURORA model runs for the LTEMP network topology, AURORA prices at the Palo Verde hub were multiplied by the aforementioned scalar. The scalars derived from ICE prices are shown in Table 1.

TABLE 1 Scalars Used to Adjust Spot Market Prices in the AURORA Model

		Sunday		Saturday		Weekday	
Month	Holiday	Daytime	Nighttime	Peak	Off Peak	Peak	Off Peak
January	1.053	1.032	1.110	1.068	1.042	1.058	1.019
February	NA[a]	1.145	1.221	1.123	1.083	1.093	1.140
March	NA[a]	1.133	1.175	1.119	1.126	1.105	1.120
April	NA[a]	1.319	1.297	1.257	1.132	1.163	1.183
May	0.943	1.143	1.126	1.156	1.046	1.165	1.053
June	NA[a]	1.210	1.241	1.241	1.067	1.200	1.066
July	1.100	1.222	1.204	1.343	1.009	1.538	1.094
August	NA[a]	1.175	1.142	1.231	1.004	1.230	1.060
September	1.088	1.133	1.251	1.218	1.051	1.170	1.116
October	NA[a]	1.134	1.235	1.156	1.118	1.094	1.142
November	1.079	1.084	1.208	1.166	1.159	1.098	1.113
December	1.082	1.279	1.470	1.233	1.265	1.228	1.299

[a] NA = not applicable.

The scaled AURORA prices were used as a surrogate for the economic value of energy based on the premise that the ICE data adequately reflects actual market prices and those market prices are a good measure of economic costs. In economic theory, a perfect market will produce prices that reflect economic costs. However, no market is perfect, including those in the Western Interconnection. Therefore, due to the complexities associated with modeling actual economic costs at the margin, power system modeler used the aforementioned scaling methodology. This not ideal, but it appears that market mechanisms in the Western Interconnection are working reasonably well and market monitors (such as those in the CAISO) help to ensure that participants do not unduly take advantage of market imperfections.

ATTACHMENT K.3:

SELECTION OF REPRESENTATIVE TRACE

Introduction

This paper briefly describes the process that was used for selecting a representative hydrology trace for use in the Long-Term Experiment and Management Plan (LTEMP) power systems modeling task. A single representative trace was required to balance the complexity and time requirements for power system simulations with task completion timelines. Goals in selecting a trace included considerations for (a) matching the probability distribution of annual water releases as exhibited in the full set of 21 hydrology traces developed by the Bureau of Reclamation, (b) representing the variability in monthly releases, (c) avoiding significant numbers of non-power release events (where monthly volumes and elevations lead to water releases not being fully utilized for power generation), and (d) providing reasonably close matches (across all six alternatives and long-term strategies) for end-of-year elevations and release volumes. The following sections describe several metrics that were developed to characterize these goals and provided the basis for selecting a representative trace.

Six alternatives and long-term strategies,[1] including a no action alternative, were originally proposed for study in the LTEMP Draft Environmental Impact Statement (DEIS). A seventh alternative, Alternative D, was proposed after this analysis for choosing a representative trace was performed, and is not included in this analysis. The alternatives have been assigned a letter designation and will be referenced in this document by that letter: Long-Term Strategies B1, C1, and E1, and Alternatives F and G. Alternative A, the no action alternative, is the current operating regime and is known as modified low fluctuating flow (MLFF) as defined in the 1996 Record of Decision.

Annual Powell Outflows—Exceedance Curves

A priority in selecting a single representative 20-year hydrology trace for power modeling is to capture the range and distribution of water conditions that occur across all 21 of the original 20-year hydrology traces. To address that objective, we constructed time-independent exceedance curves (basically representing probability distributions) for the annual Powell outflows for each of the 21 traces and six alternatives and long-term strategies. As a metric for comparing the closeness of fit for those 21 distribution profiles as compared with the full set of traces, we calculated the least-squares differentials between each trace-specific

[1] It should be noted that at the time the representative trace was chosen, the LTEMP DEIS had only 6 alternatives and long-term strategies. A hybrid or 7th alternative was subsequently added. The hybrid is a combination of the C1 and E1 long-term strategies; however, the choice of the representative trace would not be affected by the addition of the hybrid alternative.

TABLE 1 Powell Outflow Exceedance: Rankings of Traces by Least-Squares Differentials as a Measure for Matching the Distribution of Releases for All Traces[a]

	Alternative A (No Action Alternative)		Long-Term Strategy B1		Long-Term Strategy C1		Long-Term Strategy E1		Alternative F		Alternative G	
Rank	Trace	Sq. Diff[b]	Trace	Sq. Diff.	Trace	Sq. Diff.	Trace	Sq. Diff.	Trace	Sq. Diff.	Trace	Sq. Diff.
1	Trace 14	710	Trace 14	710	Trace 13	636	Trace 13	637	Trace 14	533	Trace 13	872
2	Trace 19	836	Trace 19	836	Trace 19	906	Trace 14	1,130	Trace 13	832	Trace 14	940
3	Trace 13	1,024	Trace 13	1,024	Trace 14	1,055	Trace 19	1,401	Trace 19	930	Trace 19	1,133
4	Trace 12	1,208	Trace 12	1,208	Trace 12	1,241	Trace 12	1,448	Trace 12	1,257	Trace 12	1,337
5	Trace 15	2,353	Trace 15	2,353	Trace 15	2,548	Trace 15	2,620	Trace 15	2,639	Trace 15	2,590
6	Trace 3	2,594	Trace 3	2,594	Trace 3	3,811	Trace 3	3,945	Trace 3	3,003	Trace 3	3,746
7	Trace 18	3,509	Trace 18	3,509	Trace 18	4,249	Trace 7	4,661	Trace 7	4,150	Trace 18	3,833
8	Trace 7	3,962	Trace 7	3,962	Trace 7	4,641	Trace 18	4,835	Trace 18	4,394	Trace 7	4,362
9	Trace 4	4,096	Trace 4	4,096	Trace 4	5,110	Trace 4	5,106	Trace 4	4,642	Trace 4	4,676
10	Trace 17	4,541	Trace 17	4,541	Trace 2	5,406	Trace 17	5,392	Trace 17	5,129	Trace 17	5,028
11	Trace 16	5,245	Trace 16	5,246	Trace 17	5,420	Trace 2	5,846	Trace 2	5,440	Trace 2	5,631
12	Trace 2	5,325	Trace 2	5,325	Trace 6	7,051	Trace 16	6,429	Trace 6	6,467	Trace 16	5,919
13	Trace 6	5,648	Trace 6	5,648	Trace 20	7,258	Trace 6	7,047	Trace 16	6,669	Trace 6	6,460
14	Trace 20	7,399	Trace 20	7,399	Trace 16	7,572	Trace 20	7,359	Trace 20	7,511	Trace 20	7,390
15	Trace 8	9,687	Trace 8	9,688	Trace 0	10,979	Trace 8	10,992	Trace 0	10,858	Trace 8	10,202
16	Trace 10	10,446	Trace 10	10,446	Trace 1	11,068	Trace 0	11,008	Trace 10	11,016	Trace 0	10,865
17	Trace 0	10,868	Trace 0	10,868	Trace 8	11,350	Trace 1	11,332	Trace 8	11,255	Trace 10	11,111
18	Trace 1	11,249	Trace 1	11,249	Trace 10	11,557	Trace 10	11,601	Trace 1	11,491	Trace 1	11,408
19	Trace 5	11,262	Trace 5	11,262	Trace 5	12,662	Trace 5	12,816	Trace 5	12,712	Trace 5	12,113
20	Trace 9	13,003	Trace 9	13,003	Trace 9	14,797	Trace 9	14,807	Trace 9	13,982	Trace 9	14,046
21	Trace 11	14,321	Trace 11	14,321	Trace 11	16,284	Trace 11	16,349	Trace 11	15,433	Trace 11	15,501

[a] Trace 14, the selected representative trace, is highlighted in green.

[b] Note: Sq. Diff. = least squares differential between the trace-specific exceedance curve and the all-traces exceedance curve.

exceedance curve and the all-traces exceedance curve. These differentials were calculated separately for each of the six alternatives and long-term strategies (Table 1).

Table 2 shows that hydrology Trace 14 provides a distribution of annual water releases that closely mimics the full set of releases for all traces. We also observed that differences in the rankings when examining Powell outflows versus estimated power releases were minor and relatively insignificant to the selection of a single representative trace. Thus, the illustrations used in this summary focus primarily on Powell outflows.

Trace 13 also provides a good match with all-trace outflows, especially for Alternative G and Long-Term Strategies C1 and E1, where the least-squares differences are less than those for Trace 14. However, a large portion of the least-squares difference between Traces 13 and 14 is accredited to the closer match to near-peak releases for some alternatives in Trace 13 versus Trace 14, whereas Trace 14 exhibits a closer fit over other portions of the flow distributions (illustrated in figures that follow). Additionally, alternative-to-alternative inconsistencies in end-of-year Powell elevations and annual water releases were significantly greater for Trace 13 than Trace 14.

Trace 19 represents another possible contender with a good match to the all-trace variability. It is not considered further, though, because it includes numerous occurrences of Powell elevations below the top of the penstock within the 20-year modeling period (4 months for each alternative except Alternative F). The below-penstock occurrences across the 21 traces and 20 years are listed below:

- Alternative A—Trace 8: 3 in 2032; Trace 19: 12 in 2016 to 3 in 2017 inclusive.
- Long-Term Strategy B1—Trace 8: 3 in 2032; Trace 19: 12 in 2016 to 3 in 2017 inclusive.
- Long-Term Strategy C1—Trace 8: 3 in 2032; Trace 19: 12 in 2016 to 3 in 2017 inclusive.
- Long-Term Strategy E1—Trace 8: 3 and 4 in 2032; Trace 9: 3 in 2027; trace 19: 12 in 2016 to 3 in 2017 inclusive.
- Alternative F—none; all elevations above 3,490 ft.
- Alternative G—Trace 8: 2 in 2032 to 4 in 2032 inclusive; Trace 19: 12 in 2016 to 3 in 2017 inclusive.

Figures 1 through 5 illustrate the close match between Trace 14 and all-traces exceedance curves for annual Powell outflows. For comparison purposes, we also show: (1) Trace 14 exceedance curve for Long-Term Strategy C1, where Trace 14 ranked third instead of first in the distribution match (this represents the worst-case match for Trace 14); and (2) the Trace 19, 13, and 16 exceedance curves for the No Action Alternative (Alternative A) to illustrate the

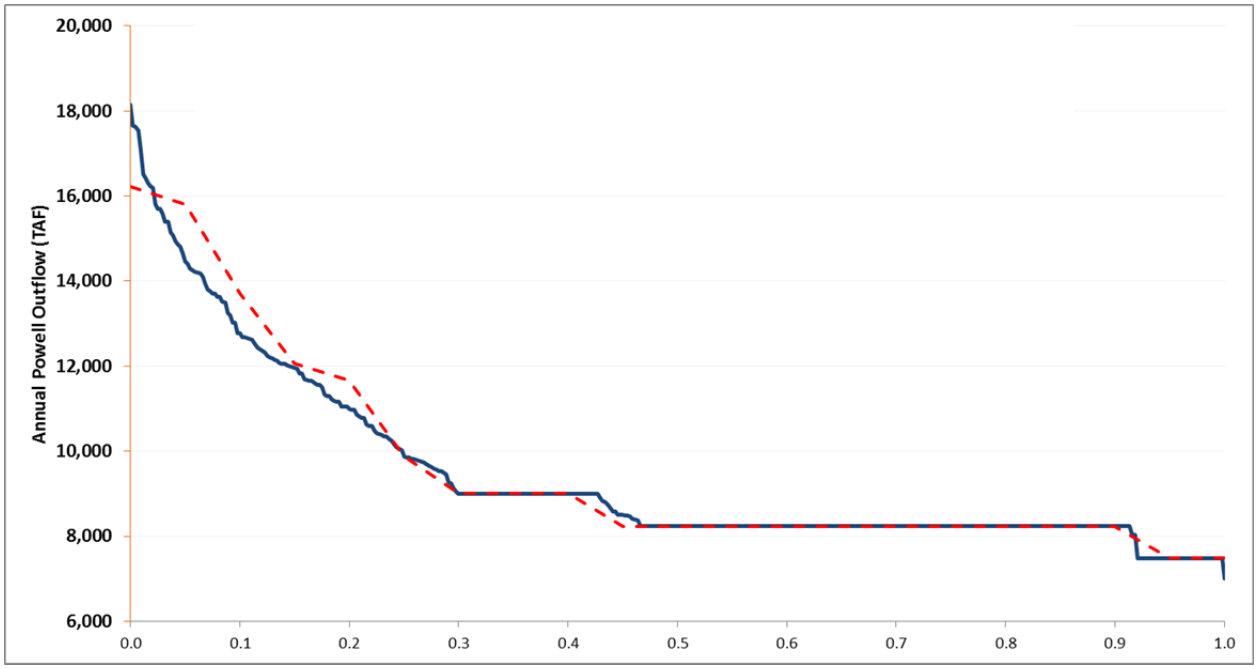

FIGURE 1 Exceedance Curve Comparing Outflows of Trace 14 (red dotted line) and the All-Trace Average (blue line) for the No Action Alternative

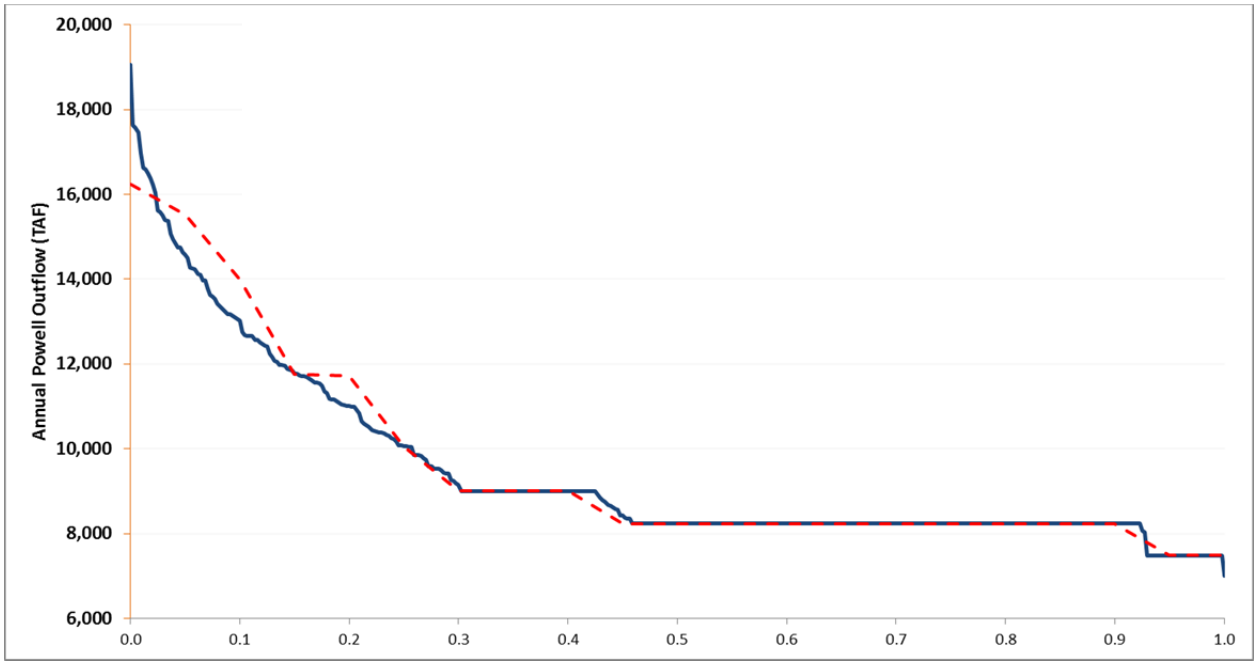

FIGURE 2 Exceedance Curve Comparing Outflows of Trace 14 (red dotted line) and the All-Traces Average (blue line) for Long-Term Strategy C1

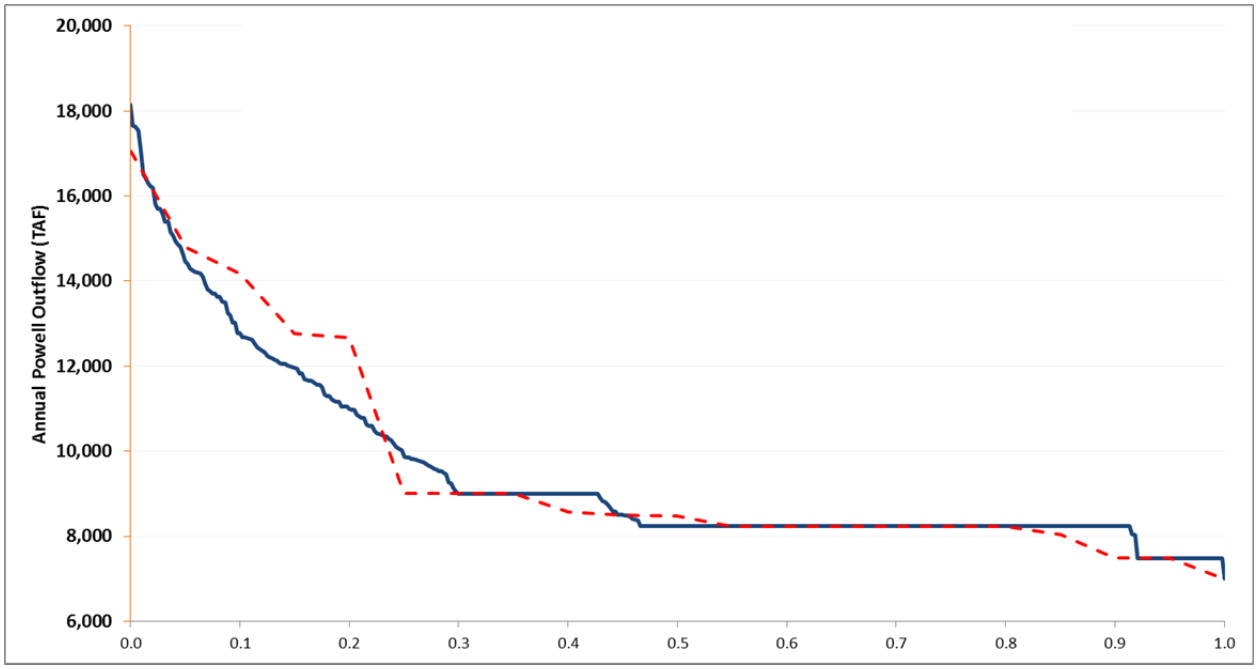

FIGURE 3 Exceedance Curve Comparing Outflows of Trace 19 (red dotted line) and the All-Traces Average (blue line) for the No Action Alternative

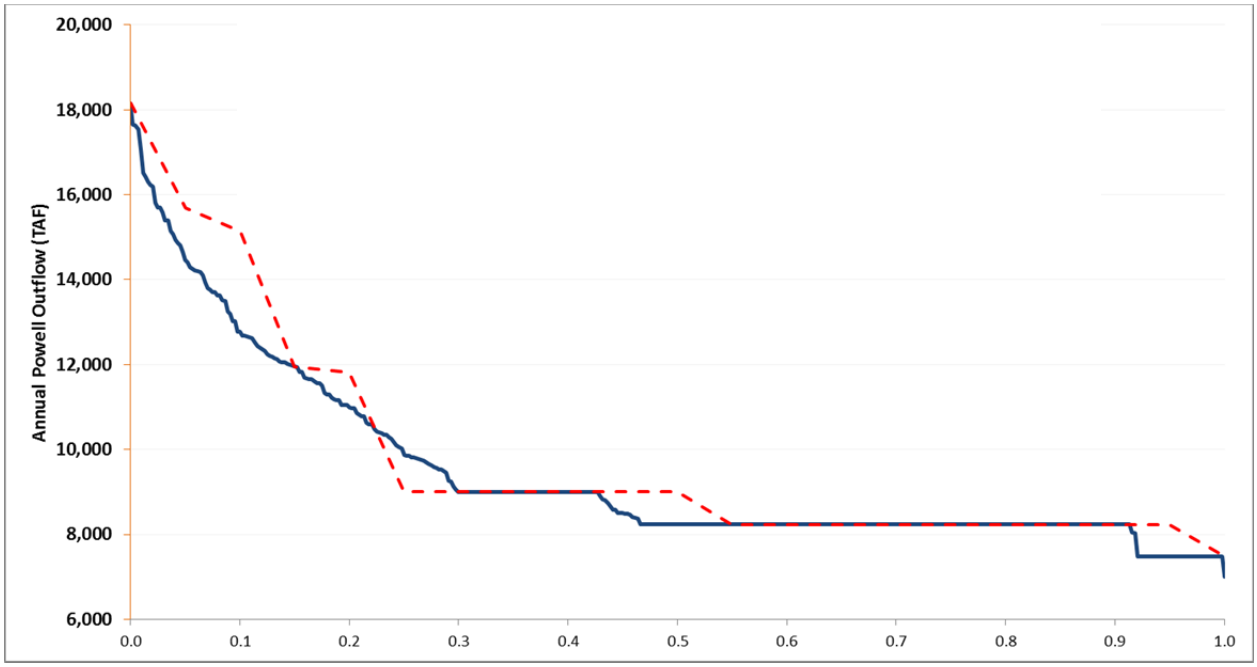

FIGURE 4 Exceedance Curve Comparing Outflows of Trace 13 (red dotted line) and the All-Traces Average (blue line) for the No Action Alternative

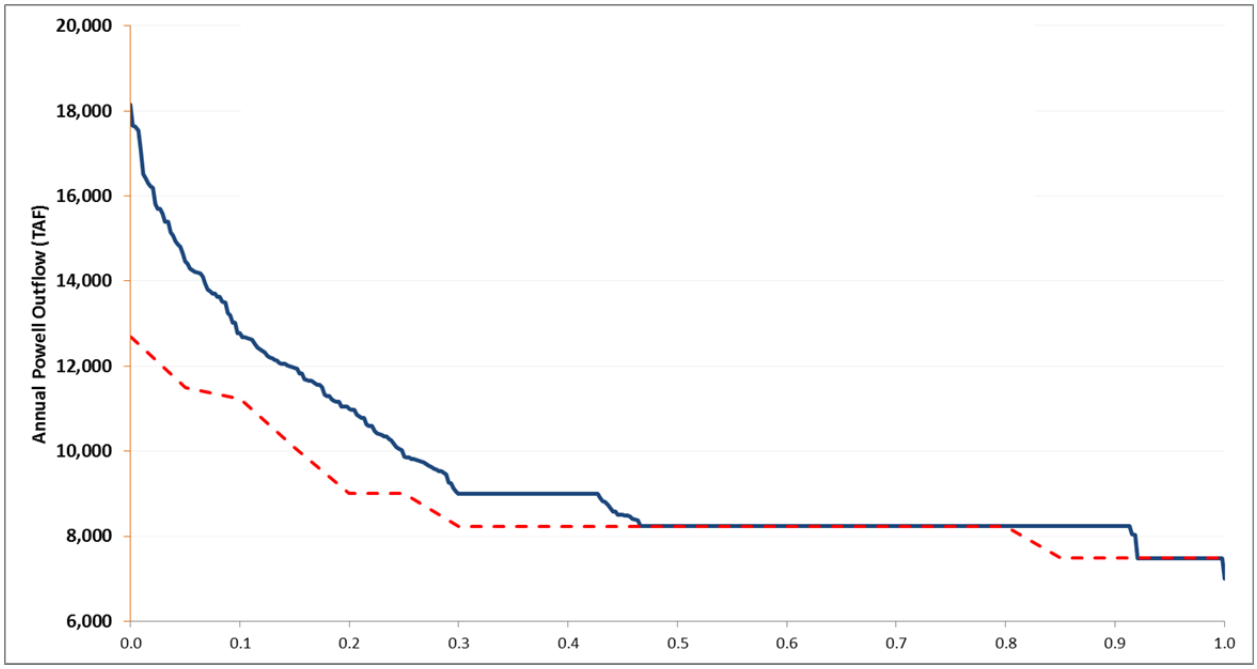

FIGURE 5 Exceedance Curve Comparing Outflows of Trace 16 (red dotted line) and the All-Traces Average (blue line) for the No Action Alternative

difference in fit between the top and middle-ranked traces (rankings for Alternative A are: Trace 19 = 2nd; Trace 13 = 3rd; and Trace 16 = 11th).

Comparison of Monthly Water Releases and Powell Elevations to Averages

Complementing the probability distribution analysis, monthly Powell elevations and water releases for each trace were compared to the associated averages for each month in the 20-year study period for all traces. Again, these comparisons were made separately for each alternative and long-term strategy. The objective in these examinations is to provide "representative variability" over the 20-year spans relative to average outcomes (i.e., the goal is to include conditions that are sometimes "wet," sometimes "dry," and sometime "average," rather than conditions that are uniformly "average" across the entire study period).

Results of monthly outflow and end-of-month elevations for Trace 14 and the all-trace averages are plotted in Figures 6 to 11. Table 3 shows the number of HFEs and the amount of water bypassed during all HFEs for Trace 14 and the all-trace average. Trace 14 is characterized by lower-than-average water outflow through 2019, higher water outflow through 2026, followed by lower-than-average water outflow through 2033. As seen from these figures, the monthly Powell elevations and water releases averaged over the 21 traces are significantly less variable than observed for a single trace.

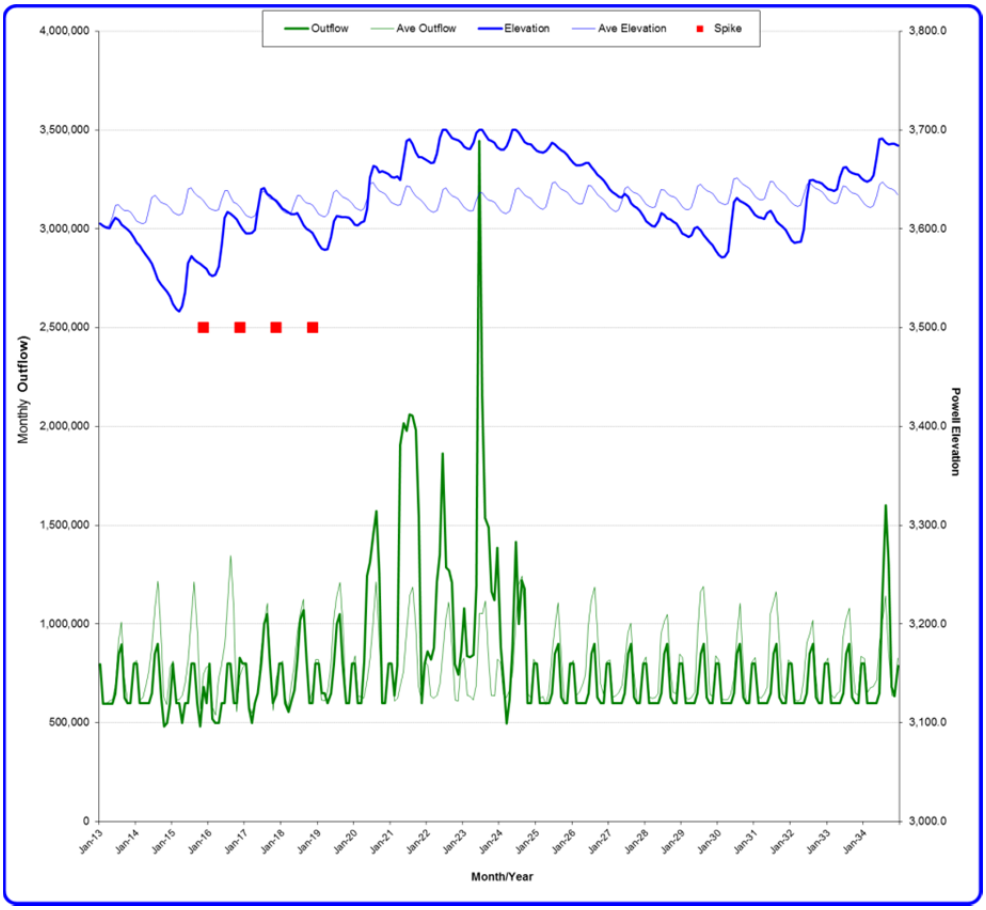

FIGURE 6 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for the No Action Alternative

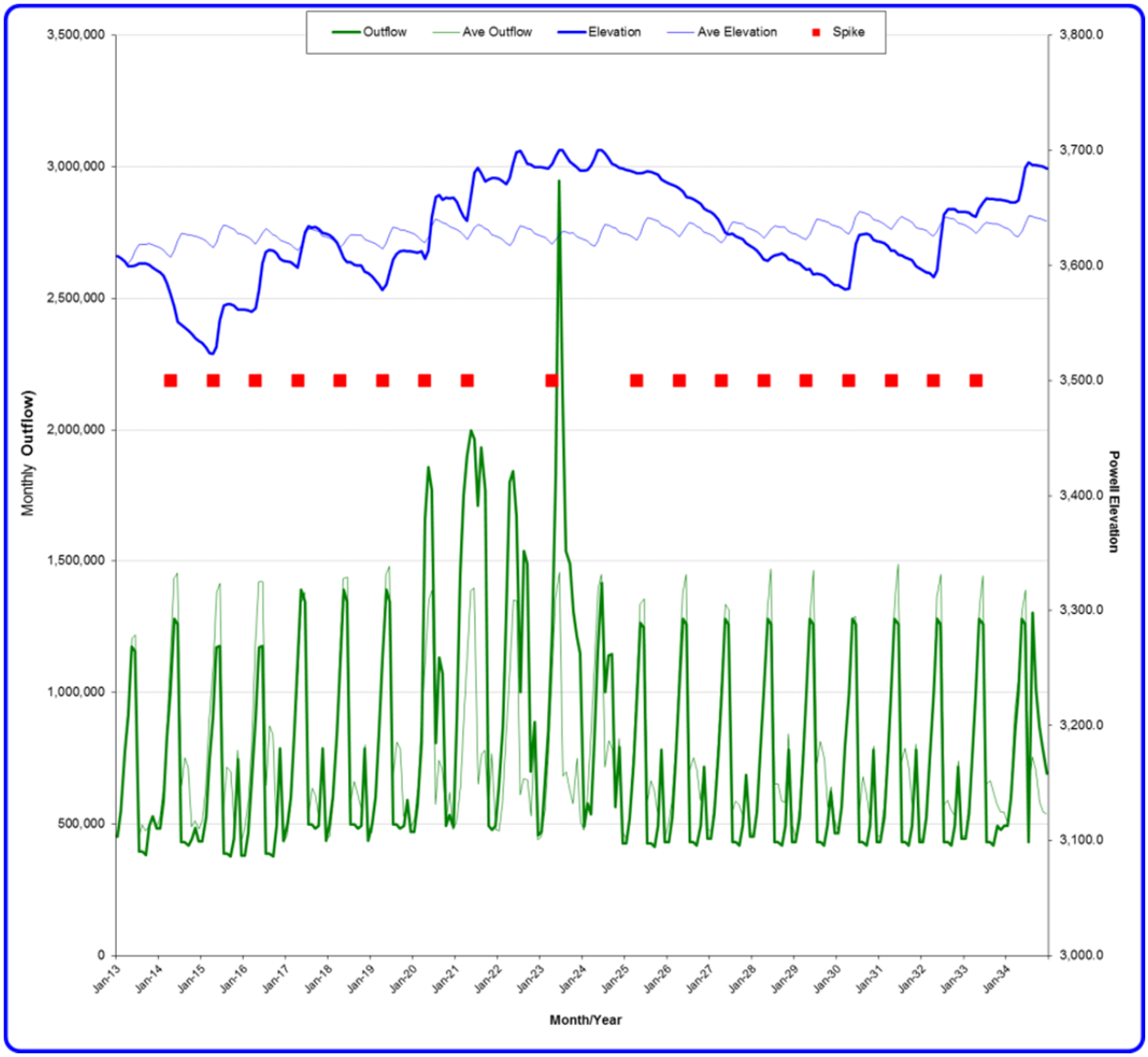

FIGURE 7 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for Alternative F



FIGURE 8 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for Alternative G

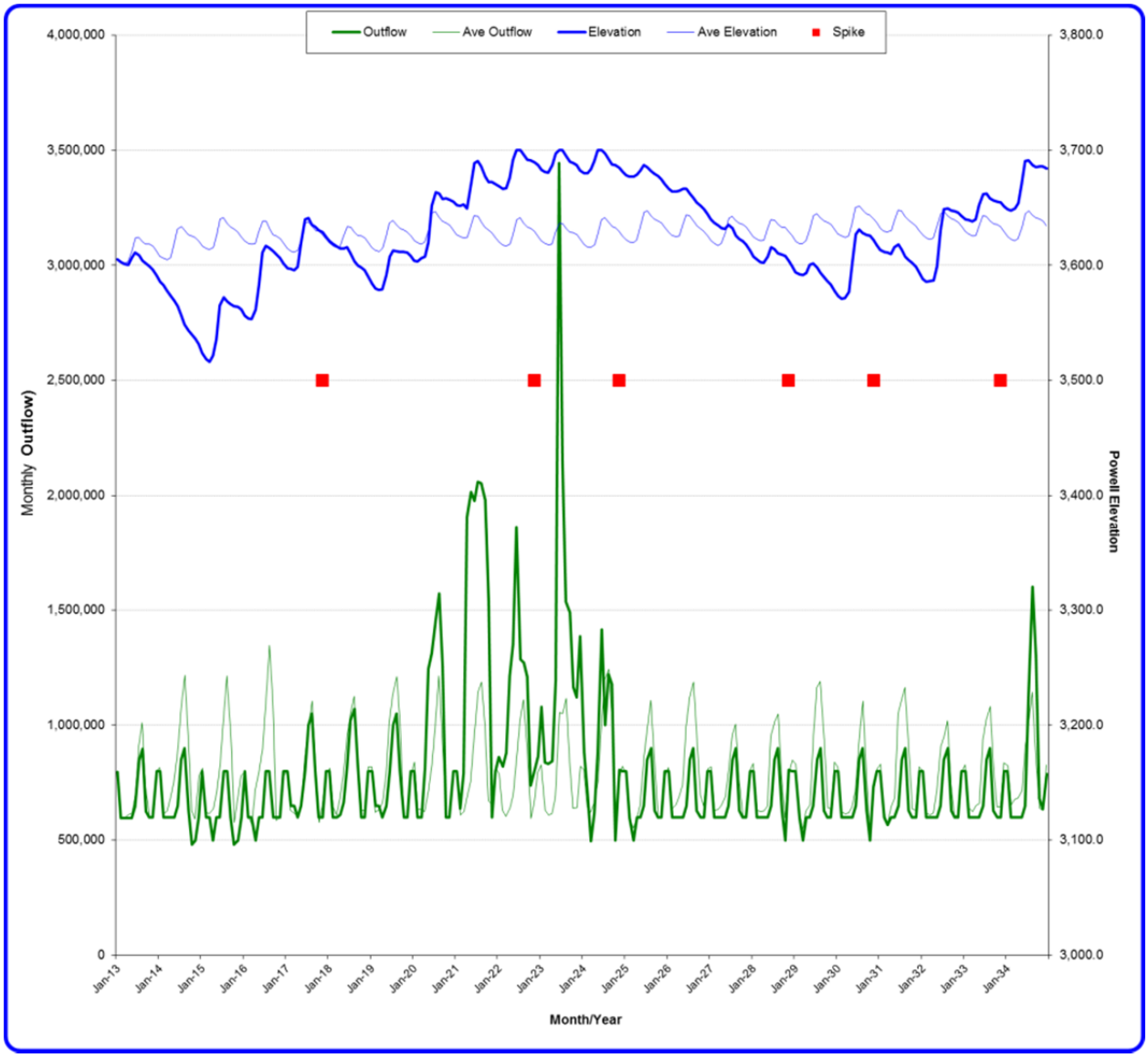

FIGURE 9 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for Long-Term Strategy B1

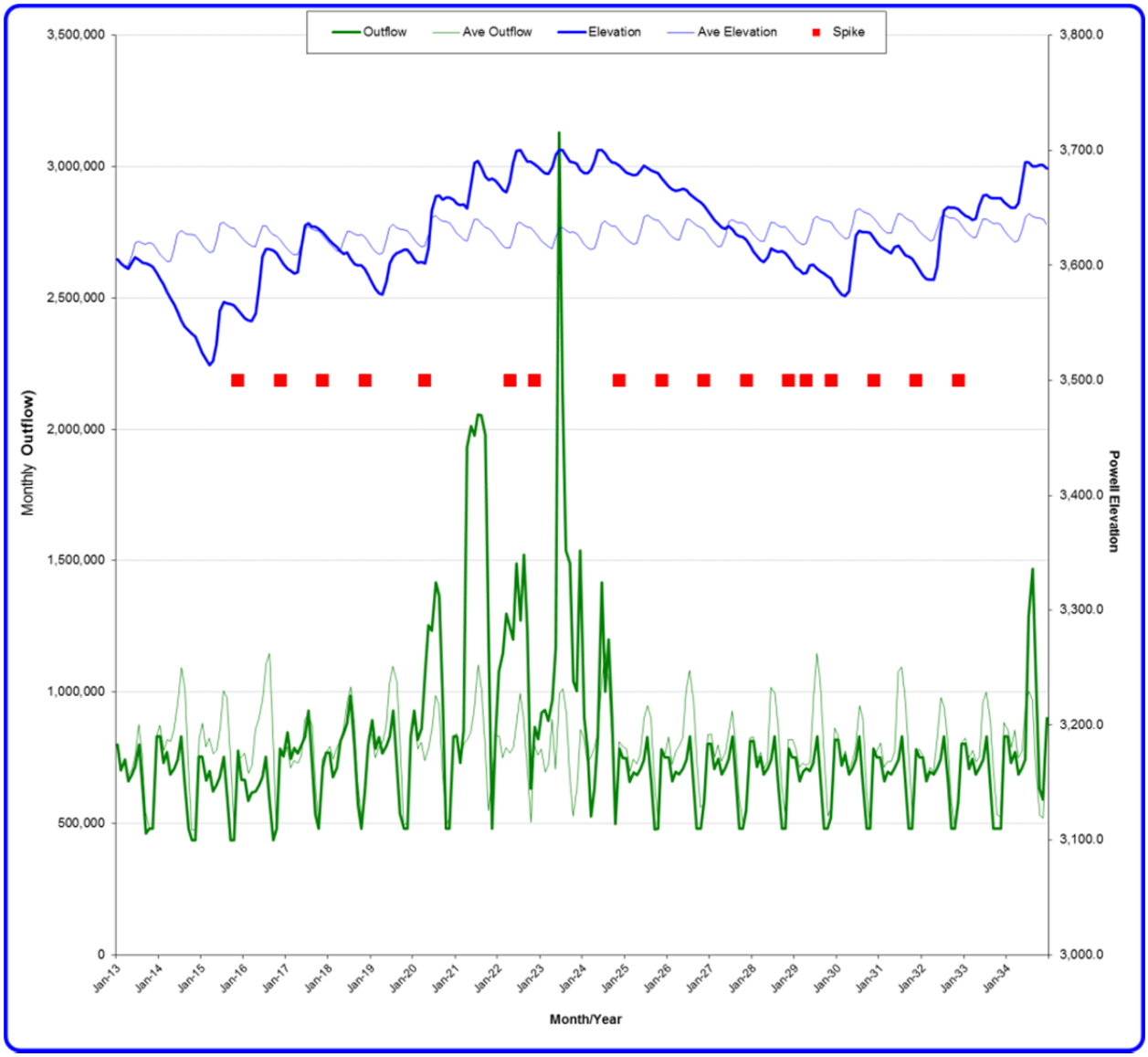

FIGURE 10 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for Long-Term Strategy C1

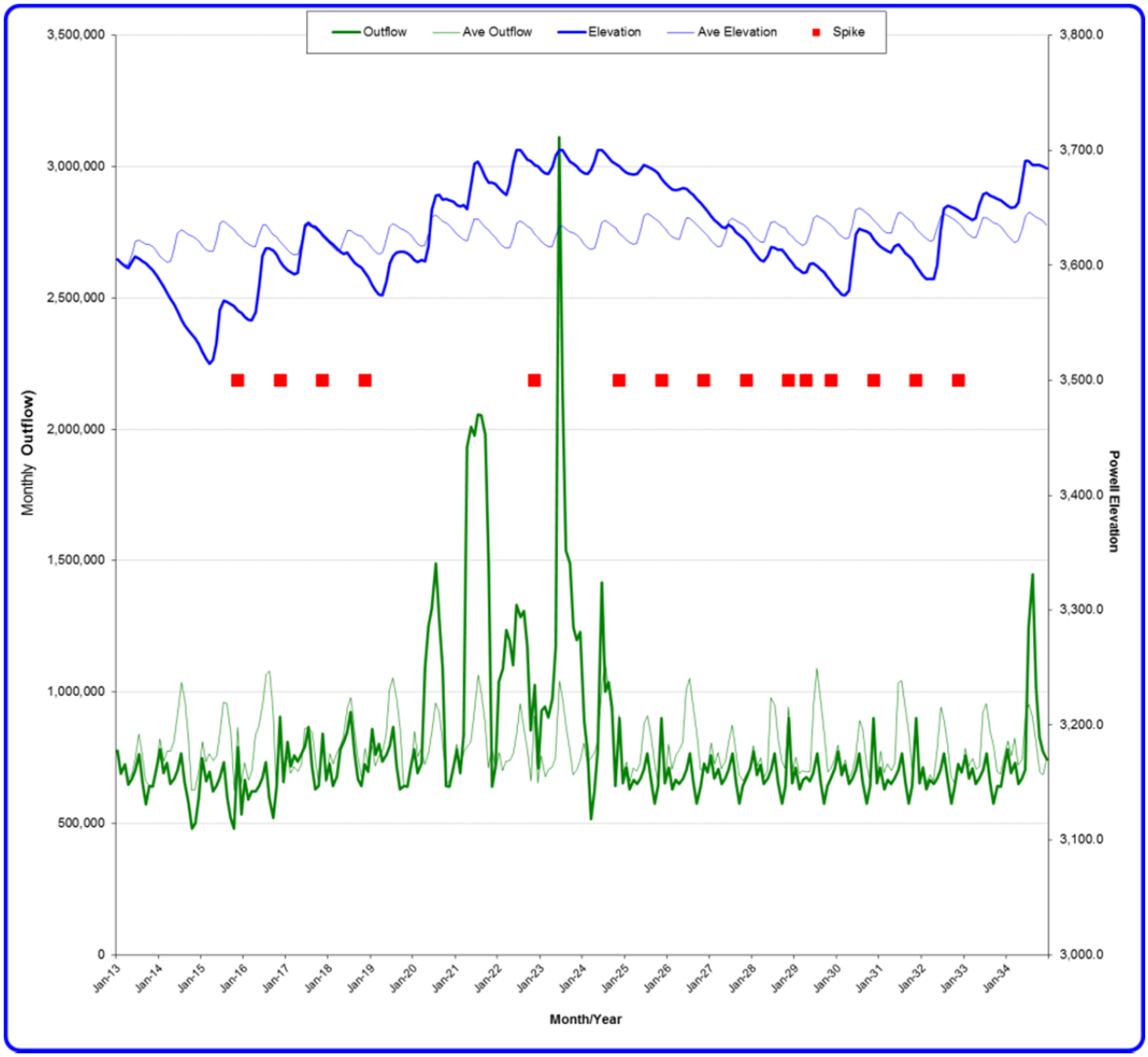

FIGURE 11 Comparison of Monthly Outflow and End-of-Month Elevation of Trace 14 and the All-Trace Average for Long-Term Strategy E1

TABLE 2 Number of HFEs and Amount of Water Spilled Bypassed during HFEs in Trace 14 and the All-Trace Average

Alternative/ Long-Term Strategy	Characteristic	Trace 14	21 Traces Average
A (No Action Alternative)	Number of HFEs	4	4
	Amount of bypassed water spilled during HFEs (kaf)	262	346
B1	Number of HFEs	6	7
	Amount of bypassed water spilled during HFEs (kaf)	472	553
C1	Number of HFEs	17	19
	Amount of bypassed water spilled during HFEs (kaf)	1,329	1,522
E1	Number of HFEs	15	16
	Amount of bypassed water spilled during HFEs (kaf)	1,236	1,211
F	Number of HFEs	18	19
	Amount of bypassed water spilled during HFEs (kaf)	1,734	1,853
G	Number of HFEs	22	22
	Amount of bypassed water spilled during HFEs (kaf)	3,188	2,591

TABLE 3 Rankings of Hydrology Trace 14 in Matching Average Elevations and Outflows Compared to the 21-Trace Average

Alternative/ Long-Term Strategy	Powell Elevation Trace 14 Rank	Powell Outflow Trace 14 Rank
A (No Action Alternative)	11	13
B1	11	13
C1	11	13
E1	10	13
F	12	13
G	10	13

Because capturing variability is an important objective for this study, an exact match to the 21-trace averages is not desirable. Table 4 illustrates how Trace 14 ranks near the middle of variability for all of the 21 traces; it is neither too close to the average during all years, nor the most extreme divergence from the average over all years.

To assess the 21 traces on a common metric, rankings were calculated based on the least-squares differences by rank relative to the monthly average of all 21 traces: Rank = 1 is the closest match to the average (smallest least-squares difference); Rank = 21 represents the largest difference relative to the average. Table 4 demonstrates that Trace 14 is in the mid-range for both elevation and outflow. The point of this comparison is to illustrate that the selected trace contains neither excessive variability, nor insufficient variability relative to all of the traces under consideration.

Evaluation of Differentials in End-of-Year Powell Elevations and Annual Water Releases

For the representative hydrology trace selection, we also examined how closely each trace's end-of-year Powell elevations and annual water releases match when compared across all six alternatives and long-term strategies. In theory, these values should match closely, but we found that this is not the case for a majority of the traces. To generate a common metric for trace-specific comparisons, we first calculated the differences in both end-of-year elevation and annual outflow between Alternatives A and F; A and G; A and Long-Term Strategy B1; A and Long-Term Strategy C1; and A and Long-Terms Strategy E1 for each of the 20 years and each hydrology trace (using Alternative A [no action alternative] as a reference point). Since these values should ideally all be zero, we calculated the least-squares differentials and ranked the traces according to the sum of the least-squares differences for the five comparisons listed above. Table 5 shows that for these criteria, Trace 14 ranks near the middle of all traces, indicating that it does not represent an extreme case for deviations in end-of-year elevations or annual water releases. In contrast, Trace 13 exhibits the worst match (21st) in annual outflows and ranks 18th in Powell end-of-year elevations.

Examining this same issue through graphical depictions, Figures 12 and 13 compare the differentials for Traces 14 and 13 side by side, in year-by-year plots of the pairwise end-of-year differentials. Trace 14 is preferred over Trace 13 because of the more consistent end-of-year Powell elevations and annual water releases across the six alternatives and long-term strategies.

Evaluation of HFE Bypasses

As a final comparison, Figure 14 shows quantities of water bypassed during the HFEs for Trace 14 (highlighted as enlarged red diamond) compared to other traces for each of the six alternatives. These comparisons show that Trace 14 exhibits outcomes that span the range of possible rankings relative to other traces. That is, Trace 14 exhibits HFE bypass volumes that are low, medium, and high, for various alternatives, in comparison with other traces. These observations make Trace 14 a favorable candidate for representative bypass characteristics across all alternatives.

TABLE 4 Rankings of Hydrology Traces Compared to All-Trace Average for End-of-Year Elevations and Annual Water Releases

Rank (1 = least differential)	Powell Elevation		Powell Outflow	
	Trace Number	Square Differential	Trace Number	Square Differential
1	Trace 4	6.51	Trace 9	0.000
2	Trace 9	20.05	Trace 4	0.000
3	Trace 11	26.91	Trace 11	0.000
4	Trace 6	32.63	Trace 6	0.001
5	Trace 0	43.05	Trace 8	0.003
6	Trace 20	47.32	Trace 12	0.006
7	Trace 3	47.95	Trace 15	0.006
8	Trace 1	54.64	Trace 14[a]	0.007
9	Trace 2	59.81	Trace 0	0.008
10	Trace 7	64.72	Trace 20	0.010
11	Trace 12	127.00	Trace 2	0.015
12	Trace 15	192.56	Trace 1	0.015
13	Trace 14[a]	235.30	Trace 3	0.016
14	Trace 17	326.53	Trace 17	0.018
15	Trace 19	354.81	Trace 7	0.019
16	Trace 16	458.47	Trace 5	0.029
17	Trace 8	583.18	Trace 19	0.060
18	Trace 13[a]	838.12	Trace 10	0.071
19	Trace 5	914.47	Trace 18	0.086
20	Trace 18	1085.39	Trace 16	0.099
21	Trace 10	2363.07	Trace 13[a]	0.112

[a] Traces 13 and 14 are highlighted to illustrate their relative rank with respect to end-of-year elevations and annual water releases.

Summary

The observations and comparisons described above were used to select hydrology Trace 14 as the representative trace. Characteristics such as annual water release distributions, monthly water release variability, bypass events, and end-of-year elevation/volume consistency were considered and a majority of these factors favor Trace 14. While a few other traces show comparable strengths in certain comparison categories, each of those candidate traces show less favorable rankings in other categories.

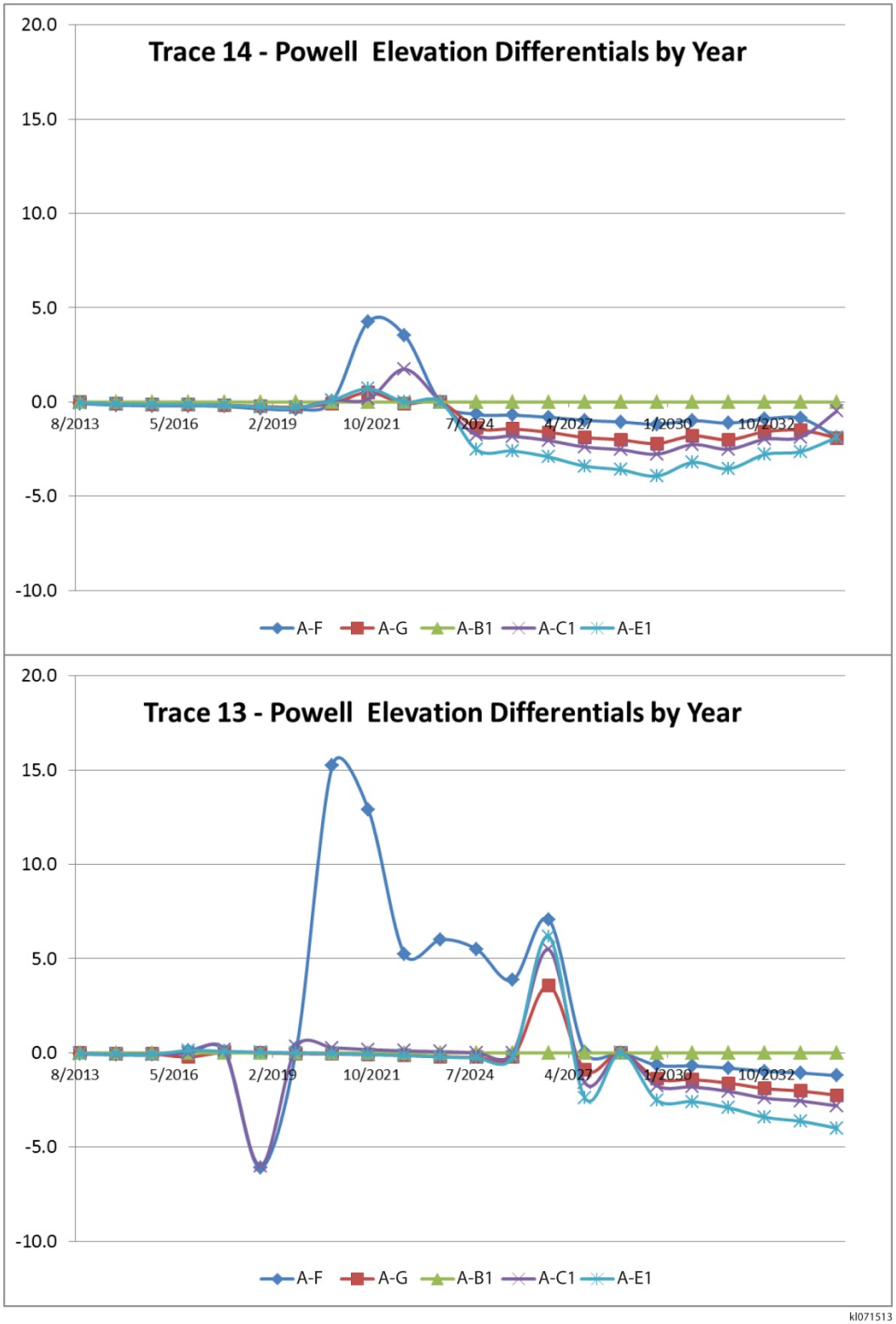

FIGURE 12 Pairwise Annual Lake Powell Elevation Differentials for Traces 14 and 13 (Alternative A is the reference case)

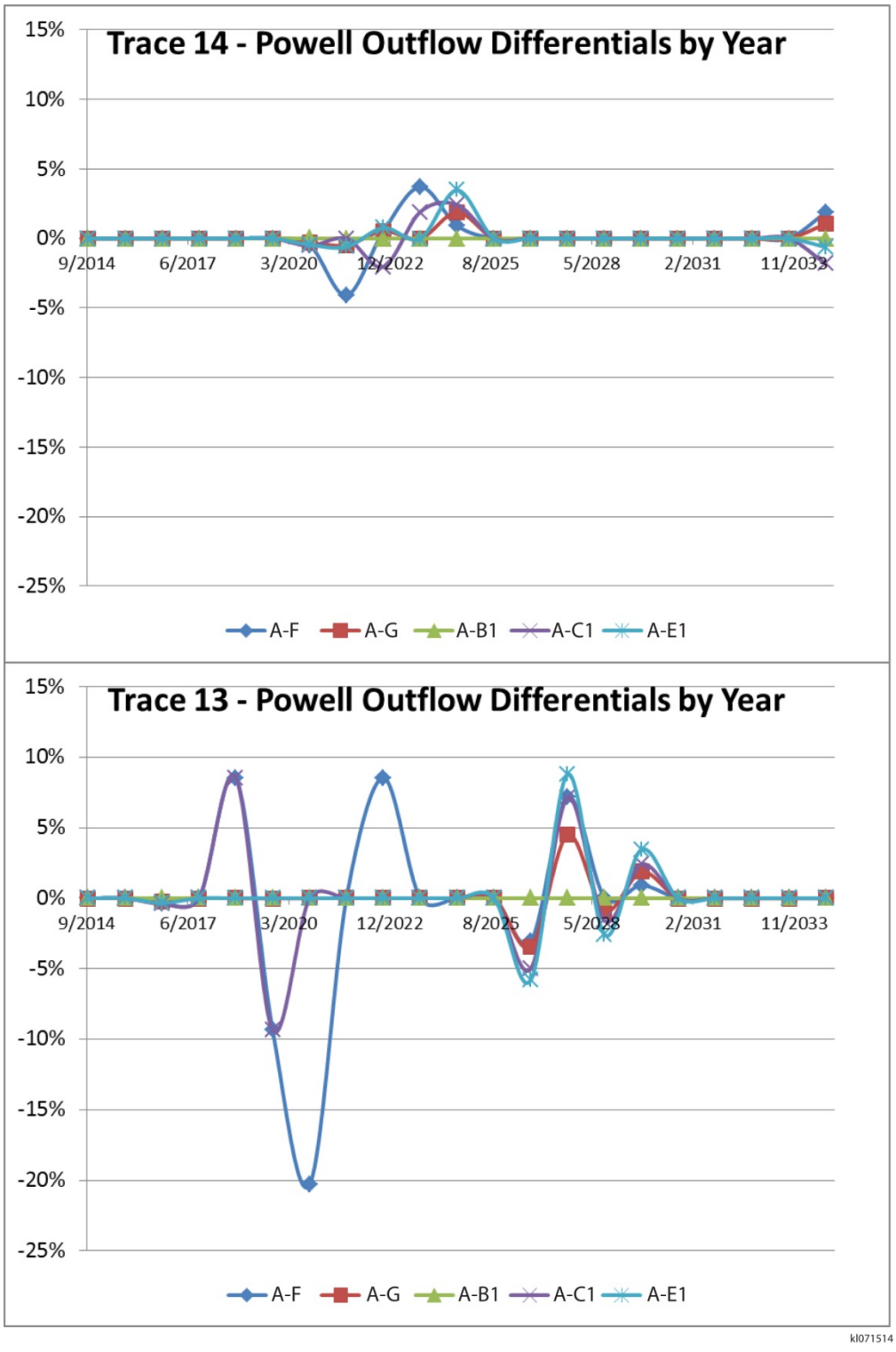

FIGURE 13 Pairwise Annual Lake Powell Outflow Differentials for Traces 14 and 13 (Alternative A is the reference case)

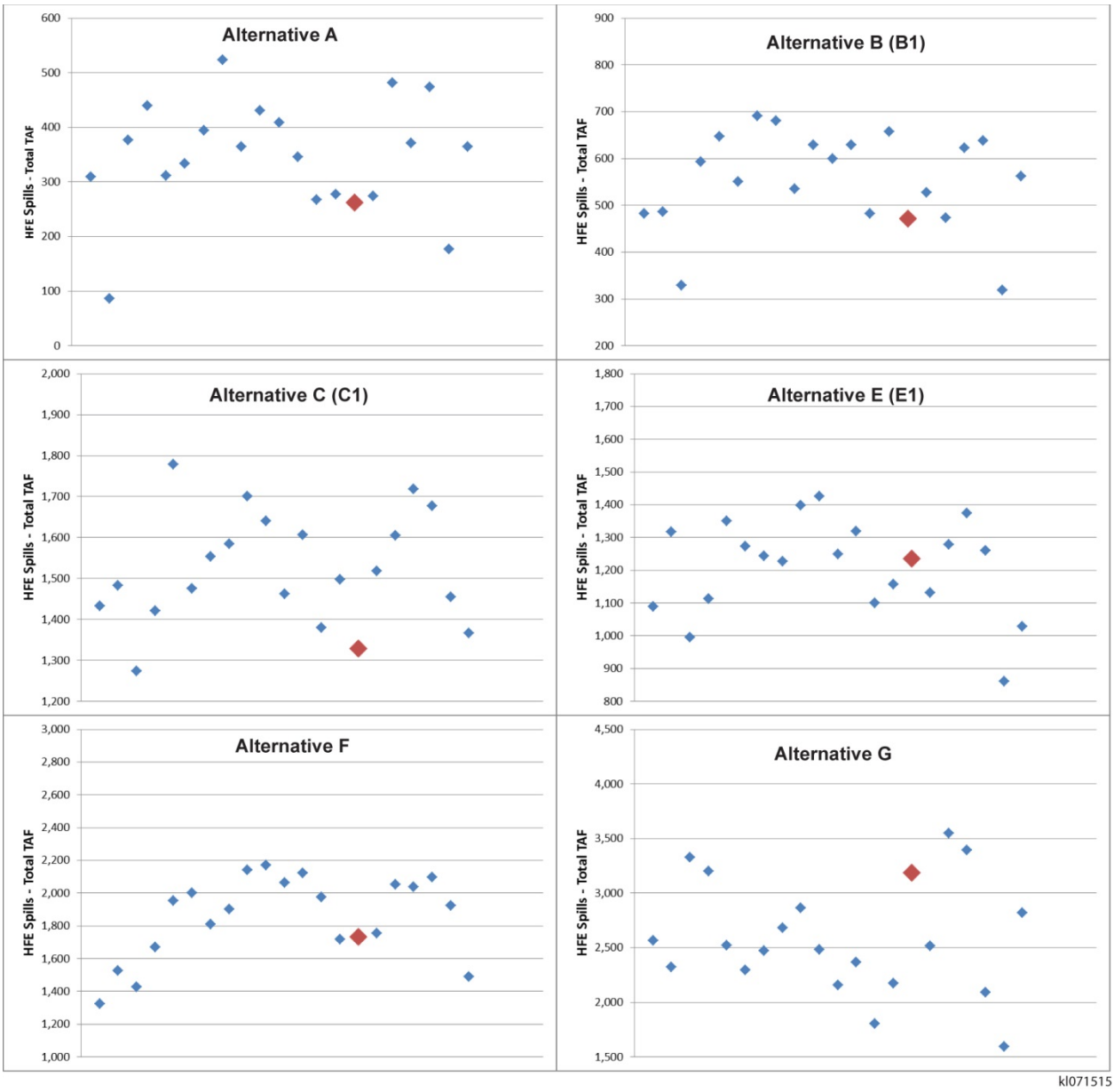

FIGURE 14 Quantity of Water Bypassed during HFEs across All Hydrology Traces and All Six Alternatives

ATTACHMENT K.4:

DISCOUNTING PROCEDURES

The costs and benefits of most environmental policies are incurred at different times over what are frequently long time horizons. A fundamental concept in finance and economics is that the timing of benefits and costs makes a difference in the attractiveness of an investment. All other things being equal, one would prefer to receive the benefits of an investment as soon as possible and to pay the costs as far out in the future as possible. Given the choice between receiving $100 today or $100 a year from now, most people would prefer $100 today. Alternatively, if given the choice between paying out $50 today or one year from now, most of us would prefer the latter.

Because the timing of these costs and benefits differs across alternatives, the responsible policy choice requires the use of appropriate techniques to allow for commensurate comparisons. Typically, the present value of the future stream of costs and benefits for each alternative is computed and the results arrayed for decision-makers.

Discounting is the method used for identifying the present value of a cost or benefit that occurs at some time in the future. The process of "discounting" is used to make costs or benefits that occur at different points in time commensurate with each other.

Although the mechanics of the discounting process are very straightforward, the magnitude of the discount rate greatly influences the degree to which future costs and benefits "count" in the decision. As a result, the choice of discount rate is the subject of much controversy.

The literature on discounting and the choice of a discount rate is vast. Many modern economics texts contain synopses of this literature (e.g., Field 2008; Tietenberg and Lewis 2009). A more lengthy assessment can be found in the Environmental Protection Agency's, *Guidelines for Preparing Economic Analyses* (EPA 2010) and Burgess and Zerbe (2011).

Federal water resource agencies, including the Bureau of Reclamation (Reclamation), are required to employ an administratively determined discount rate known as the federal plan formulation and evaluation rate when undertaking economic analyses of water resource and related matters (see 42 U.S.C. 1962d–17, Public Law 93-251-March 7, 1974 Sec. 80 (a)). This requirement and more specific analysis procedures are described in the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (U.S. Water Resources Council 1983). This document is often referred to as the "P&Gs."

A new set of water resource planning guidelines have been announced which will ultimately supersede the P&Gs (Council on Environmental Quality 2014). In March 2013, the *Principles and Requirements for Federal Investments in Water Resources* (referred to as the P&Rs) were released and in December 2014 a set of *Interagency Guidelines* (IGs) were released by the President's Council on Environmental Quality. Reclamation is now drafting agency-

specific procedures. These ongoing efforts will lead to production of a consolidated document, the *Principles, Requirements and Guidelines* (PR&Gs). Finalization of this effort is slated for calendar year 2016.

Two procedural points are relevant to this analysis. First, the forthcoming PR&Gs do not alter the statutory requirement of the Bureau of Reclamation to employ the federal plan formulation and evaluation rate in their water resource analyses. Second, this environmental impact study was initiated well-prior to completion of these new guidelines, and the PR&Gs are not applicable to the analysis reported here.

As prescribed by law and described in the P&Gs, federal water resource agencies must use an administratively determined discount rate for cost-benefit analysis. This rate is known as the federal discount rate for plan formulation and evaluation. The plan formulation and evaluation rate is calculated annually by the Secretary of the Treasury pursuant to 42 U.S.C. 1962d-1 (see the *Code of Federal Regulations* [CFR] at 18 CFR Part 704 for a description of the methodology) and then is officially transmitted to the water resource agencies. The plan formulation and evaluation rate for fiscal year (FY) 2015 is 3.375% (Reclamation 2014a,b).

Table 1 summarizes the inflation, escalation, and discounting procedures used in this analysis. As illustrated, the base year chosen for this economic analysis is 2015. The period of analysis is 21 calendar-years, spanning the period 2013 to 2033. All economic value estimates reported in this document are measured in 2015 dollars, unless otherwise stated.

The prices and values employed as input data for the economic modeling were reported at various times. To create a common input baseline, these prices and values were inflated from the year in which they were reported to 2014 dollars, using the annual Western Regional Consumer Price Index (CPI) (Bureau of Labor Statistics 2015).

TABLE 1 Discounting Procedures

Parameter	Value
Base year for reported results	2015
Period of analysis 2013 through 2033	21 years
Price escalation rate (2014 through 2015)	2.2126%
Price escalation rate (2015 through 2033)	0.0%
Discount rate[a]	3.375%

[a] Federal Water Resource plan formulation and evaluation rate for FY 2015.

Modeling output was inflated from 2014 to 2015 dollars for reporting purposes. The equivalent annual CPI rate during the most recent 10-year (2004 to 2014) period was calculated to be 2.2126 percent (rounded to 4 decimal places). Price inflation from 2014 to 2015 was assumed to be the same as it was during this 10-year period. All 2014 values and prices were escalated from 2014 to the base year of 2015 using an escalation rate of 2.2126 percent.

To summarize, consistent with applicable federal law, the procedures described in the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (U.S. Water Resources Council 1983), all costs and benefits that occur after 2015 are reported in constant 2015 dollars (they are not escalated). Costs and benefits that occur in 2015 are not discounted, given that 2015 is the base year for this analysis. All costs and benefits that occur after 2015 are discounted back to the 2015 base year using the FY 2015 federal discount rate for plan formulation and evaluation (3.375%).

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ATTACHMENT K.5:

FORCED OUTAGE SCENARIO GENERATION FOR HYDROELECTRIC POWER FACILITIES

The following is a description of the methodology used in creating a forced outage scenario for hydroelectric power facilities.

Requirement

1. Generate a reasonable forced outage scenario consistent with industry average for hydro units.

2. The forced outages should be multiple of 24 hr.

3. The forced outage always starts at the beginning of a day.

Inputs

1. Planned maintenance schedule for the hydroelectric power facility being modeled (from Reclamation)

2. Cause code statistics from the North American Electric Reliability Corporation (NERC)

3. Forced outage rate distribution from NERC

NERC publishes generating availability data system (GADS; http://www.nerc.com/page.php?cid=4|43|47). These reports contain aggregate statistics for various unit types. The cause code group statistics provides the number of forced outages and the number of hours under forced outage per unit per year. Tables 1 and 2 contain the relevant data extracted from GADS 2010.

Methodology

1. For each year and for each unit, randomly assign a forced outage rate (FOR) based on the distributions in Table 2.

2. Compute the forced outage hours based on the assigned FOR and service hours. Service hours are the number of hours the unit is not on planned maintenance schedule (i.e., available for generation).

3. Sum forced outage hours across all the units for a given year (TOTSYS)

TABLE 1 Cause Code Statistics for Hydro Plants >30 MW 2006–2010

Unit Type	Index	Cause Code	Description	Avg. No. of Outages per Unit Year	Avg. Hours Out per Unit Year
9	1	3600-3689	Electrical	0.31	25.28
9	2	3810-3899	AuxiliarySystems	0.06	2.71
9	3	3950-3999	Miscellaneous(BalanceOfPlant)	0.04	0.39
9	4	4500-4590	GENERATOR	0.17	45.18
9	5	4600-4609	Exciter	0.16	10.75
9	6	4610-4650	CoolingSystem	0.04	3.03
9	7	4700-4750	Controls	0.19	4.28
9	8	4800-4899	Miscellaneous(Generator)	0.1	9.92
9	9	7000-7099	Turbine	0.36	42.05
9	10	7100-7199	WaterSupplyDischarge	0.29	25.83
9	11	7200-7299	Miscellaneous(HydroTurbinePump)	0.23	11.25
9	12	9000-9040	Catastrophe	0.06	1.57
9	13	9135-9160	Economic	0.01	9.24
9	14	9300-9320	Miscellaneous(External)	0.26	1.4
9	15	9504-9590	Regulatory	0.01	0.01
9	16	9676-9696	OtherOperatingEnvironmentalLim	0.01	0.15
9	17	9700-9720	Safety	0	0
9	18	9900-9920	PERSONNELERRORS	0.05	0.22
9	19	9999-9999	PERFORMANCE	0.01	0.27

TABLE 2 Equivalent Forced Outage Rate Distribution

Unit Type	Index	FOR (Max)	Exceedance Curve
9	1	0	0.069
9	2	0.01	0.5727
9	3	0.02	0.7063
9	4	0.05	0.8238
9	5	0.1	0.8987
9	6	0.2	0.9383
9	7	0.3	0.9574
9	8	0.4	0.9721
9	9	0.5	0.9838
9	10	0.6	0.9883
9	11	0.7	0.9927
9	12	0.8	0.9956
9	13	0.9	0.9971
9	14	1	1

4. Using cause code statistics, calculate average outage length in hours for each cause code (column 6 divide by column 5 in Table 1).

5. Compute the total forced outage hours for each cause code across all units (column 6 * no. of units) and also the total forced outage hours across all units and all cause codes (TOTFOH).

6. Total outage hours based on cause codes are typically much lower than the hours out for units since cause codes outages are based on actual data and reflect only those hours that the unit is in service or called into service. Compute a "SCALE" as the ratio of TOTFH and TOTSYS.

7. Compute the total number of outages for each cause code across units using the "SCALE", column 5 from Table 1 and the total number of units.

8. For each cause code, loop through the number of outages. Randomly select a unit and a random start time that the unit is not on planned maintenance. Assign the forced outage for the duration of average outage length for the given cause code (from step 4 above).

9. Adjust the length of forced outage to be a multiple of 24 hr and move to the beginning of the day, if necessary.

ATTACHMENT K.6:

FORECAST OF MONTHLY PEAK LOADS AND ENERGY BY SLCA/IP LONG-TERM FIRM CUSTOMER

The development of hourly load projections over the study period is based on the 2006 representative nominal load profile and monthly projections of utility-level peak and total loads. Implementation of this method differs from utility to utility depending upon data availability. The primary source of forecast information was the utility's integrated resource plan (IRP). If these data are not available in the IRP, then generation and capacity projections from the Energy Information Administration's (EIA's) 2014 Annual Energy Outlook (EIA 2014) are used instead. The method for developing the hourly load forecast for each of the eight utilities plus Western Area Power Administration's (WAPA's) remaining small customers is described in more detail in Section K.1.6.3 of Appendix K.

Figures 1 and 2 show monthly peak loads and total monthly load projections, respectively, for each of the eight large customers and the two aggregate small customer groups. This data was used to generate the graphs shown in Figures K.1-15 and K.1-16 in Section K.1.6.3 of Appendix K.

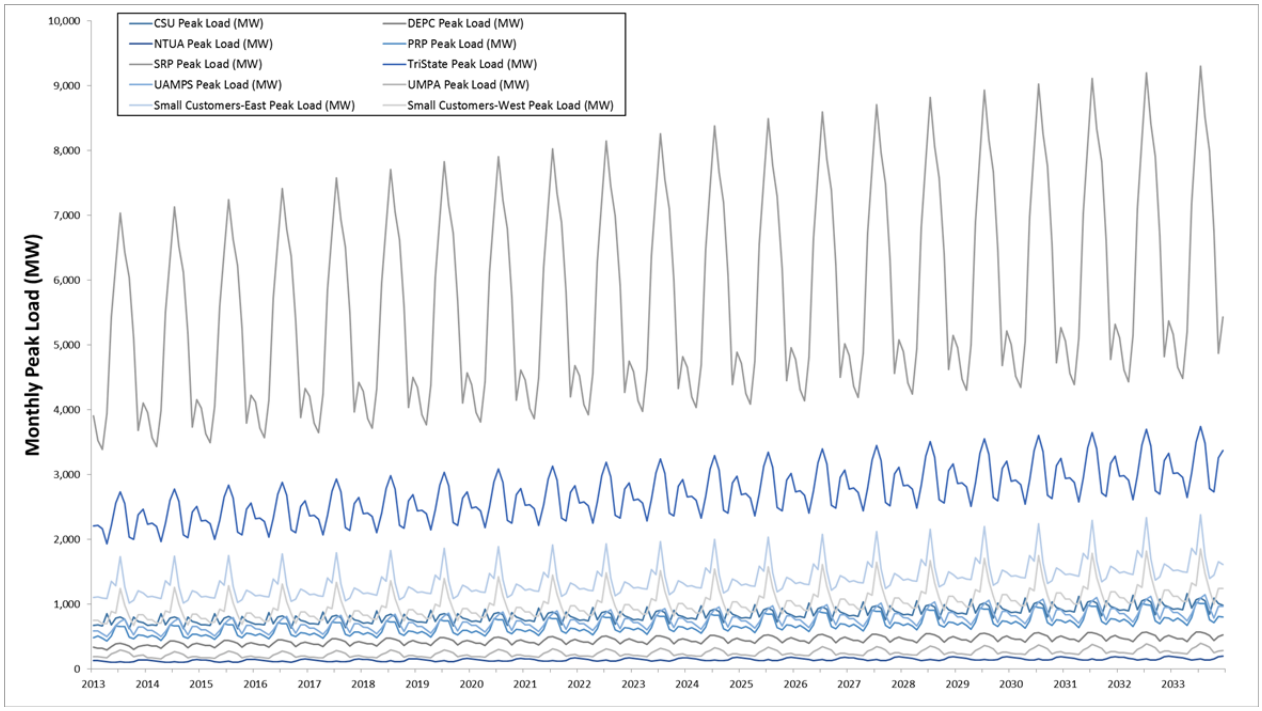


FIGURE 1 Projected Future Peak Loads by Each Large Customer and Small Customer Groups in the SLCA/IP Market System during the LTEMP Period

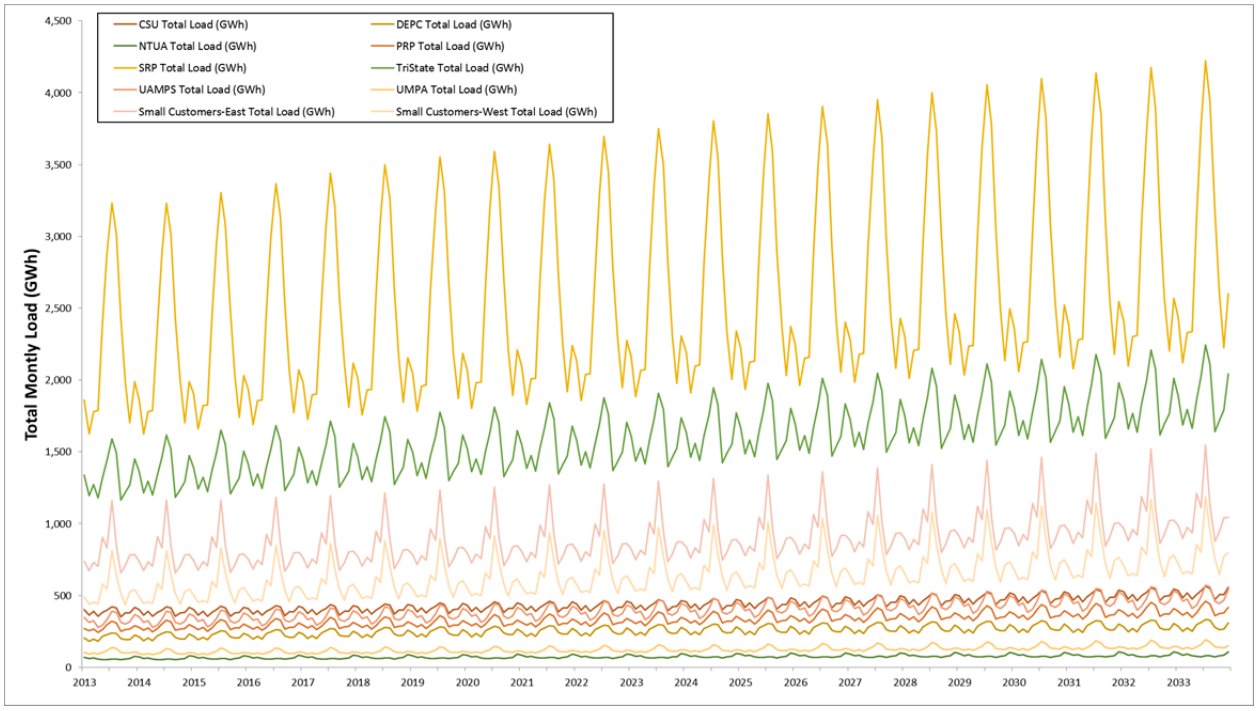


FIGURE 2 Projected Future Monthly Loads by Each Large Customer and Small Customer Groups in the SLCA/IP Market System during the LTEMP Period

Reference

EIA (U.S. Energy Information Administration), 2014, *Assumptions to the Annual Energy Outlook 2014*, Washington D.C., June. Available at http://www.eia.gov/forecasts/aeo/assumptions/pdf/0554(2014).pdf. Accessed March 2, 2015.

ATTACHMENT K.7:

ANALYSIS OF THE TIMING OF THE PEAK LOAD

In the recent past, Western Area Power Administration's (WAPA's) coincidental peak load has occurred in the summer, but it does not consistently occur in a specific month. A study was performed to determine the month in which the peak occurred in recent history.

Hourly load data was obtained for 2006 to 2012 from Federal Energy Regulatory Commission (FERC) Form 714 for WAPA's eight largest customers: Salt River Project (SRP), Tri-State Generation and Transmission Association (Tri-State), Colorado Springs Utilities (CSU), Platte River Power Authority (PRPA), Navajo Tribal Utility Authority (NTUA), Utah Associated Municipal Power Systems (UAMPS), Utah Municipal Power Agency (UMPA), and Deseret Generation and Transmission Cooperative (Desert). These customers account for 75% of WAPA's energy and capacity, so the aggregate load of these customers would determine when WAPA's peak occurs.

Table 1 shows the peak load in each month of the year from 2006 to 2012. Data was not available for NTUA and Deseret from 2010 to 2012, so those utilities were not included in those years. However, Figure 1 shows that NTUA and Deseret only account for 1% and 3% of the peak load from 2006 to 2009, respectively, so not having their data in the last 3 years of the study would not alter the occurrence of the coincidental peak.

The peak load occurs in July in 3 of the 7 years and in August in 4 of the 7 years (as indicated by the shaded areas in Table 1). Therefore, the peak occurs in either July or August

TABLE 1 Aggregate Monthly Peak Load of WAPA's Eight Large Customers for 2006 to 2012[a]

Month	2006	2007	2008	2009	2010	2011	2012
1	7,470	8,089	8,411	7,983	7,426	7,836	7,160
2	6,974	7,619	8,293	7,611	7,434	8,626	6,740
3	6,781	7,204	7,308	6,983	7,091	6,964	6,514
4	6,852	7,878	7,934	7,760	7,029	7,214	7,959
5	9,053	9,116	9,969	9,820	8,328	7,884	9,234
6	10,419	10,624	10,744	10,549	10,625	10,624	11,009
7	11,336	11,670	11,188	11,416	11,049	11,069	10,722
8	10,691	11,639	11,656	11,461	10,495	11,301	11,604
9	9,361	10,403	9,382	10,232	9,884	10,840	9,738
10	8,143	8,374	8,738	7,947	8,956	8,191	8,295
11	7,596	7,377	7,535	7,478	7,788	6,665	6,803
12	7,888	8,102	8,326	8,480	8,247	7,623	7,452
Total	11,336	11,670	11,656	11,461	11,049	11,301	11,604

[a] Missing NTUA and Deseret. Maximum values are shaded.

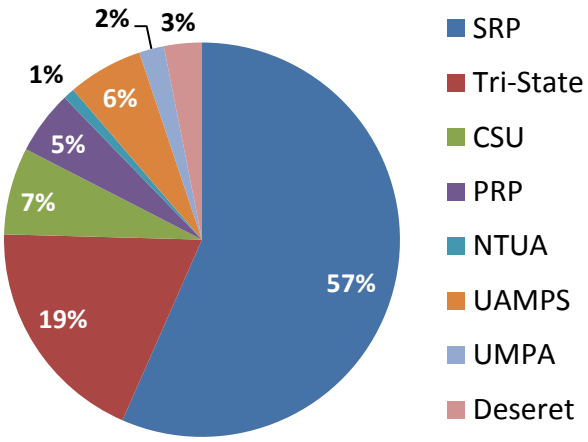


FIGURE 1 Breakdown of Non-coincidental Peak by Customer

with nearly equal frequency. For the LTEMP EIS analysis, August was chosen as the peak month.

Figures 2 through 9 show monthly peak loads for the eight large SLCA/IP LTF power customers. All customers except the NTUA peak in the summer months of either July or August. However, in one year, CSU reported an abnormally high peak load in April.

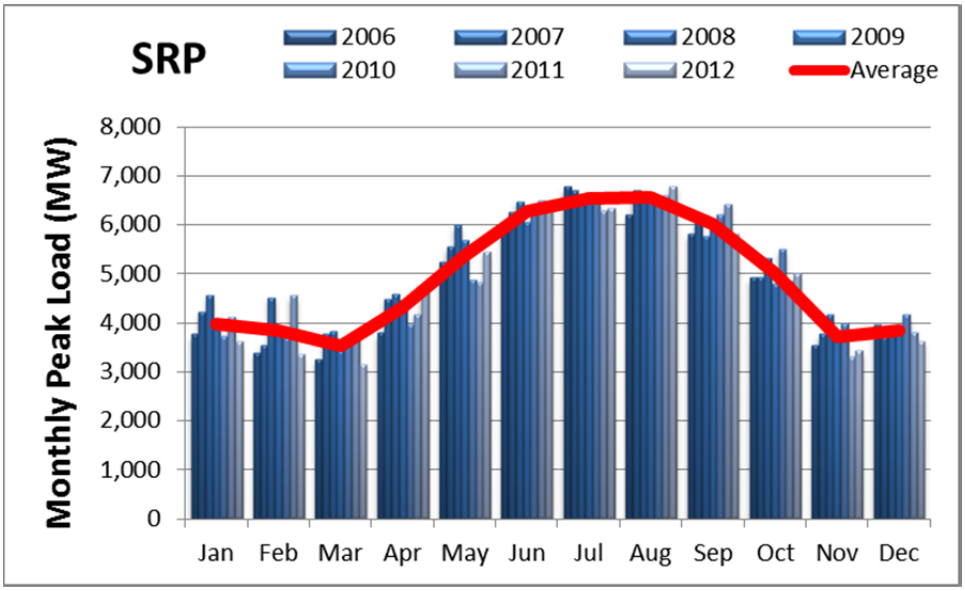


FIGURE 2 SRP Historical Monthly Peak Load

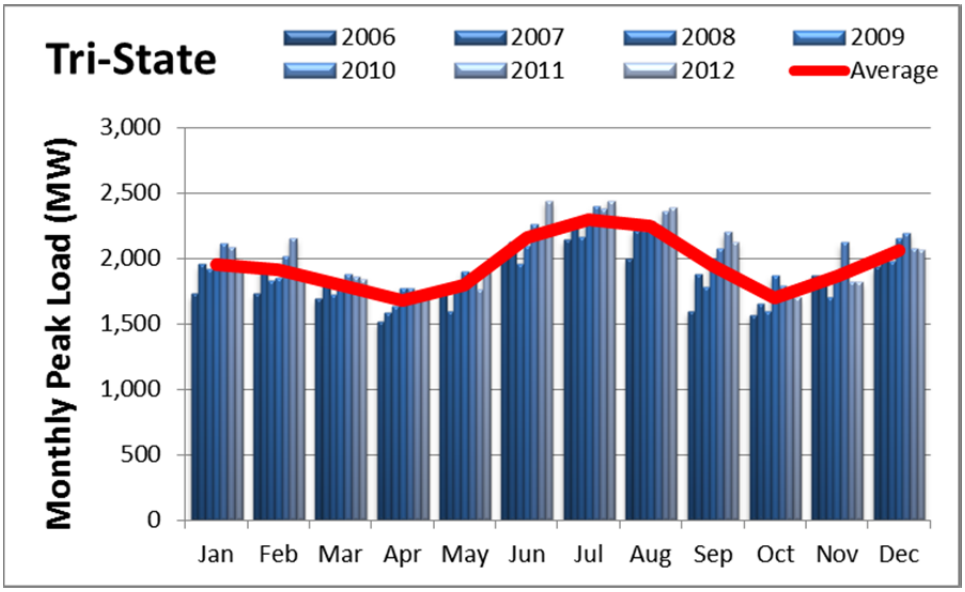


FIGURE 3 Tri-State Historical Monthly Peak Loads

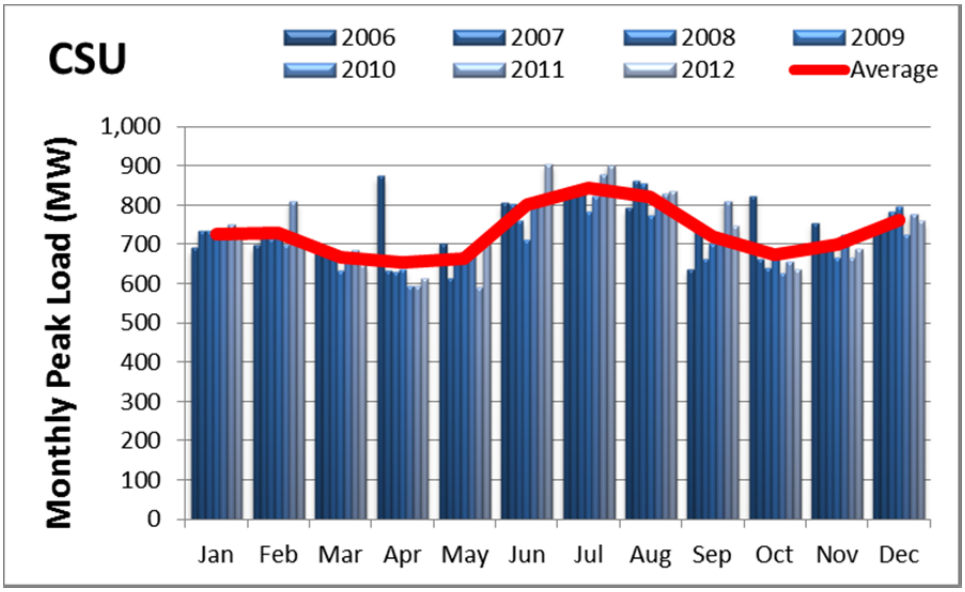


FIGURE 4 CSU Historical Monthly Peak Loads

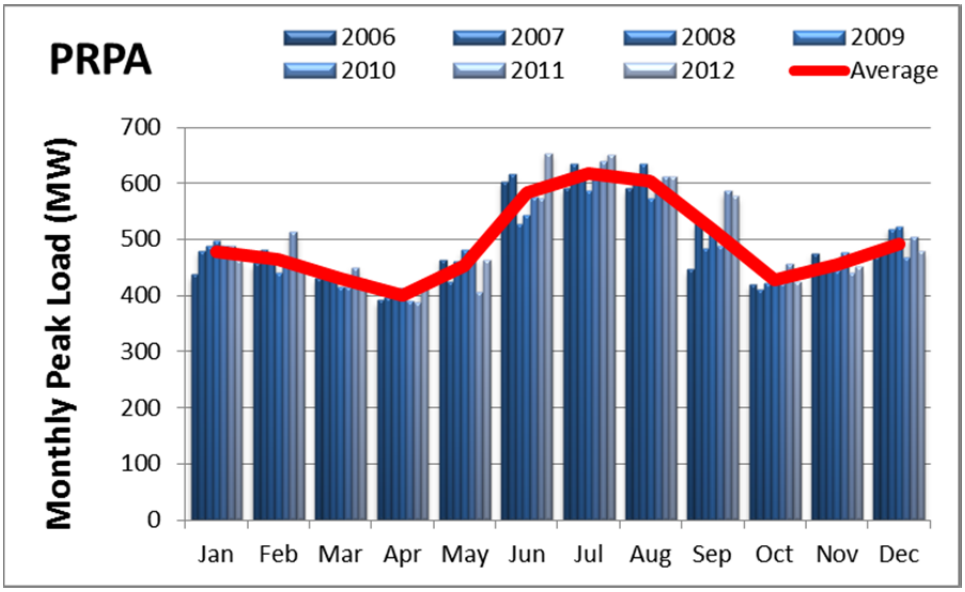


FIGURE 5 PRPA Historical Monthly Peak Loads

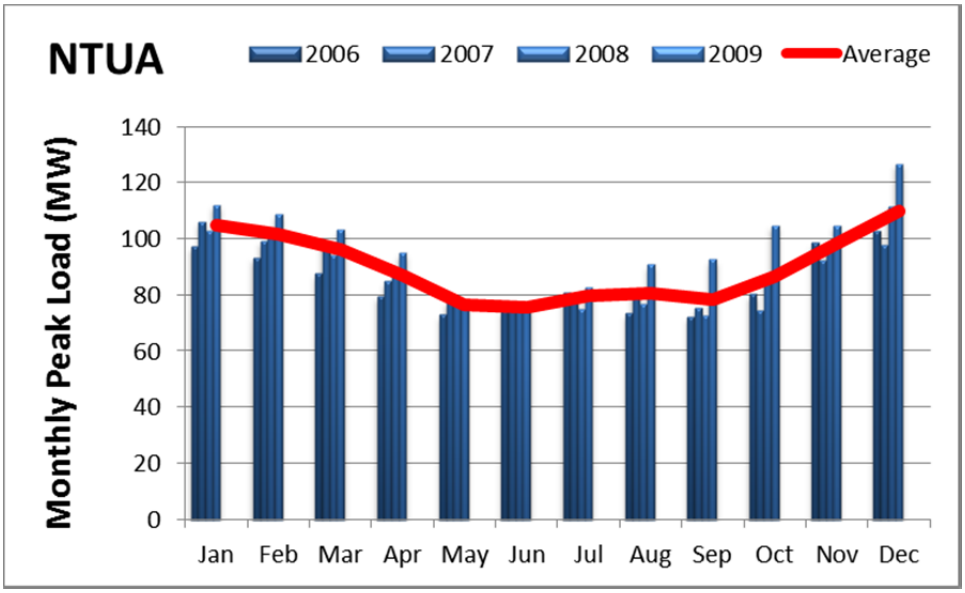


FIGURE 6 NTUA Historical Monthly Peak Loads

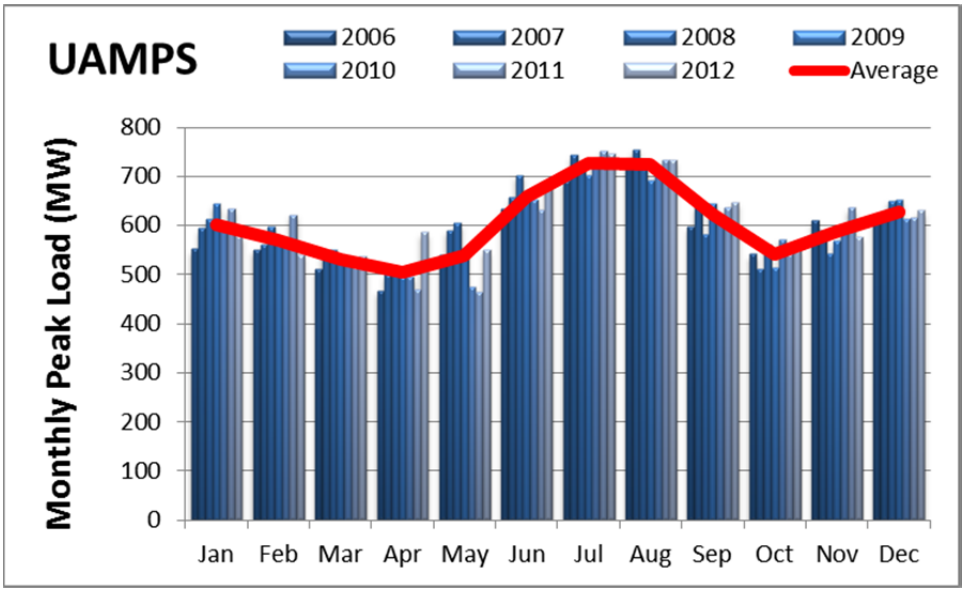


FIGURE 7 UAMPS Historical Monthly Peak Loads

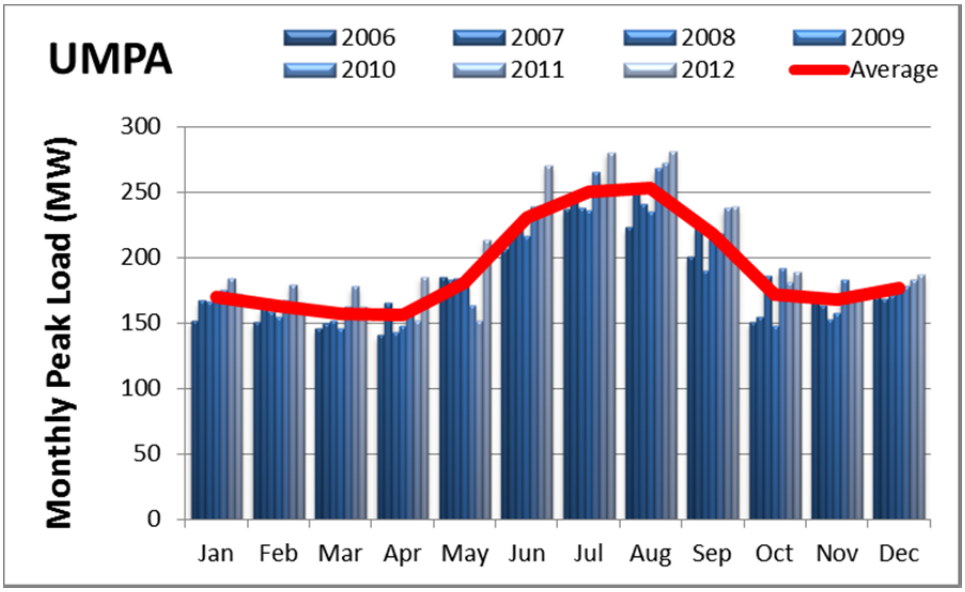


FIGURE 8 UMPA Historical Monthly Peak Loads

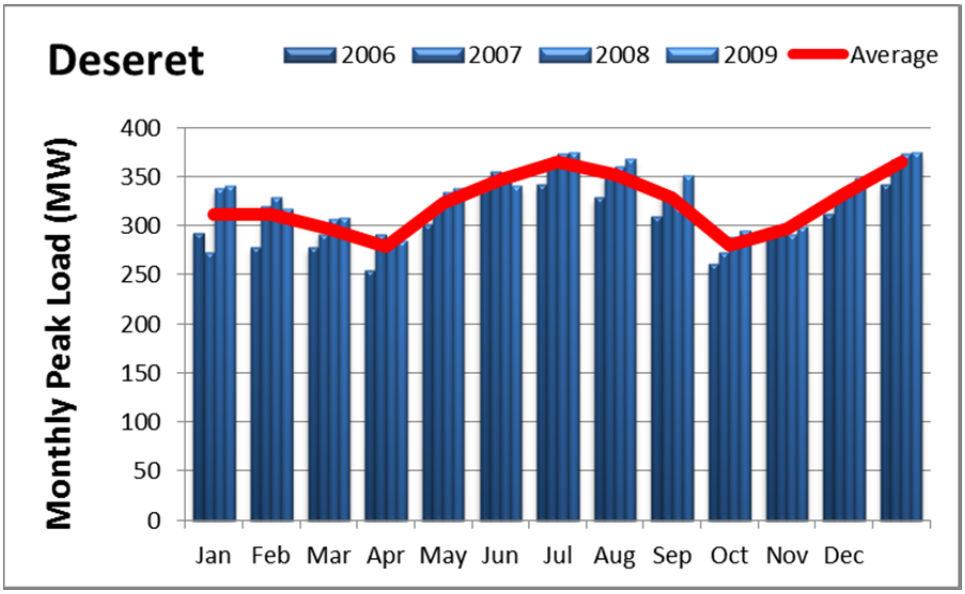


FIGURE 9 Deseret Historical Monthly Peak Loads

ATTACHMENT K.8:

ANALYSIS OF CAPACITY DETERMINATIONS— COMPARING RESULTS USING A RANGE OF EXCEEDENCE LEVELS AND TWO SUMMER PEAK MONTHS

Marketable capacity is very sensitive to the assumed exceedance level and the timing of the annual peak load. This attachment will describe that sensitivity. In the Western Interconnection annual peak loads almost always occur in either July or August; in fact, the study described in Attachment K.7 shows the peak occurs in either July or August with nearly equal frequency.

The graphs on the left side of Figure 1 show the marketable capacity for the six major alternatives and long-term strategies at exceedance levels from 10% to 99% for the three hydropower resource components combined. Marketable capacity was also shown for three different times when the peak load was assumed to occur, namely, July, August, and July/August combined. All alternatives have less marketable capacity at all exceedance levels than the no action alternative, except for Long-Term Strategy B1, which is expected because it has the least restrictive environmental constraints of any alternative.

The graphs on the right of Figure 1 show the difference in marketable capacity compared to Alternative A, which is the the no action alternative. The graphs show that the greatest difference in capacity occurs at the 50% exceedance level and the smallest at the 99% exceedance level.

There is also a noticeable difference in marketable capacity for some alternatives compared to the no action alternative depending upon the month chosen. Long-Term Strategies C1 and E1 have a much smaller difference in marketable capacity compared to Alternative A in July than in August at all exceedance levels.

The choice of the peak month and exceedence level used for Glen Canyon Dam capacity availability is a policy choice by the Western Area Power Administration (WAPA) and is related to the degree of risk WAPA chooses to take when marketing long-term capacity. There have been variations in level of risk chosen by WAPA when marketing long-term capacity from various projects. For the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), an exceedance level of 90% and a peak month of August were selected. The exceedance level was chosen based on an analysis of the current post 2004 WAPA marketing plan that demonstrated that WAPA has sufficient SLCA/IP resources to meet its firm capacity obligations 90% of the time (67 FR 5113). Results were presented in Section K.1.10.4 for exceedance levels of 50% and 99%.

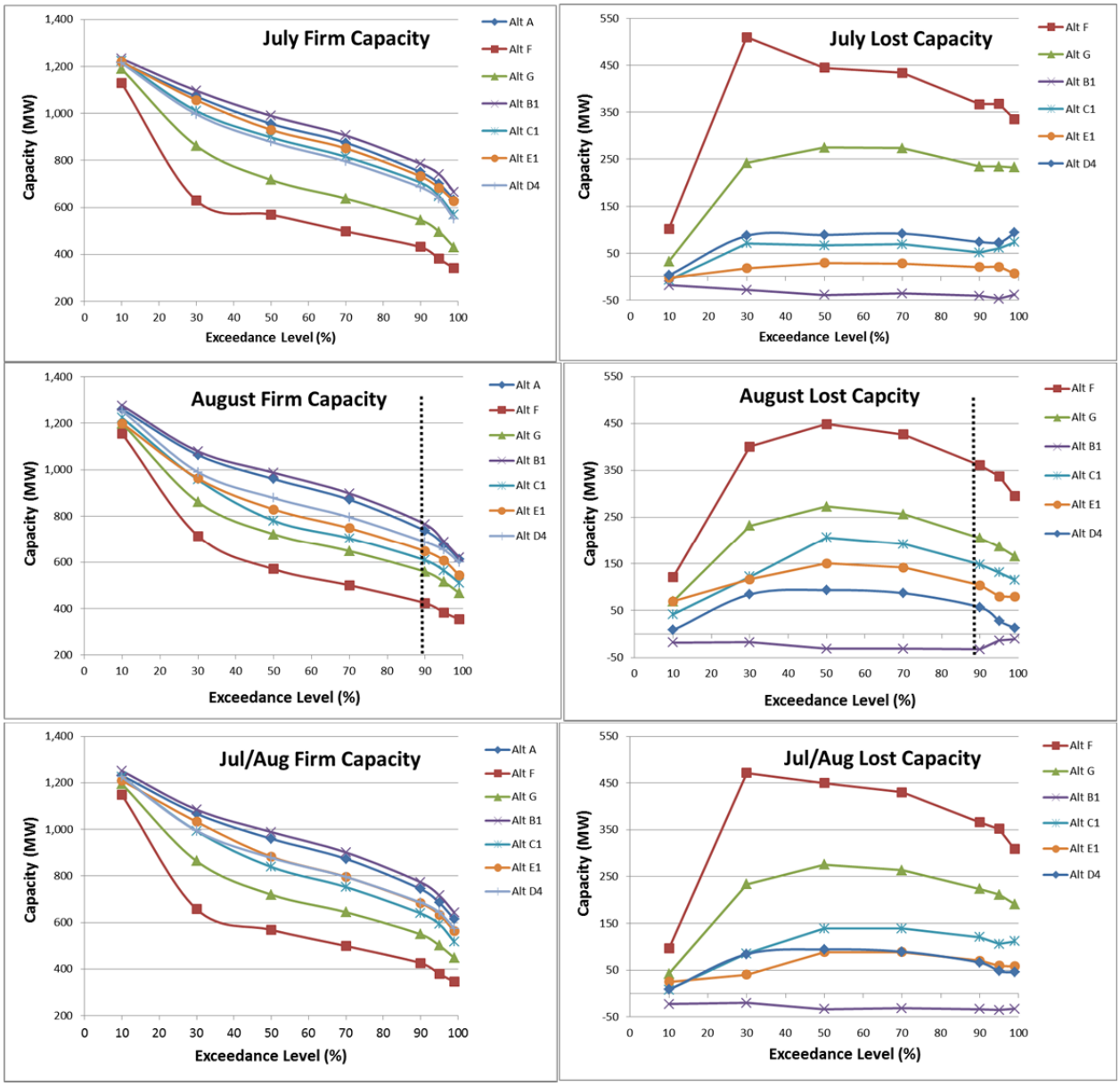


FIGURE 1 Comparison of SLCA/IP Federal Hydropower Firm and Lost Capacity Determinations across Alternatives, Exceedance Levels, and Summer Peak Months

ATTACHMENT K.9:

RESULTS OF A SURVEY OF ELECTRIC UTILITY INTEGRATED RESOURCE PLANS

An integrated resource plan (IRP) is a comprehensive decision support tool and roadmap for meeting an electric utility's objective of providing reliable and least-cost electric service to all of its customers. It is typically developed with considerable involvement from state agencies and regulators, customer and industry advocacy groups, project managers, and other stakeholders. Key elements of an IRP include determining the need for resources over a specific planning period, such as the next 10 to 20 years; the preferred portfolio of supply-side and demand-side resources to meet this need; and an action plan identifying the steps to implement the plan, such as the timing of bringing new resources online.

A survey of IRPs of Western Area Power Administration's (WAPA's) large customers that own generating facilities and large investor-owned utilities (IOUs) in the geographic and "electrical" area was conducted to determine the timing and type of resources these utilities were planning to reliably meet future electric demand. The results of this IRP survey could be compared to the results of the AURORA expansion model to see how well the AURORA prediction matched against the utility's best estimate. WAPA's customers surveyed included Platte River Power Authority (PRP), Colorado Springs Utilities (CSU), Tri-State Generation and Transmission Association (Tri-State), and Salt River Project (SRP).

Large IOUs surveyed included Public Service of Colorado (PSCO; now part of Xcel Energy), Public Service Company of New Mexico (PNM), Rocky Mountain Power (RMP; the eastern business unit of PacifiCorp or PACE), Arizona Public Service Company (AZPS), Tucson Electric Power Company (TEPC), Nevada Power Company (NEVP; the southern subsidiary of NV Energy), and Sierra Pacific Power Company (SPPC; the northern subsidiary of NV Energy). All IRPs were obtained from company websites and were all published between 2011 and 2014. These IOUs were chosen because they have contracts to supply generation to some of WAPA's customers and are also located in the same power pools in the AURORA model as WAPA's customers. Figure 1 shows the approximate service territories of these IOUs in the Western Interconnection.

If the timing and type of new generation predicted by our AURORA expansion model runs are similar to what is planned in the IRPs, then the limited scope in our model is a good surrogate for modeling the larger system.

Figure 2 shows the least-cost baseline expansion plan for PSCO in its most recent IRP, which was published in October 2011. The plan predicts that several combustion turbines will come online between 2018 and 2022 followed by a combined-cycle gas turbine in 2023. Expansion plans from the 2014 PNM IRP shown in Figure 3 forecasts a small 40-MW gas turbine in 2016 followed by a 177-MW gas turbine in 2018. Rocky Mountain Power's expansion plans from its 2013 IRP are shown in Figure 4. A 645-MW combined-cycle unit was just brought

online in 2014 as forecast by the IRP. RMP also plans to bring a combined-cycle combustion turbine and wind turbines online in 2024.

Figure 5 shows a future capacity addition plan from the APS IRP. The capacity it obtains from long-term contracts is steadily decreasing from over 2,800 MW in 2014 to less than 350 MW by 2029. ASP plans to bring over 1,000 MW of natural gas–fired generation online in 2019 followed by 2,000 MW more in 2024 and 1,000 MW in 2029. ASP also plans to rely more heavily on customer energy efficiency beginning in 2019. Additional generation from renewables will begin in 2019.

Figure 6 shows a future capacity addition plan from the TEP IRP. New natural gas generation of over 370 MW is planned for 2015 followed by another 640 MW in 2019. All short-term market resources will be phased out by 2019.

Figure 7 shows capacity addition plans from the NEVP IRP for four scenarios. To comply with a Nevada law phasing out certain coal-fired generation, a combination of new solar photovoltaic and natural gas-fired generation will be brought online between 2016 and 2021. To satisfy future demand, additional combined-cycle generation of 597 MW is planned to come online as early as 2020 and another 273 MW of capacity in 2022.

Figure 8 shows capacity addition plans from the SPP IRP for four scenarios. Depending upon the scenario, combustion turbines with a total capacity of from 273 MW to 536 MW are planned as early as 2022 and 2023. By 2025, an addition of over 570 MW of combined-cycle generation is planned followed by over 300 MW of combustion turbine capacity in 2029.

The IRPs of four of WAPA's large customers that own generation were also surveyed; namely, PRP, CSU, Tri-State, and SRP. The PRP IRP states that new peaking capacity may be needed as early as 2020 because that is when its reserve margin is forecast to drop below 15%. The CSU IRP shows capacity expansion plans for a number of future scenarios. Depending on the scenario, new renewables are expected to begin coming online beginning in 2017 to 2023. New combustion turbines of approximately 40 MW will start coming online from 2029 to 2031. The Tri-State IRP also examines numerous future scenarios. Depending on the scenario, new combined-cycle powerplants with a capacity of 588 MW will start coming online as early as 2019 to 2022; new renewable generation in multiples of 50 MW blocks will come online steadily from 2015 to 2029. Finally, SRP expects to bring new natural gas-fired peaking generation online between 2020 and 2022.

In conclusion, the survey of new capacity additions shown in IRPs for both WAPA's customers and large IOUs show that new capacity, both thermal and renewable generation, is scheduled to be brought online as early as 2017 to 2018. This means that there is very little excess capacity in the power pools in which WAPA's customers are located. Therefore, any capacity lost at Glen Canyon due to changes in operations from the Long-Term Experimental and Management Plan alternatives might cause new generation to be brought online earlier than the current IRPs indicate.

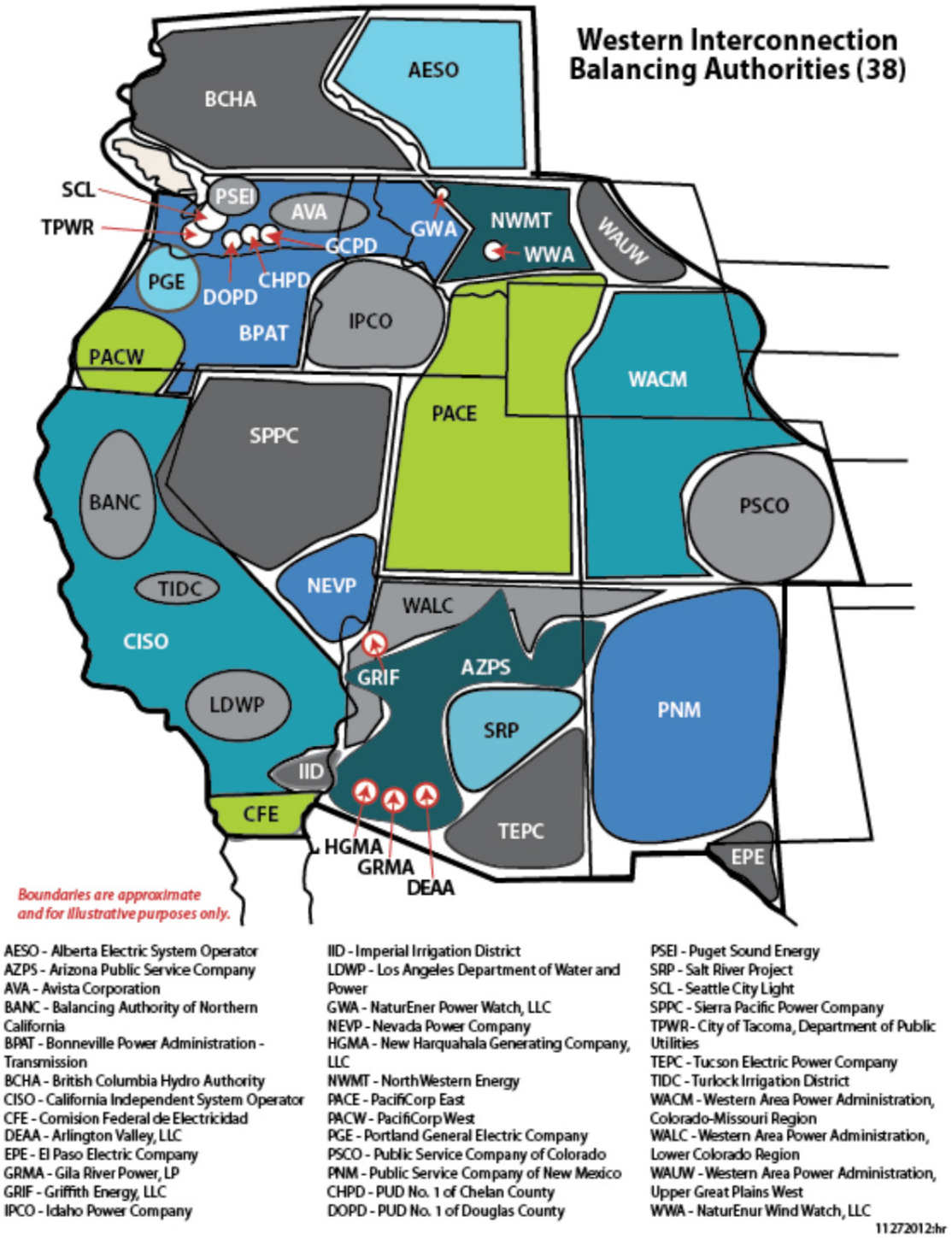


FIGURE 1 Balancing Authorities in the Western Interconnection (Source: WECC website: https://www.wecc.biz/Reliability/VGS_BalancingAuthorityCooperation Concepts_Intra-HourScheduling.pdf)

Year	Baseload[1]	2x1[1] Combined Cycle	1x1[1] Combined Cycle	Combustion Turbine[1]	Battery	Wind[2]	Solar PV[2]	Solar Thermal[2]
2011								
2012								
2013								
2014								
2015								
2016								
2017								
2018				346 MW				
2019				173 MW				
2020				173 MW				
2021				173 MW				
2022				346 MW				
2023		643 MW						
2024								
2025								
2026								
2027		643 MW						
2028								
2029				173 MW				
2030						200 MW		
2031				173 MW			100 MW	
2032		643 MW						
2033								
2034		643 MW						
2035								
2036		643 MW						
2037								
2038								
2039								
2040								
2041								
2042	485 MW	643 MW						
2043						200 MW	25 MW	
2044						200 MW	25 MW	
2045						100 MW		
2046						200 MW	25 MW	
2047						100 MW		
2048						100 MW		
2049				346 MW				
2050								

(1) Listed as summer accredited capacity rating
(2) Listed as nameplate capacity

Source: http://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/PSCo-ERP-2011/Exhibit-No-KJH-1-Volume-2.pdf

FIGURE 2 Least-Cost Baseline Expansion Plan from PSCO's Current IRP

Scenario Description	Revised SIP with PV3 78 MW Scenario	Revised SIP with PV3 132 MW Scenario
Load Forecast	Current	Current
Gas Pricing	PACE Reference Cas e	PACE Reference Case
CO2	PACE Reference Case ($11 in 2020)	PACE Reference Cas e ($11 in 2020)
San Juan Investment Recovery	$16,401,523	$16,401,523
SJ Retirements/Unit 4 Addition	Units 2 & 3 (Dec 2017) + 78 MW to SJ4	Units 2 & 3 (Dec 2017) + 132 MW to SJ4
2014		
2015	Red Mes a (102 MW)	Red Mesa (102 MW)
	2015 Solar (23 MW)	2015 Solar (23 MW)
2016	Aeroderivative (40 MW)	Aeroderivative (40 MW)
	Solar PV Tier 1 (40 MW)	Solar PV Tier 1 (40 MW)
2017	San Juan BART	San Juan BART
2018	Large GT (177 MW)	Large GT (177 MW)
	Palo Verde 3 (134 MW)	Palo Verde 3 (134 MW)
2019	Solar PV Tier 2 (60 MW)	
2020	Solar PV Tier 2 (20 MW)	Solar PV Tier 2 (20 MW)
	Solar PV Tier 3 (20 MW)	
2021	Solar PV Tier 3 (60 MW)	Solar PV Tier 2 (60 MW)
2022	Solar PV Tier 3 (60 MW)	Solar PV Tier 3 (40 MW)
2023	Large GT (177 MW)	Solar PV Tier 3 (60 MW)
		Wind (100 MW)
2024		Large GT (177 MW)
2025		
2026	Large GT (177 MW)	
	Wind (100 MW)	
2027		2nd Aeroderivative (40 MW)
2028		Large GT (177 MW)
2029		
2030	Reciprocating Engines (93 MW)	
2031	2nd Aeroderivative (40 MW)	Aeroderivative (40 MW)
		Solar PV Tier 3 (40 MW)
2032	Aeroderivative (40 MW)	Reciprocating Engines (93 MW)
2033	Small GT (85 MW)	

Source: https://www.pnm.com/documents/396023/396193/PNM+2014+IRP/bdccdd52-b0bc-480b-b1d6-cf76c408fdfc

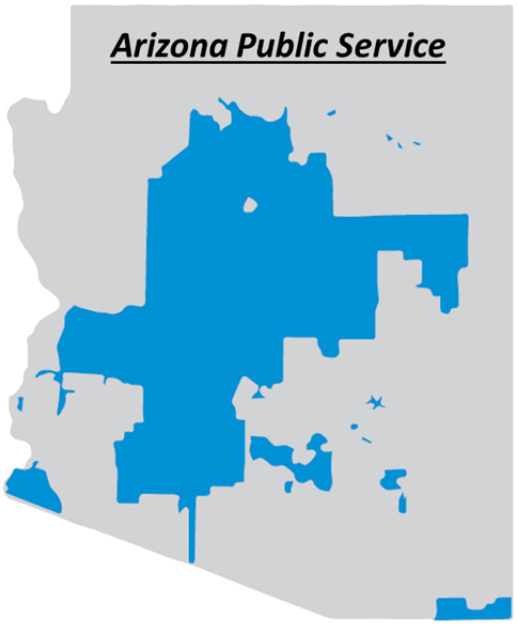
FIGURE 3 Expansion Plan for PNM in Current IRP

	Preferred Portfolio (EG-2 Case-07a)	Capacity(MW)												
		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Exi	**Existing Plant Retirements/Conversions**													
	Hayden1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Hayden2	-	-	-	-	-	-	-	-	-	-	-	-	-
	Carbon1 (Early Retirement/Conversion)	-	-	(67)	-	-	-	-	-	-	-	-	-	-
	Carbon2 (Early Retirement/Conversion)	-	-	(105)	-	-	-	-	-	-	-	-	-	-
	Johnston1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Johnston2	-	-	-	-	-	-	-	-	-	-	-	-	-
	Johnston3	-	-	-	-	-	-	-	-	-	-	-	-	-
	Johnston4	-	-	-	-	-	-	-	-	-	-	-	-	-
	Naughton1	-	-	-	-	-	-	-	-	-	-	-	-	-
	Naughton2	-	-	-	-	-	-	-	-	-	-	-	-	-
	Naughton3 (Early Retirement/Conversion)	-	-	(330)	-	-	-	-	-	-	-	-	-	-
	Coal Ret_WY - Gas RePower	-	-	338	-	-	-	-	-	-	-	-	-	-
	Expansion Resources													
	CCCTFD 2x1	-	-	-	-	-	-	-	-	-	-	-	-	-
	CCCTJ 1x1	-	-	-	-	-	-	-	-	-	-	-	423	-
	Lake Side II	-	645	-	-	-	-	-	-	-	-	-	-	-
	SCCT Frame UT	-	-	-	-	-	-	-	-	-	-	-	-	-
	SCCT Frame ID	-	-	-	-	-	-	-	-	-	-	-	-	-
	Coal Plant Turbine Upgrades	1.8	-	-	-	-	-	-	-	-	-	-	-	-
	Wind, Wyoming, 40	-	-	-	-	-	-	-	-	-	-	-	432	218
	Total Wind	-	-	-	-	-	-	-	-	-	-	-	432	218
	CHP - Biomass	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	CHP - Other	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	DSM, Class 1, ID-Curtail	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1, ID-Irrigate	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1, UT-Curtail	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1, UT-Irrigate	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1, WY-Curtail	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1, WY-Irrigate	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 1 Total	-	-	-	-	-	-	-	-	-	-	-	-	-
	DSM, Class 2, ID	3	3	3	3	3	3	4	3	4	4	3	3	3
	DSM, Class 2, UT	63	61	54	52	50	48	48	43	42	40	30	33	30
	DSM, Class 2, WY	4	4	5	5	6	6	6	6	7	7	6	7	7
	DSM, Class 2 Total	69	67	61	60	59	57	58	52	52	51	39	42	39
	Micro Solar - PV	7.11	11.0	14.2	16.4	17.0	13.1	13.1	13.1	13.1	13.1	13.1	13.1	13.1
	Micro Solar - Water Heating	-	-	-	-	0.8	0.4	0.5	0.6	2.4	2.4	2.4	2.4	2.4
	FOT Mona Q3	-	-	-	-	-	37	151	248	19	161	255	-	132

Source: http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2013IRP/PacifiCorp-2013IRP_Vol1-Main_4-30-13.pdf *(see page 239)*

FIGURE 4 Rocky Mountain Power Expansion Plan from 2013 IRP

2014 IRP (VALUES IN MW AT PEAK)				
	2014	2019	2024	2029
TOTAL PROJECTED LOAD REQUIREMENTS (NEEDS)	8,124	9,543	11,276	12,982
EXISTING RESOURCES AS OF DEC. 31, 2013				
APS-Owned Generation	6,315	6,086	6,063	6,066
Long-Term Contracts	2,872	1,490	389	346
Total Existing Resources as of Dec. 31, 2013	**9,187**	**7,576**	**6,452**	**6,412**
FUTURE* PROJECTED CUSTOMER RESOURCES				
Energy Efficiency	109	877	1,230	1,447
Distributed Energy	45	109	203	261
Demand Response	0	0	150	275
Total Future* Customer Resources	**153**	**986**	**1,584**	**1,983**
FUTURE* PROJECTED GENERATION RESOURCES				
Natural Gas	0	1,010	3,030	4,205
Renewable Energy	0	57	295	425
Total Future* Projected Utility Resources	**0**	**1,067**	**3,325**	**4,630**
Total Future* Projected Resource Additions	**153**	**2,053**	**4,909**	**6,613**
Total Resources	**9,340**	**9,630**	**11,361**	**13,025**



*Future resources added after December 31, 2013 Source: http://www.aps.com/library/resource%20alt/2014_IntegratedResourcePlan.pdf

FIGURE 5 Capacity Expansion Plan for Arizona Public Service Company from 2014 IRP

Future Resources (Nameplate Capacity MW)	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Natural Gas Resources	-	374	374	374	374	1,016	1,018	1,020	1,022	1,114	1,116	1,118	1,210	1,212	1,214
Utility Scale Renewables	208	258	258	258	258	258	258	258	326	326	475	529	529	529	529
Distributed Generation (DG)	71	78	94	110	125	141	157	173	190	210	229	250	254	259	265
Energy Efficiency (EE)	48	80	110	137	164	191	217	229	233	238	244	249	253	259	262
Demand Response (DR)	15	19	24	29	35	40	45	45	45	45	45	45	45	45	50
Total Nameplate Capacity	342	808	859	908	956	1,646	1,695	1,724	1,817	1,933	2,109	2,191	2,291	2,304	2,320
Short-Term Market Resources	400	250	200	200	570	-	-	-	-	-	-	-	-	-	-
Total System Resources	742	1,058	1,059	1,108	1,526	1,646	1,695	1,724	1,817	1,933	2,109	2,191	2,291	2,304	2,320

Source: https://www.tep.com/doc/planning/2014-TEP-IRP.pdf

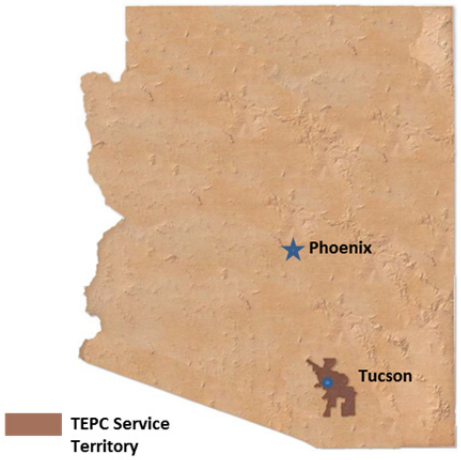


FIGURE 6 Capacity Expansion Plan for Tucson Electric Power Company from 2014 IRP

Nevada Power Company Expansion Plans - Base Load			
Case A	**Case B**	**Case C**	**Case D**
To replace retired coal plants in accordance with Nevada Law (SB 123)			
15 MW PV - 2016	15 MW PV - 2016	496 MW Merchant CC	274 MW Merchant CC
597 MW CC - 2018	568 MW CTs (8) - 2018	15 MW PV - 2016	15 MW PV - 2016
35 MW PV - 2021	35 MW PV - 2021	200 MW PV - 2016	200 MW PV - 2016
		35 MW PV - 2021	500 MW PV - 2018
Future conventional resource additions			
597 MW CC - 2020	597 MW CC - 2020	597 MW CC - 2020	597 MW CC - 2020
273 MW CC - 2022	273 MW CC - 2022	273 MW CC - 2022	273 MW CC - 2022
213 MW CTs (3) - 2023	213 MW CTs (3) - 2023	213 MW CTs (3) - 2023	213 MW CTs (3) - 2023
597 MW CC - 2024	597 MW CC - 2024	597 MW CC - 2024	597 MW CC - 2024
234 MW CTs (3) - 2030	234 MW CTs (3) - 2030	213 MW CTs (3) - 2027	234 MW CTs (3) - 2030
234 MW CTs (3) - 2032	234 MW CTs (3) - 2032	234 MW CTs (3) - 2030	234 MW CTs (3) - 2032
		234 MW CTs (3) - 2032	

Source: https://www.nvenergy.com/company/rates/filings/IRP/NPC_IRP/ERCR_NPC/Vol4-Narratives.pdf

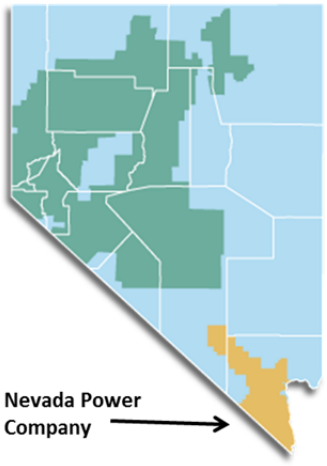


FIGURE 7 Capacity Expansion Plan for Nevada Power Company from 2014 IRP

Sierra Pacific Power Expansion Plans - Base Load			
Case 1 **ALL Market**	**Case 2** **Renewable**	**Case 3 - Alternative Plan** **CT's**	**Case 4 - Preferred Plan** **CC's**
	402 MW CTs (6) - 2022	536 MW CTs (6) - 2022	273 MW CC - 2022
237 MW CTs (3) - 2023			
571 MW CC - 2025	571 MW CC - 2025	571 MW CC - 2025	571 MW CC - 2025
316 MW CTs (4) - 2029	316 MW CTs (4) - 2029	316 MW CTs (4) - 2029	316 MW CTs (4) - 2029

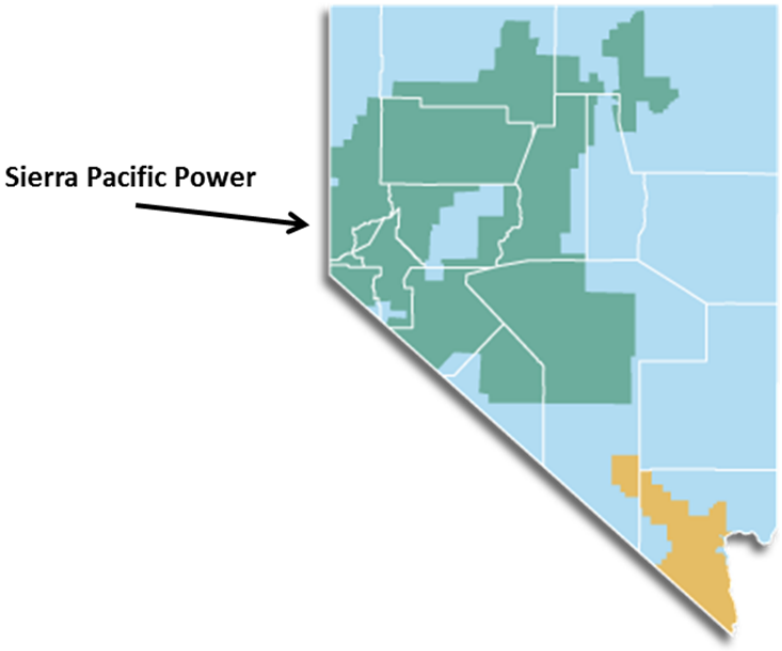


FIGURE 8 Capacity Expansion Plan for Sierra Pacific Power Company from 2014 IRP

ATTACHMENT K.10:

INDICES USED FOR CONVERTING DOLLARS FROM ONE YEAR TO ANOTHER

The Argonne National Laboratory Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) power systems team has data that are expressed in terms of various nominal dollars. However, it is important that model runs and analysis be performed on a consistent dollar year basis. The range of nominal dollars that was used ranges from 2010 dollars to 2013 dollars. In addition, the LTEMP EIS co-lead team has also decided that results presented to the public should be expressed in terms of 2015 dollars. For all power systems analyses, the gross national product (GNP) implicit price deflator (IPD) was used for converting nominal dollars from one year to another. Argonne staff used the Federal Reserve Economic Data (FRED) for the IPD with the series ID of the Gross Domestic Product: Implicit Price Deflator (GDPDEF) found on the St. Louis Federal Reserve Bank (Fed) website (http://research.stlouisfed.org/fred2/data/GDPDEF.txt).

The IPD is a good measure of the rate of price change in the economy as a whole. However, the last data point available from the St. Louis Fed is for October 2014. Therefore, the index was projected through January 2015. Based on a simple trend analysis using a third-order polynomial to fix the GNP price deflator over the January to October 2014 time period, the projected IPD was approximately 107.7 in January 2015 (January 2010 index = 100); that is a decline of about 0.3% from the October 2014 level. Figure 1 and Table 1 below show results of the trend analysis.

As shown in Figure 2, there is a similar, but somewhat more pronounced, decline when a trend analysis was conducted using monthly data for the seasonally adjusted (SA) consumer price index (CPI) for all U.S. cities/all items (series ID: CUSR0000SA0) (see http://download.bls.gov/pub/time.series/cu/cu.data.1.AllItems) and also for producer price index (PPI) data for total final demand (series ID: WPUFD4) from January 2014 through December 2015 (see http://www.bls.gov/news.release/ppi.nr0.htm). Both the CPI and PPI are about 1.0% lower in December 2014 relative to September 2014.

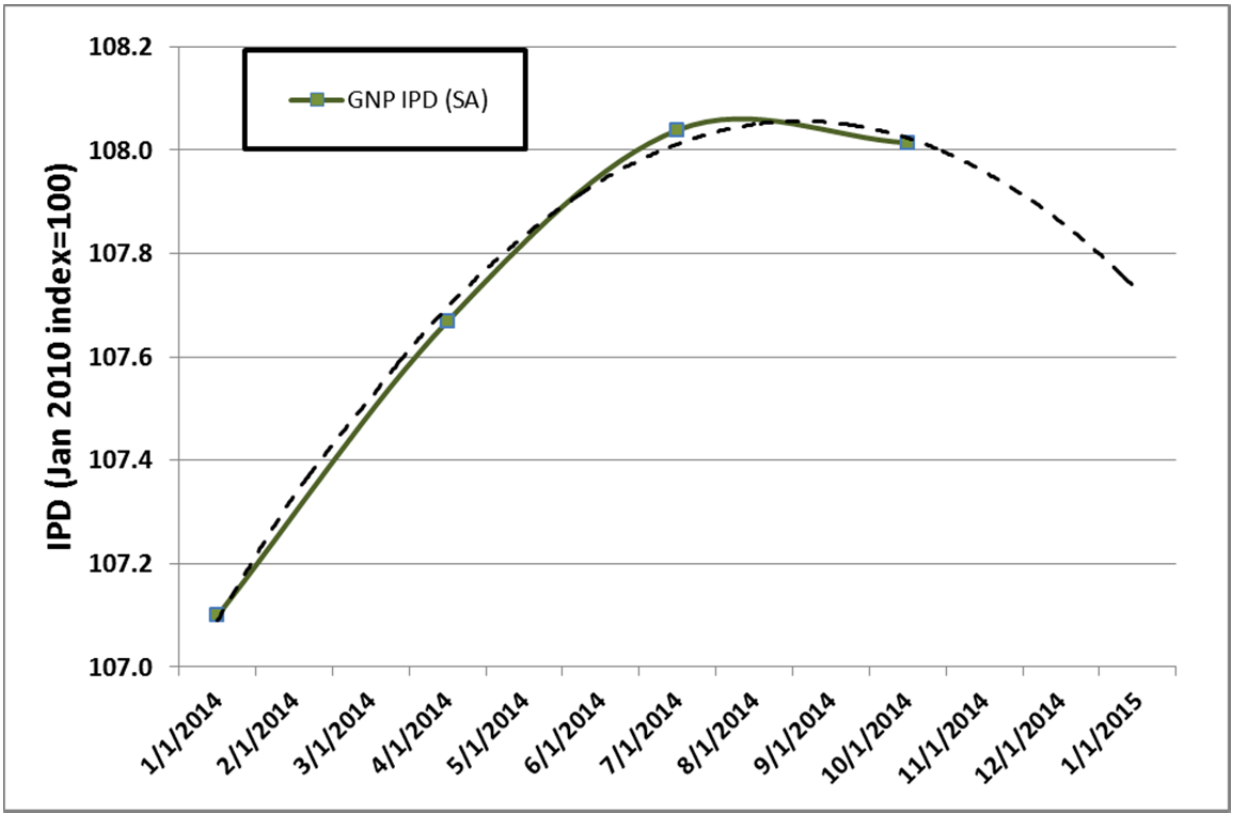


FIGURE 1 Results of Trend Analysis to Project Implicit Price Deflator (IPD) to January 2015 (SA = seasonally adjusted)

A downward trend in future producer prices through January 2015 is also in line with projections made by the Financial Forecast Center, which projects a 1% lower PPI for all commodities in January 2015 compared to December 2014 levels (see http://www.forecasts.org/ppi.htm).

The lower, but not as dramatic decrease in the IPD is further supported by Figure 3 below that shows both the CPI and PPI compared to the IPD. Both roughly follow the same trend in the January 2010 and October 2015 time period. However, the IPD tends to follow a smoother, less jagged track, implying that in general it may be somewhat less responsive to short-term economic drivers.

TABLE 1 Historical Quarterly Implicit Price Deflators and Projection for January 2015

Date	IPD
1/1/2010	100.0
4/1/2010	110.4
7/1/2010	100.9
10/1/2010	101.4
1/1/2011	101.9
4/1/2011	102.6
7/1/2011	103.2
10/1/2011	103.4
1/1/2012	103.9
4/1/2012	104.4
7/1/2012	104.9
10/1/2012	105.3
1/1/2013	105.7
4/1/2013	105.9
7/1/2013	106.4
10/1/2013	106.7
1/1/2014	107.1
4/1/2014	107.7
7/1/2014	108.0
10/1/2014	108.0
1/1/2015	107.7[a]

[a] Projected.

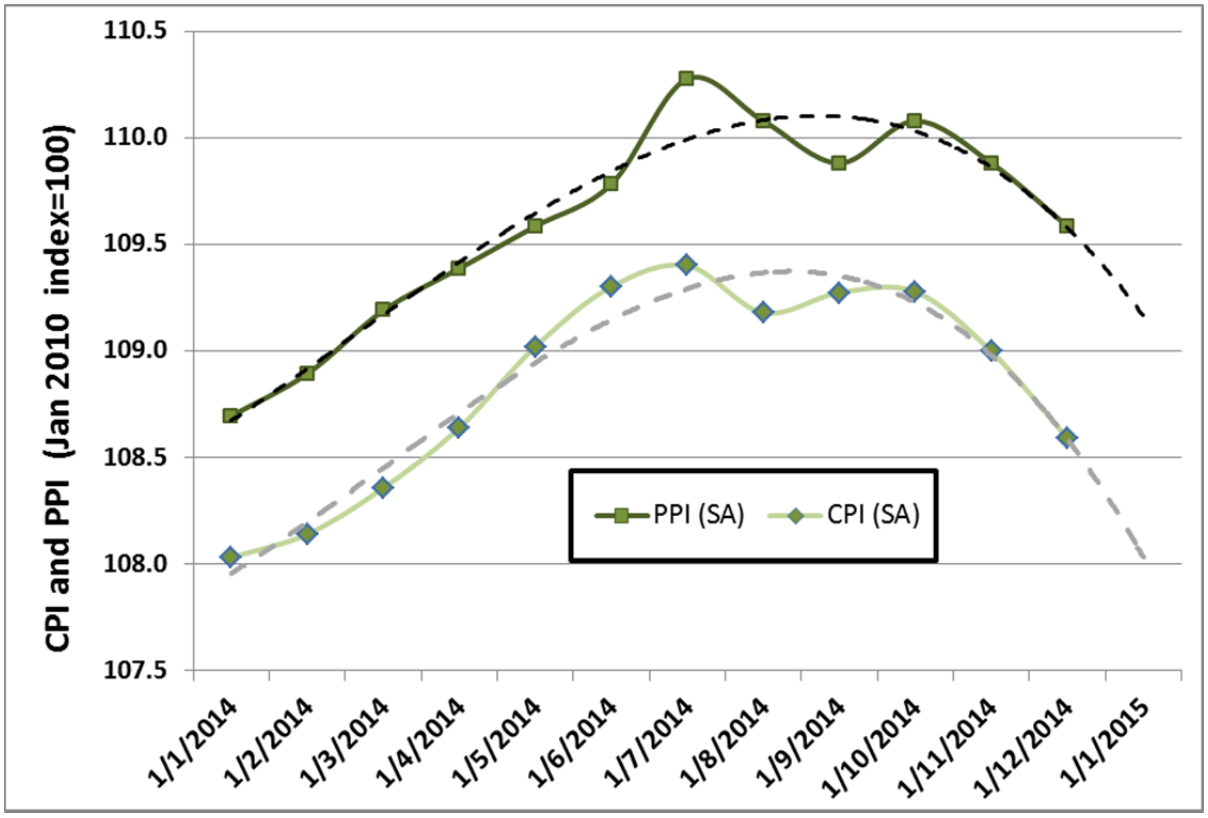


FIGURE 2 Comparison of Trend Analyses Projecting Produce Price Index (PPI) and Consumer Price Index (CPI) to January 2015 (SA = seasonally adjusted)

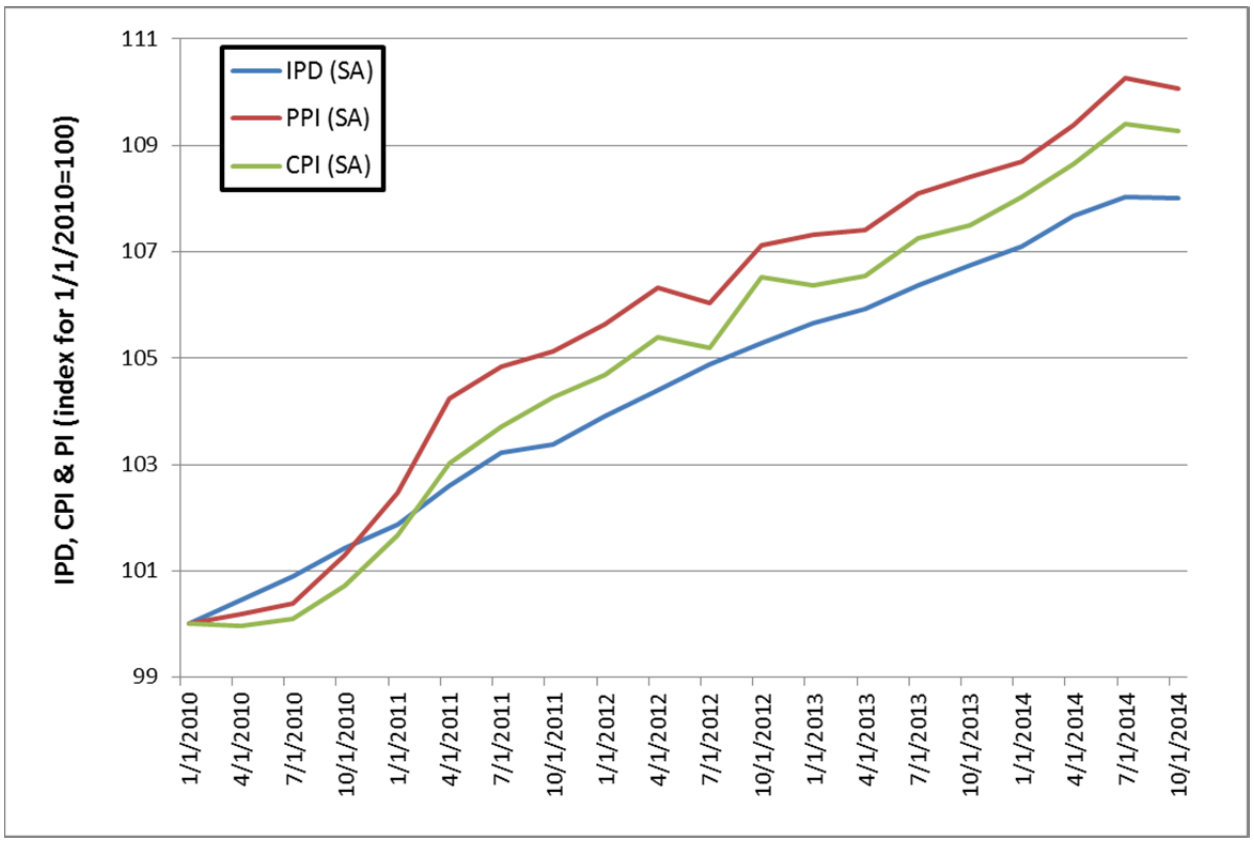


FIGURE 3 Comparison of Historical Trends for Implicit Price Deflator (IPD), Consumer Price Index (CPI), and Producer Price Index (PPI) from January 2010 to January 2014 (SA = seasonally adjusted)

ATTACHMENT K.11:

SUMMARY IRP OF CAPACITY ADDITIONS (MW) IN THE JOINT SYSTEM AND SURROUNDING UTILITY SYSTEMS THROUGH THE END OF CY2034

Utility[a]	CT	Aero-Derivatives CT	NGCC	Natural Gas (Technology Unspecified)	Wind/Solar	Other	Total
PSCO	1,730		1,929		1,500		5,159
PNM(132 MW)	531	120			383	461	1,495
PAC			2,625				2,625
APS				5,229	288		5,517
TEP					270		270
NVE	2,043		2,064		50		4,157
Sierra Pacific	1,264		870				2,134
PRPA					108		108
CSU					250	11	261
TSGT			1,040		700		1,740
SRP					132		132
Total	5,568	120	8,528	5,229	3,681	472	23,598
% without Aero	39.5		60.5				100
% Including Aero	40.0		60.0				100

[a] Utilities in the joint system (WAPA LTF customers) are highlighted in light green.

Data Sources

Public Service of Colorado
https://www.xcelenergy.com/staticfiles/xe/Regulatory/Regulatory%20PDFs/PSCo-ERP-2011/Exhibit-No-KJH-1-Volume-2.pdf

Public Service Company of New Mexico
https://www.pnm.com/documents/396023/396193/PNM+2014+IRP/bdccdd52-b0bc-480b-b1d6-cf76c408fdfc

PacifiCorp
https://www.rockymountainpower.net/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2015%20IRP%20Update/2015%20IRP%20Update_20160426.pdf

Arizona Public Service
https://www.aps.com/library/resource%20alt/APS%20Preliminary%202017%20IRP_Resource%20Planning-15-0094_030116.pdf

Tucson Electric Power
https://www.tep.com/doc/planning/2016-TEP-IRP.pdf

Nevada Energy
https://www.nvenergy.com/company/rates/filings/IRP/NPC_IRP/ERCR_NPC/Vol4-Narratives.pdf

Sierra Pacific
https://www.nvenergy.com/company/rates/filings/IRP/SPPC_IRP/images/Vol.11SPPCIRPupplynarrativeta383pgs.pdf

Platte River Power Authority
http://www.prpa.org/wp-content/uploads/2016/04/2017-Western-IRP.pdf

Colorado Springs Utilities
https://www.csu.org/pages/eirp-b.aspx

Tri-State Generation and Transmission Association, Inc.
http://www.tristategt.org/resourceplanning/documents/2015%20ERP%20Report%20with%20SEC%20FLS%20and%20all%20Appendices.pdf

Salt River Project
http://www.srpnet.com/about/financial/pdfx/ResourceStewardship-2014.pdf

ATTACHMENT K.12:

ANNUAL SLCA/IP ALLOCATIONS TO AMERICAN INDIAN TRIBES AND BENEFIT INFORMATION

Customer Name	Winter Season Capacity (kW)	Winter Season Energy (kWh)	Summer Season Capacity (kW)	Summer Season Energy (kWh)	Supplier Responsible for Benefit Crediting	Utility Serving Tribal Reservation
Ak-Chin Indian Community	1,920	3,520,881	4,244	7,722,879	N/A	Operate own utility
Bureau of Indian Affairs Colorado River Agency	881	1,593,277	442	883,290	N/A	Bureau of Indian Affairs operated utility
San Carlos Irrigation Project	1,840	3,373, 246	1,366	2,486,780	N/A	Bureau of Indian Affairs operated utility contracted with Gila River Indian Community Utility Authority (GRICUA)
Alamo Navajo Chapter	196	373,654	184	329,415	Tri-State	Socorro Electric Cooperative—Member of Tri-State
Canoncito Navajo Chapter	145	276,206	135	241,351	Tri-State	Continental Divide Electric Cooperative—Member of Tri-State
Cocopah Indian Tribe	1,058	2,022,535	1,281	2,289,809	NTUA	Arizona Public Service Company
Colorado River Indian Tribes	3,772	7,207,343	5,978	10,685,860	Page Electric Utility	Arizona Public Service Company
Confederated Tribes of the Goshute Reservation	62	118,806	39	69,992	Deseret/Mt. Wheeler	Deseret/Mt. Wheeler
Duckwater Shoshone Tribe	67	128,586	69	122,947	Deseret/Mt. Wheeler	Deseret/Mt. Wheeler
Ely Shoshone Tribe	129	246,599	78	138,741	Deseret/Mt. Wheeler	Deseret/Mt. Wheeler
Fort Mojave Indian Tribe	272	520,611	282	504,931	N/A	Operate own utility
Ft. McDowell Mojave-Apache Indian Community	2,270	4,336,951	2,346	4,192,957	SRP	Salt River Project
Gila River Indian Community	13,330	25,473,606	13,920	24,883,872	N/A	Operate own utility
Havasupai Tribe	237	452,237	199	356,282	NTUA	Provided by BIA—Truxton Canon Agency, but power is from Mohave Electric, Member of AEPCO, which has a SLCA/IP allocation—see APPA Contract No. 87-BCA-10001

Customer Name	Winter Season Capacity (kW)	Winter Season Energy (kWh)	Summer Season Capacity (kW)	Summer Season Energy (kWh)	Supplier Responsible for Benefit Crediting	Utility Serving Tribal Reservation
Hopi Tribe	2,810	5,369,665	2,716	4,854,810	NTUA	NTUA and Arizona Public Service Company (depends where on reservation)
Hualapai Tribe	609	1,163,130	625	1,118,127	NTUA	Mojave Electric Cooperative
Jicarilla Apache Tribe	735	1,403,805	580	1,036,264	N/A	Operate own utility/buy wholesale from PNM for supplemental
Las Vegas Paiute Tribe	523	999,427	721	1,288,008	NTUA	NV Energy
Mescalero Apache Tribe	990	1,890,996	976	1,743,837	Tri-State	Otero County Electric Cooperative—Member of Tri-State
Nambe Pueblo	65	124,829	59	104,627	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Navajo Agricultural Products Industries	500	2,212,425	22,900	48,833,990	N/A	All Requirements Met by WAPA
Navajo Tribal Utility Authority	48,052	97,612,554	42,614	84,194,098	N/A	Operate own utility. Tucson Electric Power provides other wholesale power resources
Paiute Indian Tribe of Utah	154	294,452	158	282,873	NTUA	PacifiCorp, City of St. George, and Flowell Electric (Tribe fragmented geographically)
Pascua Yaqui Tribe	1,032	1,972,271	1,320	2,360,127	NTUA	TriCo Electric Cooperative—Member of AEPCO, which has a SLCA/IP allocation—see APPA Contract No. 87-BCA-10001
Picuris Pueblo	22	42,183	76	135,363	Tri-State	Kit Carson Electric Cooperative—Member of Tri-State
Pueblo De Cochiti	224	428,910	185	330,732	PNM-non-WAPA customer	Public Service Company of New Mexico

Customer Name	Winter Season Capacity (kW)	Winter Season Energy (kWh)	Summer Season Capacity (kW)	Summer Season Energy (kWh)	Supplier Responsible for Benefit Crediting	Utility Serving Tribal Reservation
Pueblo of Acoma	410	783,229	420	750,759	Tri-State	Continental Divide Electric Cooperative—Member of Tri-State
Pueblo of Isleta	1,109	2,119,606	1,098	1,962,172	NTUA	Public Service Company of New Mexico
Pueblo of Jemez	265	505,513	214	382,418	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of Laguna	753	1,438,435	742	1,326,495	Tri-State	Continental Divide Electric Cooperative—Member of Tri-State
Pueblo of Pojoaque	271	517,903	208	371,891	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of San Felipe	422	805,473	328	586,285	PNM-non-WAPA customer	Public Service Company of New Mexico
Pueblo of San Ildefonso	64	122,213	63	112,702	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of San Juan	303	579,114	298	533,433	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of Sandia	817	1,561,033	943	1,684,993	PNM-non-WAPA customer	Public Service Company of New Mexico
Pueblo of Santa Clara	264	505,350	214	382,268	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of Santo Domingo	438	837,643	452	807,426	PNM-non-WAPA customer	Public Service Company of New Mexico
Pueblo of Taos	340	649,082	221	395,819	Tri-State	Kit Carson Electric Cooperative—Member of Tri-State

Customer Name	Winter Season Capacity (kW)	Winter Season Energy (kWh)	Summer Season Capacity (kW)	Summer Season Energy (kWh)	Supplier Responsible for Benefit Crediting	Utility Serving Tribal Reservation
Pueblo of Tesuque	598	1,143,446	628	1,121,780	PNM-non-WAPA customer	Public Service Company of New Mexico
Pueblo of Zia	85	161,712	68	122,326	Tri-State	Jemez Mountains Electric Cooperative—Member of Tri-State
Pueblo of Zuni	1,185	2,264,600	1,020	1,822,622	Tri-State	Continental Divide Electric Cooperative—Member of Tri-State
Quechan Indian Tribe	729	1,393,402	505	902,692	N/A	Arizona Public Service Company
Ramah Navajo Chapter	412	786,592	300	536,096	Tri-State	Continental Divide Electric Cooperative—Member of Tri-State
Salt River Pima-Maricopa Indian Community	13,380	25,569,197	16,144	28,858,050	SRP	Salt River Project
San Carlos Apache Tribe	3,780	7,222,993	4,152	7,421,915	NTUA	Arizona Public Service Company
Santa Ana Pueblo	410	783,525	460	822,045	PNM-non-WAPA customer	Public Service Company of New Mexico
Skull Valley Band of Goshute Indians	15	28,290	15	27,269	N/A	PacifiCorp
Southern Ute Indian Tribe	1,174	2,243,756	1,122	2,006,482	Tri-State	La Plata Electric Association—Member of Tri-State
Tohono O'Odham Utility Authority	3,044	5,816,784	1,047	1,871,035	N/A	Operate own utility
Tonto Apache Tribe	349	667,470	382	683,459	NTUA	Arizona Public Service Company
Ute Indian Tribe	688	1,315,260	457	816,884	Page Electric Utility	Deseret/Moon Lake Electric
Ute Mountain Ute Tribe	508	970,293	477	852,108	Tri-State	Empire Electric Association—Member of Tri-State

Customer Name	Winter Season Capacity (kW)	Winter Season Energy (kWh)	Summer Season Capacity (kW)	Summer Season Energy (kWh)	Supplier Responsible for Benefit Crediting	Utility Serving Tribal Reservation
White Mountain Apache Tribe	5,999	11,463,994	5,822	10,407,621	Ak-Chin	Arizona Public Service Company
Wind River Reservation	491	938,332	484	865,612	Tri-State	High Plains Power—Member of Tri-State
Yavapai Apache Nation	1,465	2,800,451	1,893	3,383,533	NTUA	Arizona Public Service Company
Yavapai Prescott Indian Tribe	805	1,538,623	733	1,309,825	NTUA	Arizona Public Service Company
Yomba Shoshone Tribe	30	58,232	31	56,131	NTUA	NV Energy

APPENDIX L:

SOCIOECONOMIC TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX L:

SOCIOECONOMIC TECHNICAL INFORMATION AND ANALYSIS

The socioeconomic analysis of changes in Glen Canyon Dam operations conducted for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) included a number of parts:

- Analysis of changes in recreational activity in Lake Mead, Lake Powell, and the Colorado River in terms of recreation use values, non-use (passive use) values, and regional economic impacts; and

- Analysis of the regional economic impacts of changes in retail electricity prices resulting from changes in Western Area Power Administration (Western) wholesale electricity rates, and the analysis of the impacts of the construction and operation of additional Western customer utility generating capacity.

L.1 RECREATION ECONOMIC ANALYSES

L.1.1 Recreation Use Values

Estimation of use values associated with potential changes in recreational resources under each of the alternatives used benefits transfer methods; this involves applying existing use value data or estimates for a particular time period, site, level of resource quality, or combination thereof at an original or study site to a policy site for which data are not available. The benefits transfer method involves choosing study and policy sites with similar socioeconomic and environmental characteristics, similar recreational activities, and similar ranges of change in recreational quality.

Benefits transfer studies involve either the transfer of use values from a study site or the transfer of a statistical model used to estimate use values. The traditional benefits transfer approach to valuing recreation has been to employ existing use values from either travel cost or contingent valuation studies conducted at a study site, adjusting estimates to account for inflation by converting the original values to current dollars using the consumer price index (CPI) or some other price index, and applying them to analysis at the policy site. Given improvements in valuation techniques over time, however, the preferred approach is to employ statistical recreation models developed for a study site at a policy site. Proposed alternative-specific information about variables in the model can be gathered for the policy site. This information is used in conjunction with coefficients from the study site to estimate recreation visitation and/or value at the policy site, allowing the model transfer technique to improve the validity of the results compared to the use value transfer approach.

Benefits transfer methods present a reliable alternative to conducting original research when the analysis is not expected to be controversial, when time and budget constraints prevent the pursuit of original research, or when original research efforts have already been conducted at most of the geographic areas of interest. Because statistical models have been developed for estimating recreation value per trip for two of the three river reaches in the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) study area—Glen Canyon and Upper Grand Canyon—and models estimating recreation use have been developed for Lake Powell and Lake Mead, while other studies have estimated values per trip for recreation use of Lake Powell and Lake Mead, the benefits transfer methods provides a useful and reliable approach to estimating river use values and lake visitation. More information on the background literature, data, and assumptions in applying the benefits transfer method to the analysis undertaken for the EIS can be found in Reclamation (2014).

For the EIS, the net economic value of recreation was estimated for Lake Powell, Lake Mead, and three reaches of the Colorado River—Glen Canyon (from Glen Canyon Dam to Lees Ferry), Upper Grand Canyon (from Lees Ferry to Diamond Creek), and Lower Grand Canyon(from Diamond Creek to Lake Mead)—using two utility programs:

- The Lake_Full program was used to estimate recreation economic value for Lake Powell and Lake Mead.

- The GCRec_Full utility program was used to estimate the economic value for recreation on the Colorado River.

L.1.1.1 Lake_Full Utility Model

The Lake_Full utility model incorporates the recreation-use relationships for Lake Powell and Lake Mead described in Neher et al. (2013). The model operates on a monthly time step and was designed to use all years and all traces of monthly data supplied by the Colorado River Storage Simulation (CRSS) model. The utility uses the end-of-month (EOM) reservoir contents to predict recreation use at the specified reservoir. The user supplies a unit economic value per trip and the utility employs the predicted recreation use in a given month and the unit economic value to calculate the monthly economic value of recreation. This calculation is repeated for each month in the period of analysis and for each hydrologic trace or sequence. The major analytical modeling steps are shown in Figure L-1.

The user also supplies appropriate inflation, escalation, and discount rates for the intended analysis. The Lake_Full utility program employs these economic inputs to compute the present economic value of recreation for each hydrologic trace present in the dataset. The results of these computations are reported for each reservoir as summary metrics computed from the distribution of trace present economic values. Current versions of the utility model output the 5% exceedance, 10% exceedance, 25% exceedance, mean, median (50% exceedance), standard deviation, 75% exceedance, 90% exceedance, and 95% exceedance.

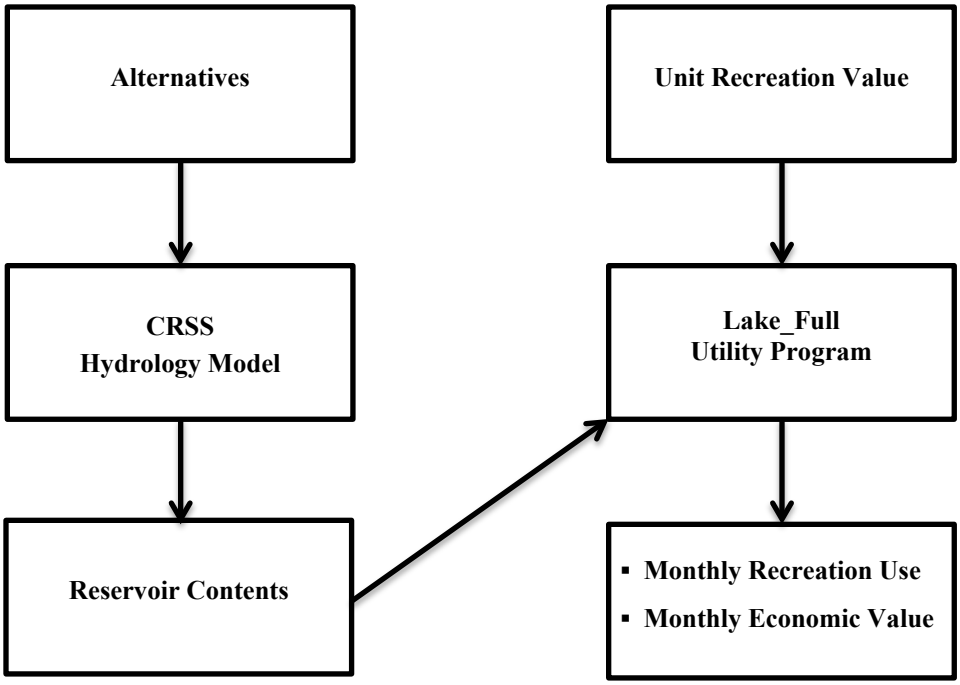

FIGURE L-1 Elements of the Lake_Full Utility Model

L.1.1.2 GCRec_Full Utility Model

The GCRec_Full utility model uses the recreation value relationships for Glen Canyon and Upper Grand Canyon estimated by Bishop et al. (1987). For purposes of this study, these relationships are extended to the Lower Grand Canyon. The model operates on a monthly time step and was designed to use all years and all traces of monthly data supplied by the CRSS model. The utility uses the mean monthly release from Glen Canyon Dam and the presence or absence of daily fluctuations exceeding 10,000 cfs per day during the month to predict the economic value of day-use rafting and angling in Glen Canyon and the economic value of commercial and private whitewater boating in the Upper Grand Canyon. The user also supplies the monthly recreation use, by activity. The utility employs the recreation use in a given month and the estimated economic value per trip to calculate the monthly net economic value of recreation for each activity. These calculations are repeated for each month in the period of analysis and for each hydrologic trace or sequence in the supplied dataset. The major analytical modeling steps are shown in Figure L-2.

The analyst also supplies appropriate inflation, escalation, and discount rates for the intended analysis. The GCRec_Full utility program employs these economic inputs for computing the present economic value of recreation for each hydrologic trace in the dataset. The results of these computations are aggregated and then reported as summary metrics computed from the distribution of trace present economic values. Current versions of the utility model output the 5% exceedance, 10% exceedance, 25% exceedance, mean, median (50% exceedance), standard deviation, 75% exceedance, 90% exceedance, and 95% exceedance levels.

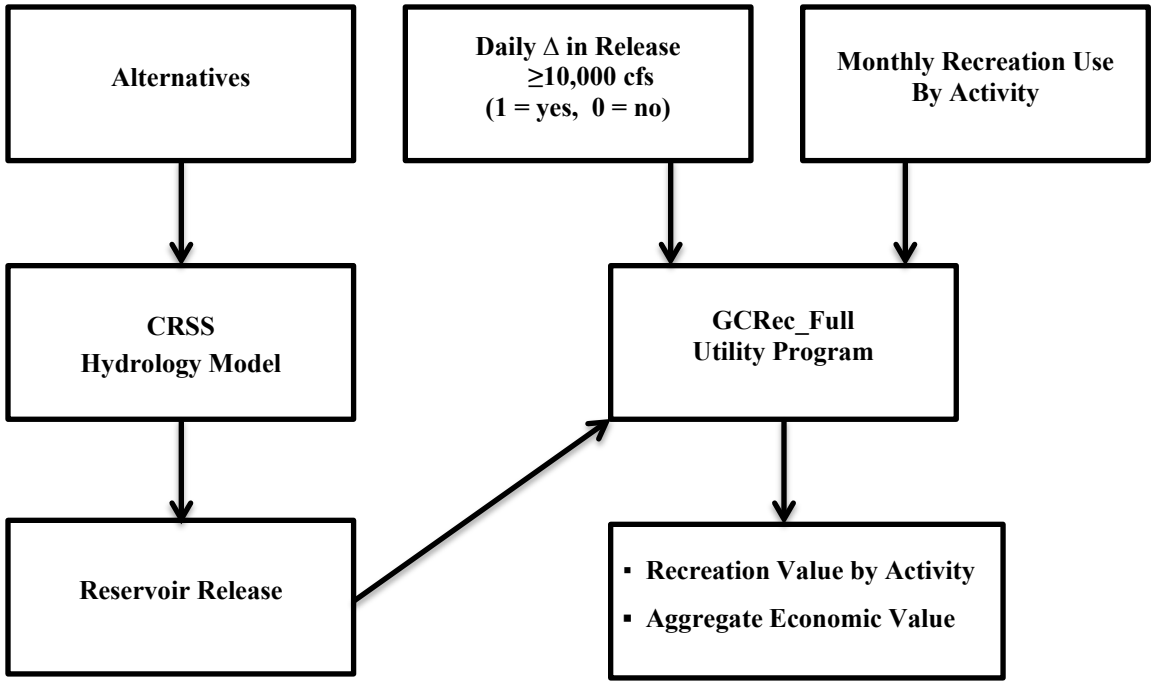

FIGURE L-2 Elements of the GCRec_Full Utility Model

More information on the background literature, data, assumptions, and output for these two models can be found in Reclamation (2014).

L.1.2 Recreation Non-Use Values

Non-use values are values that may be placed on the status of the natural or physical environment by non-users, or individuals who may never visit or otherwise use a natural resource that might still be affected by changes in its status or quality, and may assign a non-use or passive-use economic value to a resource. Although there are two approaches for measuring non-use values—revealed preference and stated preference methods—stated preference methods are typically used.

Stated preference valuation techniques include contingent valuation (CV), which is a means of eliciting the maximum dollar amount an individual would be willing to pay for a resource of a specified quantity and quality. CV methods use surveys to ascertain value by asking people about their willingness to pay (WTP) for a carefully specified change in environmental amenities. The dichotomous choice CV methodology is frequently employed in non-use valuation studies to estimate the net economic value for natural resource amenities. Respondents are presented with a hypothetical situation, including a price that they may be willing to pay for a change in an environmental condition, and they are then asked to respond to a dichotomous choice (yes or no) question. Using the data obtained from these surveys, the probability that an individual will respond "yes" is estimated using logistic regression analysis;

estimated regression coefficients are used to estimate the consumer surplus or net economic value associated with a particular resource.

Stated preference methods also include conjoint analysis, where respondents are presented with the characteristics or attributes of different hypothetical situations, and are then asked to either rank them or choose between them. Using the resultant survey data, the probability that an individual will rank or choose any particular scenario is then estimated, with data used to estimate households' total value for outcome changes associated with each alternative. There is a growing body of work that suggests that CV models and discrete choice methods can yield valid measures of willingness to pay (see, for example, Vossler and Evans [2009], and Vossler et al. [2012]).

Contingent valuation and conjoint methods have been applied widely in policy analysis, in particular in studies relating to measuring non-use values associated with river and lake resources associated with Grand Canyon National Park, Lake Mead National Recreation Area, and Glen Canyon National Recreation Area. Government agencies have also begun to use contingent valuation methods in benefit-cost analyses. The Bureau of Reclamation (Reclamation), for example, used contingent valuation to place a value on the impact of removing dams and restoring river habitat within the Klamath River Basin (RTI International 2012). The non-use values were used in a subsequent benefit-cost analysis (U.S. Department of the Interior 2012).

Contingent valuation surveys have been applied widely in the published economics literature to estimate passive-use values associated with preserving river and lake resources. Sanders et al. (1990), for example, estimated the total value of preserving 15 wild and scenic rivers in Colorado. They reported that Colorado residents expressed a use value of $19.15 and a non-use value of $81.96 per household per year. The total (use and non-use) value of protecting 15 Colorado rivers aggregated over these 12 million households was estimated at approximately $120 million annually, approximately four times the recreation use value. Welsh et al. (1995) estimated the willingness to pay to improve native vegetation, native fishes, game fish, river recreation, and cultural sites in Glen Canyon National Recreation Area and Grand Canyon National Park. Value estimates varied between $17.74 and $26.91 for a U.S. sample, and between $29.05 and $38.02 for a western U.S. sample.

Other studies indicate that the range of values per household or respondent can be large, producing larger ranges in aggregated values. For example, Duffield and Patterson (1991) estimated a willingness to pay $2.24 per licensed angler to maintain fisheries resources, based on a one-time cash donation, while Hanemann et al. (1991) estimated $181 per California household per year. Large ranges in value have also been found in lake studies, with values ranging from about $45 per household annually for the preservation value of Flathead Lake in Montana (Sutherland and Walsh 1985) to about $60 per year for an increment of lake elevation at Mono Lake, California (Loomis 1989). In a 2010 survey, the annual value (in 2011 dollars) of Klamath River Basin restoration after the removal of dams, water sharing agreements, and improved fish habitat was estimated at $122 for households in a 12-county area, $213 by households in the rest of Oregon and California, and $213 in the rest of the United States (RTI International 2012).

Understanding nonmarket values affected by proposed operational changes at Glen Canyon Dam (GCD), for both recreational use and environmental non-use values, has been the topic of a considerable number of prior investigations (e.g., Bishop et al. 1987; Welsh et al. 1995). These studies have been important in bringing nonmarket values into consideration for managing the resources of the Colorado River Basin (Harpman et al. 1995; Loomis et al. 2005). In that regard, two additional studies (Loomis 2014 and Jones et al. 2016) have been conducted regarding nonmarket values.

Loomis (2014) concluded that there is a theoretical basis for nonmarket values associated with hydropower and water. He used the example of how people can place value on maintaining the ranching and farming way of life associated with western rural communities as irrigated agriculture landscapes are correlated with open space. In addition, people may place value on the existence and well-being of farming communities. Indirect empirical support for altruism toward farmers is cited in this report. Nonmarket values associated with hydropower and water resources may also exist to the extent that hydropower and developed water assist in the maintenance of Native American Tribe cultural values and social well-being. Loomis (2014) concluded that research on this subject is limited and that additional research may be warranted.

The National Research Council (2005) has concluded that the results of studies using contingent valuation methods are of high quality; however, the results and findings of studies relating to the Colorado River Corridor are considerably outdated. Others have emphasized the need for additional or updated research on the sources and magnitudes of values associated with operational goals (see National Research Council 1999). To address these concerns, the National Park Service (NPS) has conducted a survey to determine non-use values associated withthe impacts of each of the six action alternatives on the endangered humpback chub, sandbars in the Grand Canyon, and populations of large trout in Glen Canyon. The survey used a discrete choice model to estimate household and aggregate willingness to pay for the six action alternatives based on data collected from two household samples, a national sample including all U.S. households, and a regional sample, consisting of all households receiving power from Western Area Power Administration, and including all utilities receiving power from the Glen Canyon Dam. The study involved a repeat contact mail-back survey method (Dillman 2007) in three phases.

The first phase was a survey of a subsample (n = 200) of the total sample population to pretest the survey instrument (24% response rate). These responses were used to conduct preliminary analysis on the data to determine whether the levels were adjusted up or down to create greater differences between the LTEMP alternatives. If more than 80% (n = 160) of individuals in the subsample selected the No Action Alternative, then the cost of the alternatives was adjusted downward. The results from this sample inform the choice of attribute levels in the final conjoint version of the survey mailed to the respondents in the second phase of the study. Once the attributes were evaluated and adjusted, the final mail survey was used to collect data. Two survey instruments, both of which use identical sampling methods, were used. All respondents received the same instructions and answered a series of common introductory questions to determine general socio-demographic background, visitation patterns, recreational preferences, values, and other information. Then 75% (n = 4,668) of individuals in the sample received Survey A with a section that included conjoint questions. The remaining 25%

(n = 1,500) received Survey B, which included contingent valuation questions. The local survey received an 18% reponse rate, the national survey, 12%. The final phase included a short nonresponse phone survey that was used to help test for any nonresponse bias. The results are presented in Neher et al. (2016) and include discussion of the survey, data collection, response rates, analysis of the results, and nonresponse corrections.

Respondents to the survey were given two discrete choice valuation questions relating to different impacts on the endangered humpback chub, sandbars, and large trout populations under each alternative. The effects of changes in hydropower operations were also included in the survey to incorparate a trade-off between improved resource conditions and their costs. In addition to the physical canyon attributes, respondents were asked to choose between current management at no cost and a changed outcome management plan that would cost between $12 and $280 per year per household over a 20-year period. The levels of the cost parameter and the management outcome attributes were varied among 12 versions of the survey to provide an efficient sampling design.

To estimate the parameters of the conjoint model, a standard conditional logit (CL) model was utilized, which used maximum-likelihood methods to estimate the attribute parameters. The parameter estimates from the CL model were then used to estimate the average marginal value of each noncost attribute.

A recently published study (Jones et al. 2016) offers an alternative Total Economic Value analysis to that presented by Neher et al. (2016). The Jones et al. analysis relied on the contingent valuation methodology, which is similar to the methodology used by Welsh et al. (1995) but different from the methodology used by Neher et al. The Neher et al. analysis relied on the choice experiment methodology, which incorporates recent methodological advances in nonmarket valuation. However, the Jones et al. analysis is also different from the Neher et al. analysis because it included two additional attributes: (1) impacts to Native American and rural western communities that depend on hydroelectric production, and (2) increases in air pollution by switching to nonrenewable fossil fuels in the power generation system. The Jones et al. study concludes that including these additional attributes will "significantly decrease WTP for changing Glen Canyon Dam operations, and demonstrate a significant fraction of the population with a positive WTP for maintaining dam operations."

The Jones et al. (2016) study was a pilot study that relied on an internet panel rather than a randomized mail survey; the Tribe and rural western community attributes did not identify specific causal relationships or quantified values to ensure consistent respondent interpretation, and potential air quality impacts associated with increased fossil fuel use may be overstated for the range of alternatives analyzed for LTEMP (see Sections 4.15 and 4.16). While this study created a new framework that provided a different way to evaluate some of the attributes that would not have been analyzed otherwise, the issues discussed above limit the application of this study to the LTEMP EIS.

L.1.3 Regional Recreation Economic Impacts

Economic impacts of changes in recreational activity are measured by changes in visitor expenditures associated with various types of recreational activities, including angling, rafting, and boating. Visitor expenditures in the river corridor may include spending on food and beverages, fishing and boating equipment, gasoline for vehicles and boats, camping fees or motel expenses, guide services, and fishing license fees. Economic impacts also include the secondary effects of changes in expenditures that may occur on income, employment, and tax revenues. The major analytical modeling steps are shown in Figure L-3.

Analysis of these effects was undertaken in the six-county region in which the majority of current Glen Canyon, Grand Canyon, and Colorado River recreational expenditures occur:

- Coconino County and Mohave County, Arizona; and
- Garfield County, Kane County, San Juan County, and Washington County, Utah.

The following data were used in the analysis:

- Changes in visitation rates, by alternative and river reach, from the analysis of changes in activity resulting from changes in lake and river water levels for a range of river and lake segments using the Net Economic Valuation (NEV) model (see Section L.1), and
- Typical per-capita expenditure data by type of activity, based on studies of typical visitor spending patterns reported in existing technical and academic literature.

Data from these sources are combined to produce changes in expenditure by activity type, by year, and by alternative.

Two types of effects result from changes in recreational expenditures: (1) direct effects are employment and income effects in sectors of the economy in which recreational expenditures occur, while (2) indirect effects are employment and income effects in sectors providing materials, equipment, and services to sectors in which recreational expenditures occur. Indirect effects occur when suppliers to local businesses increase or decrease their purchases of equipment, materials, and services from other businesses, and those businesses in turn change their level of purchases. For food and beverages, for example, indirect effects occur when local food manufacturers purchase additional produce from local farmers, and the farmers then purchase additional supplies in order to grow products necessary to meet this demand. Additional, induced effects result from wages paid to households by both directly and indirectly affected businesses.

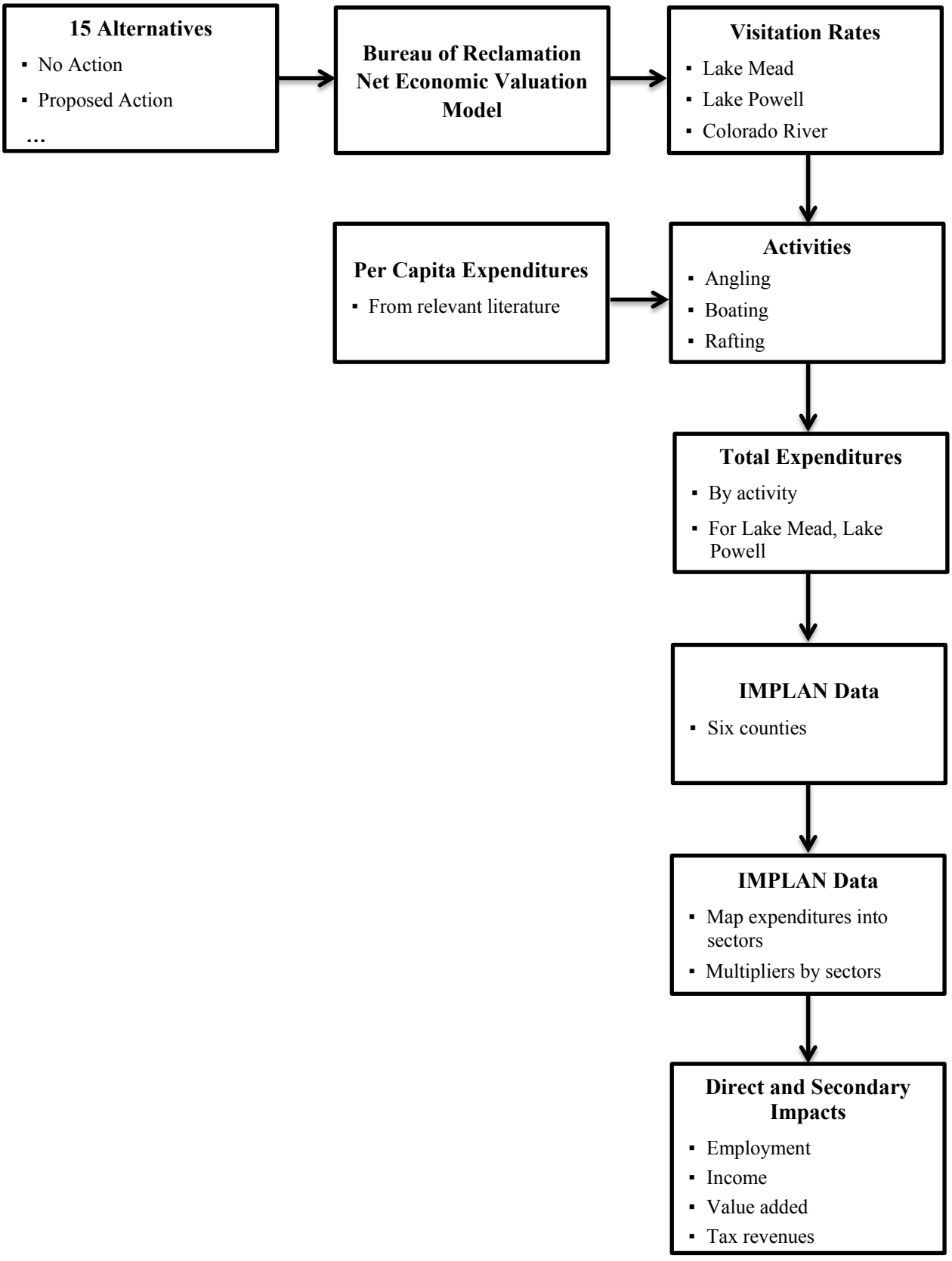

FIGURE L-3 Elements of the Regional Recreation Impacts Analysis

Input-output data and the associated multipliers can be readily used to determine the impact of changes in recreational expenditures through the estimation of multipliers for each sector in the multi-county region in which recreational expenditures occur. These multipliers typically give the total (direct plus indirect plus induced) benefits to the region in terms of employment, income, and taxes. Input-output data includes information for 440 separate North American Industry Classification System (NAICS) industries used by the U.S. Department of Commerce, Bureau of Economic Analysis. These accounts show the flow of commodities between industries and institutional consumers. Industries represented are those in agriculture, mining, construction, manufacturing, wholesale and retail trade, utilities, finance, insurance and real estate, and consumer and business services. Each industry is described in terms of its purchases from, and sales to, all other industries in the local economy.

Input-output accounts also provide information on value added by industry, and sales by industry, to final demand. Value added includes employee compensation (wages and salary payments, benefits, life insurance, retirement, etc.), proprietary income (payments received by self-employed individuals as income), other property-type income (payments received from royalties and dividends), and indirect business taxes (primarily excise and sales taxes paid by individuals to businesses). Final demands include personal consumption expenditures (payments by individuals/households to industries for goods and services used for personal consumption), federal government (military and nonmilitary) purchases and sales, state and local government (public education and non-education) purchases and sales, inventory purchases (unsold annual output), sales (where inventory reduction exceeds additions from production), capital formation (expenditures made to obtain capital equipment), and exports outside the region and nation.

Estimates of the regional economic impacts of changes in recreation expenditure came from the IMPLAN model, an "off-the-shelf" model produced by IMPLAN Group, LLC, that provides county-level and state-level input-output data. The model allows detailed analysis of the impacts of changes in recreation expenditures by mapping changes in expenditures by item (gas, food, lodging, etc.) into the appropriate sectors in the model, and then using IMPLAN multipliers to provide estimates of indirect effects and total effects, by alternative, activity type, and year in terms of employment (full-time equivalent staff, or ftes), income ($m), and the various components of value added ($m), including employment compensation, proprietor income, and tax revenues.

L.1.4 Estimates of Recreational Economic Impacts

Glen Canyon and Grand Canyon attract large numbers of visitors every year (see Section 3.10), and expenditures on gas, food and drink, lodging, guide services, and outdoor equipment are substantial. They produce direct income and employment both in sectors of the economy in which expenditures occur, and in the remainder of the economy; wages and salaries, and dollars spent on the purchases of goods and services, in these sectors circulate through the regional economy, producing indirect effects (effects in other industries) and induced effects (household effects). In 2011, spending by visitors to the Glen Canyon National Recreational Area, Grand Canyon National Park, and Lake Mead National Recreational Area produced 10,301 direct, indirect, and induced jobs and $373.7 million in total income (Table L-1).

TABLE L-1 Total Regional Economic Impacts (Direct, Indirect, and Induced) of Non-Local Recreation Expenditures, 2013

Parameter	Glen Canyon National Recreation Area	Grand Canyon National Park	Lake Mead National Recreation Area	Total
Employment	1,435	6,238	2,628	10,301
Income ($m 2013 dollars)	39.3	235.9	98.5	373.7

Source: Thomas et al. (2014).

As part of the overall impact of recreational visitation, various studies have attempted to estimate the regional economic impacts of specific recreational activities. Douglas and Harpman (1995) estimated that Glen Canyon and Grand Canyon recreational use in the region comprised of Coconino and Mojave Counties supported approximately 585 jobs. More recently, Hjerpe and Kim (2007) estimated that Grand Canyon boating recreation spending supported approximately 394 jobs in Coconino County, with commercial boating producing the majority (357) of the jobs created; Douglas (2005) found that whitewater boating in Grand Canyon National Park supported 438 jobs.

In addition to the economic impacts of recreational visitation in Glen Canyon and Grand Canyon, recreation in the region also provides employment and income for Navajo tradespeople selling jewelry and souvenirs to the traveling public along various routes in the region; jewelry production and sales provides 400 to 700 jobs (Reclamation 2011). Jobs held by the Navajo people are especially important because wage earners usually support extended families.

L.2 REGIONAL ELECTRICITY ANALYSES

L.2.1 Regional Electricity Price Impacts

The analysis of increases in electricity rates considered (1) changes in customer utility electricity prices resulting from changes in Glen Canyon Dam operations; and (2) impacts of constructing and operating additional power plants with customer utility capacity expansion plans to replace energy and capacity previously provided by Western

Analyses were conducted in the seven-state region in which Western markets CRSP power: Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. This includes the service territories of the eight major Western customer utilities:

- Colorado Springs Utilities,
- Deseret Generation and Transmission Cooperative,

- Navajo Tribal Utility Authority,
- Platte River Power Authority,
- Salt River Project,
- Tri-State Generation and Transmission,
- Utah Municipal Power Agency, and
- Utah Associated Municipal Power Systems.

Separate analyses considered the following:

- The effects changes in Glen Canyon operations and changes in power marketing by the Colorado River Storage Project (CRSP) would have on wholesale electricity rates charged to customer utilities, by state and customer utility, from the GTMax/GTMax Lite models (see Appendix H); and
- The impacts changes in Glen Canyon and CRSP electricity rates would have on commercial, industrial, and residential electricity rates charged by the eight largest Western customer utilities, by state and customer utility, from the ratepayer analysis (see Appendix K).

Data used to analyze the regional economic impact of increases in electricity prices consisted of the following:

- Current and forecasted electricity prices, by state, from Energy Information Administration (EIA) data and other sources; and
- Estimates of the response in customer demand to changes in electricity prices (elasticities) for each customer class—commercial, industrial, and residential—taken from the technical and academic literature.

IMPLAN input-output models (see Section L.1), were used to estimate the regional economic impacts of changes in electricity prices, with a separate IMPLAN model representing each of the seven states in the Western marketing area. The analysis involved a number of steps:

- Aggregation of sectors in each state input-output models into the three customer classes: commercial, industrial, and residential;
- Calculation of electricity expenditure shares for each customer class; and
- Calculation of IMPLAN multipliers for each customer class.

These data, combined with changes in prices and price elasticities, give the total (direct plus indirect plus induced) impact of changes in aggregate electricity prices on the economy of each state, by alternative, state, and year, in terms of employment (ftes), income ($m), and the various components of value added ($m), including employment compensation, proprietor income, and tax revenues. The major analytical modeling steps are shown in Figure L-4.

L.2.2 Regional Electricity Generating Capacity Expansion Impacts

Analysis of the effects changes in Glen Canyon operations would have on electricity rates and capacity expansion required data on capital and operating expenditures, by alternative, including the following:

- Capacity expansion requirements, by state and customer utility, from the GTMax/GTMax Lite models (see Appendix K); and

- Expenditures on materials, equipment, services, direct and indirect labor, by year, from appropriate projects (similar in terms of fuel type, technology, size, and location), from the Jobs and Economic Development Impact (JEDI) model (NREL 2015).

Capacity expansion capital and operating expenditures were mapped into the appropriate sectors in an IMPLAN input-output model for each state, which were then used to estimate the appropriate multipliers to provide estimates of indirect effects and total effects, by alternative and year, in terms of employment (ftes), income ($m), and the various components of value added ($m), including employment compensation, proprietor income, and tax revenues. The major analytical modeling steps are shown in Figure L-5.

L.3 ADDITIONAL SOCIOECONOMIC DATA

Table L-2 contains data pertaining to population, median household income, and poverty in each community in the six-county affected environment forming the basis of the regional recreational economy.

L.3.1 Urban Population in the Six-County Region

Within the six counties in 2010, there were 86 places identified by the U.S. Census Bureau in the region of influence (ROI), including incorporated cities and Census Designated Places CDPs (unincorporated areas). The population of the ROI in 2010 was 83% urban; the largest town, St. George, Utah, had a 2010 population of 72,897; other places in the ROI with more than 10,000 inhabitants include Flagstaff (65,870), Lake Havasu City (52,527), Bullhead City (39,540), Kingman (28,068), New Kingman-Butler (12,134), and Sedona (10,031), all of which are in Arizona. There were 27 smaller towns in the ROI with 2010 populations of between 1,000 and 10,000, and an additional 50 places with populations of less than 1,000.

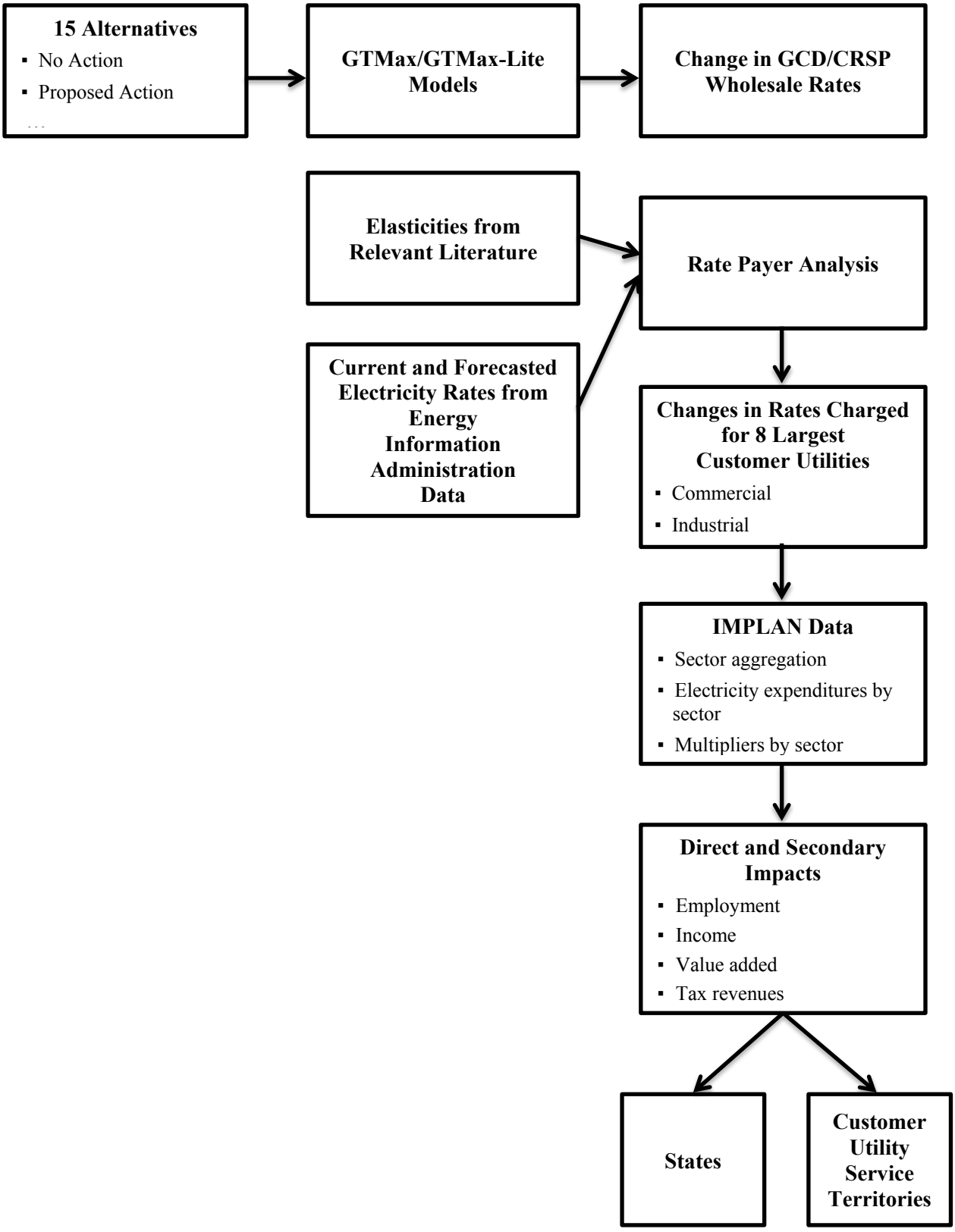

FIGURE L-4 Elements of the Regional Electricity Price Impacts Analysis

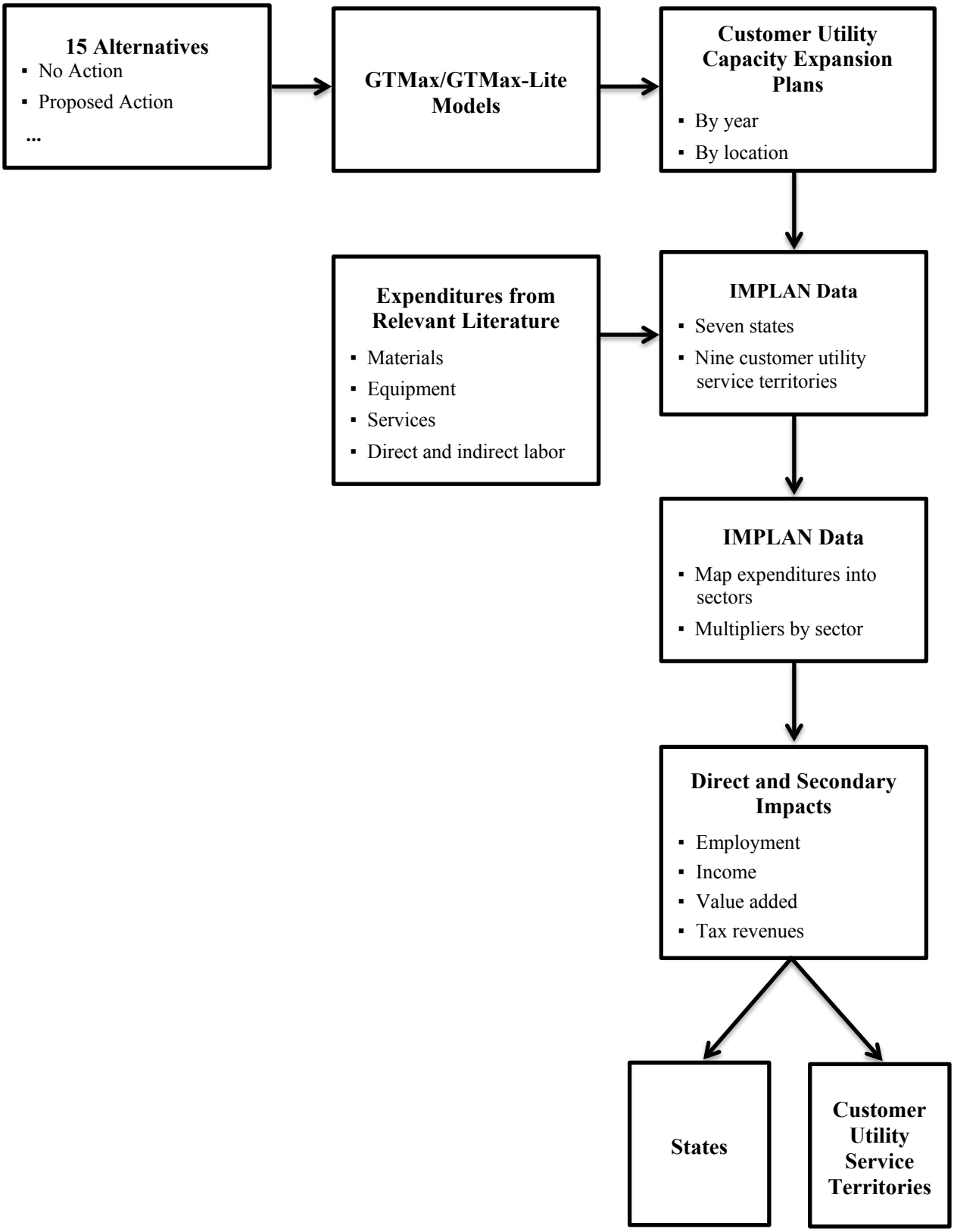

FIGURE L-5 Elements of the Regional Electricity Generating Capacity Expansion Impacts Analysis

TABLE L-2 Urban Population, Income, and Poverty in the Six-County Region

	Population			Median Household Income			
City	2000	2010	Average Annual Growth Rate, 2000–2010 (%)	2000 (2013 dollars)	2010 (2013 dollars)	Average Annual Growth Rate, 2000–2010 (%)	Percent of Individuals Living in Poverty, 2010
Alton	134	119	–1.2	41,712	51,414	2.1	31.4
Aneth CDP	598	501	–1.8	23,393	22,435	–0.4	54.2
Antimony	122	122	0.0	30,439	31,160	0.2	32.9
Apple Valley	NA	701	NA[a]	NA	67,365	NA	1.6
Arizona Village	351	946	10.4	35,723	44,549	2.2	25.6
Big Water	417	475	1.3	40,961	32,623	–2.3	19.9
Bitter Springs CDP	547	452	–1.9	33,666	44,350	2.8	33.5
Blanding	3,162	3,375	0.7	44,631	46,949	0.5	23.0
Bluff CDP	320	258	–2.1	32,341	38,801	1.8	35.4
Boulder	180	226	2.3	40,585	46,618	1.4	0.0
Bryce Canyon City	NA	198	NA	NA	36,724	NA	0.0
Bullhead City	33,769	39,540	1.6	40,884	39,047	–0.5	20.7
Cameron CDP	978	885	–1.0	33,514	23,916	–3.3	46.1
Cannonville	148	167	1.2	38,894	47,407	2.0	7.5
Central	NA	645	NA	NA	50,951	NA	6.0
Colorado City	3,334	4,821	3.8	44,408	43,115	–0.3	35.3
Dammeron Valley	NA	803	NA	NA	66,400	NA	6.4
Desert Hills	2,183	2,245	0.3	36,091	40,971	1.3	20.8
Dolan Springs	1,867	2,033	0.9	23,411	33,736	3.7	8.2
Doney Park CDP	NA	5,395	NA	NA	79,457	NA	7.2
Enterprise	1,285	605	–7.3				0.0
Escalante	818	797	–0.3	43,484	44,363	0.2	7.5
Flagstaff	52,894	65,870	2.2	50,252	52,852	0.5	19.4
Fredonia	1,036	1,314	2.4	40,974	45,168	1.0	7.0
Glendale	355	381	0.7	48,618	51,580	0.6	15.0
Golden Valley	4,515	8,370	6.4	37,686	36,477	–0.3	15.7
Grand Canyon Village CDP	1,460	2,004	3.2	56,931	49,731	–1.3	13.5
Halchita CDP	270	266	–0.1	13,359	12,383	–0.8	47.1
Halls Crossing CDP	89	6	–23.6	36,033	NA	NA	0.0
Hatch	127	133	0.5	50,167	48,576	–0.3	0.7
Henrieville	159	230	3.8	38,556	60,391	4.6	12.1
Hildale	1,895	2,726	3.7	44,209	32,623	–3.0	50.3
Hurricane	8,250	13,748	5.2	44,461	54,311	2.0	7.9
Ivins	4,450	6,753	4.3	55,868	53,417	–0.4	13.4
Kachina Village CDP	2,664	2,622	–0.2	61,828	50,975	–1.9	4.4
Kaibab CDP	275	124	–7.7	29,029	32,451	1.1	24.8
Kaibito CDP	1,607	1,522	–0.5	49,040	34,350	–3.5	31.6
Kanab	3,564	4,312	1.9	47,518	45,176	–0.5	6.5
Kingman	20,069	28,068	3.4	46,112	46,845	0.2	13.2
La Sal CDP	339	395	1.5	35,073	58,457	5.2	0.0

TABLE L-2 (Cont.)

City	Population 2000	Population 2010	Population Average Annual Growth Rate, 2000–2010 (%)	Median Household Income 2000 (2013 dollars)	Median Household Income 2010 (2013 dollars)	Median Household Income Average Annual Growth Rate, 2000–2010 (%)	Percent of Individuals Living in Poverty, 2010
La Verkin	3,392	4,060	1.8	48,633	47,997	–0.1	14.8
Lake Havasu City	41,938	52,527	2.3	49,377	46,630	–0.6	11.6
LeChee CDP	1,606	1,443	–1.1	65,443	59,912	–0.9	20.7
Leeds	547	820	4.1	55,804	54,936	–0.2	8.3
Leupp CDP	970	951	–0.2	29,029	30,848	0.6	29.8
Mesquite Creek	205	416	7.3	44,812	46,206	0.3	23.7
Mexican Hat CDP	88	31	–9.9	77,999	NA	NA	0.0
Moenkopi CDP	901	964	0.7	52,368	56,229	0.7	33.5
Mohave Valley	13,694	2,616	–15.3	46,430	57,353	2.1	11.8
Mohave Ranch Estates	28	52	6.4	NA	43,179	NA	0.0
Montezuma Creek CDP	507	335	–4.1	39,739	32,851	–1.9	23.4
Monticello	1,958	1,972	0.1	48,606	42,026	–1.4	8.8
Mountainaire CDP	1,014	1,119	1.0	55,804	67,333	1.9	3.5
Munds Park CDP	1,250	631	–6.6	56,050	59,620	0.6	3.8
Navajo Mountain CDP	379	354	–0.7	19,205	46,473	9.2	24.1
New Harmony	190	207	0.9	46,785	45,071	–0.4	3.1
New Kingman-Butler	14,810	12,134	–2.0	35,061	31,765	–1.0	23.0
Oljato-Monument Valley CDP	864	674	–2.5	43,545	47,742	0.9	40.6
Orderville	596	577	–0.3	48,389	34,357	–3.4	16.0
Page	6,809	7,247	0.6	63,495	53,787	–1.6	17.2
Panguitch	1,623	1,520	–0.7	45,320	43,910	–0.3	14.0
Parks CDP	1,137	1,188	0.4	53,959	66,850	2.2	8.4
Peach Springs	600	1,090	6.2	24,613	45,636	6.4	40.0
Pine Valley	NA	186	NA	NA	81,015	NA	0.0
Rockville	247	245	–0.1	51,295	44,069	–1.5	6.5
Santa Clara	4,630	6,003	2.6	71,389	73,078	0.2	3.4
Sedona	10,192	10,031	–0.2	59,581	53,149	–1.1	10.8
Spanish Valley CDP	181	491	10.5	67,923	74,055	0.9	0.0
Springdale	457	529	1.5	56,287	38,727	–3.7	2.6
St. George	49,663	72,897	3.9	49,385	51,815	0.5	11.1
Supai CDP	0	208	NA	0	40,063	NA	48.0
Tonalea CDP	562	549	–0.2	43,370	15,357	–9.9	46.5
Toquerville	910	1,370	4.2	46,048	48,648		12.2
Tropic	508	530	0.4	57,495	64,354	1.1	7.6
Tselakai Dezza CDP	103	109	0.6	63,921	144,726	8.5	7.5
Tuba City CDP	8,225	8,611	0.5	52,160	49,509	–0.5	24.5
Tusayan CDP	562	558	–0.1	47,237	53,468	1.2	6.6
Valle CDP	NA	832	NA	NA	31,511	NA	36.4
Veyo	NA	483	NA	NA	31,511	NA	4.6
Virgin	394	596	4.2	NA	52,160	NA	4.5
Washington	8,196	18,761	8.6	47,810	55,407	1,5	11.7

TABLE L-2 (Cont.)

	Population			Median Household Income			
City	2000	2010	Average Annual Growth Rate, 2000–2010 (%)	2000 (2013 dollars)	2010 (2013 dollars)	Average Annual Growth Rate, 2000–2010 (%)	Percent of Individuals Living in Poverty, 2010
White Mesa CDP	277	242	–1.3	18,601	21,100	1.3	37.7
Williams	2,842	3,023	0.6	43,906	46,072	0.5	19.3
Willow Valley	585	1,062	6.1	53,099	37,577	–3.4	23.5
Winslow West CDP	131	438	12.8	11,161	35,122	12.1	45.9

[a] NA = data not available.

Source: U.S. Census Bureau (2013).

Urban population in the ROI grew at an average annual rate of 2.9% over the period from 2000 to 2010, although growth rates within the ROI varied considerably. Winslow West, Arizona, grew at an average annual rate of 12.8%; Spanish Valley, Utah, at 10.5%; and Arizona Village, Arizona, at 10.4% during this period, with higher than average growth also experienced in Washington, Utah (8.6%); Mesquite Creek, Arizona (7.3%); Mojave Ranch Estates, Arizona (6.4%); Golden Valley, Arizona (6.4%); Peach Springs, Arizona (6.2%); and Willow Valley, Arizona (6.1%). The remaining places experienced lower growth rates between 2000 and 2010, with 29 places experiencing negative growth rates during this period. Rural population in the ROI grew at an annual average rate of 7.5% between 2000 and 2010.

L.3.2 Urban Income in the Six-County Region

Median household incomes in 2010 varied considerably across places in the ROI. Ten places in the Arizona portion of the ROI had median incomes that were higher than the average for the state ($50,991); these included Doney Park ($79,457), Mountainaire ($67,333), Parks ($66,850), LeChee ($59,912), Munds Park ($59,620), Mohave Valley ($57,353), and Moenkopi ($56,229). Twenty-eight places in the Arizona portion of the ROI had median incomes lower than the state average, and two places, Cameron ($23,916) and Tonalea ($15,357), had incomes that were less than half that of the state average. In 21 places, more than 20% of individuals were living in poverty, with poverty particularly marked in four communities, Supai (48.0% of individuals), Tonalea (46.5%), Cameron (46.1%), and Winslow West (45.9%).

Nine places in in the Utah portion of the ROI had median incomes higher than the state average ($59,014) in 2010; these included Tselakai Dezza ($144,726), Enterprise ($104,585), Pine Valley ($81,015), Spanish Valley ($74,055), and Santa Clara ($73,078). Thirty-six places had median incomes lower than the state average, and three places, Aneth ($22,435), White Mesa ($21,100), and Halchita ($12,383), had incomes that were less than half the state average.

In 11 places, more than 20% of individuals were living in poverty, with higher poverty levels in four communities, Aneth (54.2% of individuals), Hildale (50.3%), Halchita (47.1%), and Oljato-Monument Valley (40.6%).

Median income growth rates within the ROI varied considerably over the period from 2000 to 2010. In the Arizona portion of the ROI, 39 places had annual average growth rates higher than the state rate (–0.7%), with high growth rates in Winslow West (12.1%) and Peach Springs (6.4%) during this period. The remaining places experienced lower growth rates between 2000 and 2010, with 15 places experiencing negative growth rates. In the Utah portion of the ROI, 24 places had annual average growth rates higher than the state rate (–0.6%), including Navajo Mountain (9.2%), Tselakai-Dezza (8.5%), and Enterprise (8.0%). The remaining places experienced lower growth rates between 2000 and 2010, with 16 places experiencing negative growth rates.

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APPENDIX M:

AIR QUALITY AND CLIMATE CHANGE TECHNICAL INFORMATION AND ANALYSIS

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APPENDIX M:

AIR QUALITY AND CLIMATE CHANGE TECHNICAL INFORMATION AND ANALYSIS

This appendix provides a description of the analysis used to evaluate the impacts on air quality and climate change of the alternatives considered in the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). Glen Canyon Dam hydropower generation does not generate air emissions. However, dam operations can affect air emissions and ambient air quality over the 11-state Western Interconnection, comprising Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets generation from other non-hydropower-generating facilities in the Salt Lake City Area Integrated Project (SLCA/IP) and in the Western Interconnection. Differences among alternatives in the amount of Glen Canyon Dam generation at peak demand hours could affect regional air emissions, through differences in the technology mix of compensating generating facilities within SLCA/IP and, if SLCA/IP generation is insufficient to meet the Western Area Power Administration's (WAPA's) long-term firm contract obligations, through generation from combustion sources in the greater Western Interconnection.

Air quality issues within the 11-state Western Interconnection area include visibility degradation in Federal Class I areas. Coal, natural gas, and oil units emit sulfur dioxide (SO_2) and nitrogen oxides (NO_x), which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an important role in visibility degradation by contributing to haze. Among anthropogenic sources, sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor contributor. Effects on visibility are analyzed through a comparison of regional SO_2 and NO_x emissions under the various alternatives.

Differences among alternatives in the amount and timing of Glen Canyon Dam generation directly affect the generation needed from coal, natural gas, or oil units within the 11-state Western Interconnection region, of which the SLCA/IP system is a part, from the wholesale power market. As described in Section M.2, changes in generation from facilities within this interconnected system under various LTEMP alternatives result in small changes in total emissions because of similarly small differences in emissions from the contributing facilities.

Effects on visibility were analyzed through a comparison of SO_2 and NO_x emissions under the various alternatives. SO_2 and NO_x are also criteria air pollutants with limits on ambient concentrations under the National Ambient Air Quality Standards (NAAQS). Alternatives were compared on the basis of total emissions of these two pollutants from the contributing generation facilities in the interconnected system.

Electricity generation of combustion facilities in the system produces carbon dioxide (CO_2) and other greenhouse gases (GHGs). LTEMP alternatives can affect GHG emissions through changes in Glen Canyon Dam operations and related changes in GHG emissions of

interconnected combustion facilities, as for SO_2 and NO_x. For the purpose of this analysis, the principal GHG of concern is CO_2, which accounts for over 99% of GHG emissions related to power generation. However, facility- or technology-specific GHG emission factors also consider other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), which may be emitted during facility operations.

M.1 ANALYSIS METHODS

To compute total air emissions under the LTEMP alternatives, emissions were summed from all generating facilities in the SLCA/IP system. This analysis was tiered off the power systems analysis (Section 4.13 of the EIS and Appendix K), which estimated electrical power generation for the same facilities under each alternative, including base operations and experimental flows, such as high-flow experiments (HFEs) and trout management flows (TMFs). Emissions were estimated using emission factor and corresponding generation level along with emission control efficiency for facilities equipped with a control system. Emission factors (either lb/MWh for power output or lb/MMBtu for heat input) were taken from standard references (EIA 2013; EPA 2014). Generation levels (either MWh/yr or MMBtu/yr) were the estimated electricity generation of each facility and the electricity traded on the spot market under each alternative by calendar year, which were obtained from the AURORA model outputs described in Appendix K. Emissions were then estimated by multiplying emission factors by electrical power generation. Emission controls were reflected in the emission factors used. Table M-1 presents emission factors used for SO_2, NO_x, and GHGs by plant for individual plants in the SLCA/IP system and the spot market. Table M-2 presents annual-average power generation for the same plants and for the spot market.

M.1.1 System Power Generation

Table M-1 presents emission factors by power generation type for (1) specific existing powerplants, (2) specific generating stations with multiple generating units under long-term contract, (3) power generation under long-term contract where no generating units are specified, and (4) future plants needed to provide additional capacity employing advanced gas technologies. For specific powerplants in the SLCA/IP system, pollutant emission factors (in lb/MWh) available in the *Emissions and Generation Resource Integrated Database* (eGRID)[1] with year 2010 data (EPA 2014) were used to estimate air emissions (Table M-1).

For advanced natural-gas-fired simple-cycle and combined-cycle generating units to be built in the future, emission factors for advanced combustion turbine (ACT) and advanced generation natural gas combined cycle (AG-NGCC) in EIA (2013) were used with the following

[1] eGRID is a comprehensive inventory of environmental attributes of electric power systems. The preeminent source of air emissions data for the electric power sector, eGRID is based on available plant-specific data for all U.S. electricity-generating plants that provide power to the electric grid and report data to the U.S. Government. eGRID plant-level emissions reflect monitored data, estimated data, or a combination of both.

values: 0.001 lb/MMBtu for SO_2 for both simple cycle (0.0098 lb/MWh) and combined cycle (0.0064 lb/MWh); 0.03 lb/MMBtu (0.29 lb/MWh) for simple cycle and 0.0075 lb/MMBtu (0.048 lb/MWh) for NO_x for combined cycle; and 117 lb/MMBtu for CO_2 for both simple cycle (1,141 lb/MWh) and combined cycle (752 lb/MWh).

Because emission factors for future plants and plants under long-term contract (Coolidge and Fort Lupton generating stations) are based on emissions per heat energy input (lb/MMBtu), conversion to lb/MWh is needed to produce the values shown in Table M-1 for these entities. Conversion factors were taken from the AURORA model outputs described in Appendix K and had the following values (in units of MWh/MMBtu): 6.43 for advanced combined cycle; 9.75 for advanced simple cycle; 9 for Coolidge; and 9.19 for Fort Lupton. For Brush 2 under long-term contract, emission factors in the eGrid database were used.

The Coolidge Generating Station under long-term contract has 12 simple-cycle natural-gas-fired peaking units with a total capacity of 575 MW, and began service in 2011. For this station, emission factors in lb/MMBtu for a conventional combustion turbine (CT) are assumed, which are the same as those for ACT (EIA 2013). The Fort Lupton Cogeneration Powerplant is a 272-MW combined-cycle natural-gas-fired station. For this station, emission factors in lb/MMBtu for conventional NGCC are assumed, which are the same as those for AG-NGCC (EIA 2013).

For unspecified powerplants under long-term contract, composite emission factors were employed that are representative of all types of powerplants (such as fossil-fuel-fired, hydroelectric, nuclear, and renewable resources) currently in operation over the 11-state Western Interconnection region. Composite emission factors were estimated to be 0.74, 1.07, and 963 lb/MWh for SO_2, NO_x, and GHGs in units of CO_2 equivalents (CO_2e),[2] respectively. Note that three plants (Kyrene, Rawhide, and Ray D. Nixon) have more than one type of generation, but only one plant-wide composite emission factor for each pollutant is given in the EPA's eGRID database (EPA 2014). The available emission factors were applied to all generation at these three plants.

M.1.2 Spot Market

For spot market purchases and sales, composite emission factors in Table M-1 that were used are representative of power generation from gas powerplants currently in operation over the Western Interconnection, based on the assumption that spot market generation is primarily to serve peak loads. Composite emission factors were estimated to be 0.0083, 0.266, and 888 lb/MWh for SO_2, NO_x, and GHGs, respectively (EIA 2013).

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2 Emission factors for GHGs are expressed in CO_2e for the long-term contract (unspecified generation type) and power stations available in the EPA eGrid database. CO_2e is a measure used to compare the emissions from various GHGs on the basis of their global warming potential, defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period (usually 100 years).

M.1.3 Generation Type

Tables M-1and M-2 group plants and other generation entities according to the type of generation technology used. Such grouping is for the purpose of understanding the differences in emissions under various LTEMP alternatives because of differences in generation from contributing generation technologies. Different operating regimes of Glen Canyon Dam under the various LTEMP alternatives supply different proportions of baseload or peaking power. Peaking power produced at the dam is assumed to displace power that would otherwise be produced by plants using gas turbine technologies, while baseload power produced at the dam is assumed to displace power produced by plants employing steam turbine technologies, most typically coal-fired plants. Gas- and coal-fired technologies have distinctly different emission profiles and levels. Gas-fired plants emit far less SO_2 and NO_x than coal-fired plants per unit of energy produced. Different mixes of these two types of technologies under various alternatives are related to the total levels of emissions. The technology groupings shown in Tables M-1 and M-2 are used below in the reporting and interpretation of results.

M.2 RESULTS

M.2.1 SO_2 and NO_x

The potential effects on visibility from emissions of SO_2 and NO_x, which are precursors of sulfate and nitrate aerosols, respectively, and which contribute to haze, are shown in Table M-3 for LTEMP alternatives. The geographic area of potential visibility impacts corresponds to the location of contributing powerplants in the SLCA/IP system and, to a small degree, the 11-state Western Interconnection and includes Grand Canyon National Park. Because the sources are geographically dispersed, effects would be similarly dispersed and low at any particular location. Further, because of very small differences in SO_2 and NO_x precursor emissions, negligible differences are expected among the alternatives with regard to visibility and haze in the region.

Emissions of SO_2 and NO_x under various LTEMP alternatives are compared with respect to air quality effects under NAAQS. Tables M-4 and M-5 show emissions of SO_2 and NO_x, respectively, under each LTEMP alternative, from contributing plants (35 primary facilities) and other contributing entities in the SLC/IP system, and present subtotals of emissions by generation technology type. These tables also show contributions from the spot market computed according to the level of electrical power generated at each plant and entity, using the emission factors in Table M-1.

Table M-6 presents a summary of total system emissions by type of generation technology drawn from Tables M-4 and M-5 for the generation facilities within the SCLA/IP system and from contributions from the spot market. The 35 generating facilities within the SLCA/IP system are categorized according to generation technology type, such as gas turbine or steam turbine (usually coal-fired), so that contributing emissions can be summed by technology type across the system to evaluate emissions from different technology mixes under alternatives.

With respect to the spot market entries in these tables, "sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by SLCA/IP system utilities from other utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

Total SO_2 and NO_x emissions in the system averaged over the 20-year LTEMP period under Alternative A are estimated to be about 42,465 tons/yr and 78,496 tons/yr, respectively, while emissions under other LTEMP alternatives are similar to those under Alternative A. Differences in emissions of SO_2 and NO_x under LTEMP alternatives relative to those under Alternative A are very small, at most −0.04%, and correspond to average annual emission differences that range from −18 to 5 tons/yr for SO_2 and from −10 to 6 tons/yr for NO_x, compared to those under Alternative A.

With respect to type of generation technology, SO_2 and NO_x emissions within the SLCA/IP system are dominated by steam turbine technologies, mainly coal-fired powerplants. Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies; these are attributed to small differences in baseload and peaking energy generated by Glen Canyon Dam. As noted above, gas turbine peaking plant technologies produce lower SO_2 and lower NO_x emissions than baseload coal-fired plants. Thus, offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a potentially lower effect on total system emissions than offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

Table M-6 shows levels of electricity generation at Glen Canyon Dam in MWh/day that would be produced under each LTEMP alternative. Differences in generation at the dam affect the amount of power needed by other contributing generators in the system. Little difference exists in generation at the dam among alternatives, which ranges from 11,438 MWh/day to 11,650 MWh/day. Alternative A produces the most energy, while Alternatives F and G produce roughly 2% less hydropower energy than Alternative A (98.3% and 98.2%, respectively). This reduction in generation is a consequence of the more frequent HFEs under these alternatives, in which a portion of flows bypass the powerplant turbines.

Despite the facts that the steady-flow Alternatives F and G generate less power at Glen Canyon Dam than the fluctuating-flow Alternatives A–E and that this lost generation must be made up by additional generation at other facilities in the system, Alternatives F and G have the lowest total emissions of all alternatives. This result may be explained by the operational regime of the dam under these alternatives with respect to baseload or peaking power. Under steady-flow Alternatives F and G, the dam produces baseload power, which would displace baseload power from other facilities in the system, mainly coal-fired (steam turbine) facilities with relatively high emissions, while under fluctuating-flow Alternatives A–E, the dam produces a portion of peaking power, which offsets gas-fired peaking plants in the system, with relatively low emissions. A more detailed discussion of this interpretation of results is given in Section 4.14.2 of the EIS.

M.2.2 GHG Emissions

Table M-7 presents emissions in CO_2e for contributing plants (approximately 35 primary facilities) and other contributing entities in the SLC/IP system described above under each LTEMP alternative and presents subtotals of emissions by generation technology type and for contributions from the spot market. The spot market reflects the effects of Glen Canyon Dam operations on the larger Western Interconnection region and represents an offset of about 1% of system emissions. Emissions are computed from the level of electrical power generated at each plant and entity under each alternative using the emission factors in Table M-1.

Table M-8 summarizes emissions in Table M-7 by type of technology and presents total emissions under the LTEMP alternatives. Total CO_2e emissions in the system averaged over the 20-year LTEMP period under Alternative A are estimated to be 55,177,668 MT/yr (60,822,967 tons/yr), while emissions under other LTEMP alternatives are similar to those under Alternative A. Differences in emissions of CO_2e from Alternative A are very small, ranging from an increase of 0.011% (Alternative B) to 0.081% (Alternative F), and correspond to average emission increases ranging from 5,900 MT/yr (6,503 tons/yr) (Alternative B) to 44,522 MT/yr (49,077 tons/yr) (Alternative F), considering total emissions (system generation plus spot market sales and purchases) compared to those under Alternative A. Alternatives C, D, E, and G would have intermediate increases in CO_2e emissions of 18,161, 22,908, 16,503, and 40,960 MT/yr (0.033%, 0.042%, 0.030%, and 0.074%), respectively, compared to Alternative A.

With respect to type of generation technology, CO_2e emissions are dominated (about 87%) by steam turbine technologies within the system, mainly coal-fired powerplants, as is the case for SO_2 and NO_x (about 98%). Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies providing baseload and peaking energy in conjunction with Glen Canyon Dam, as discussed above for SO_2 and NO_x. Since gas turbine peaking plant technologies produce about half the CO_2e emissions as baseload coal-fired plants per unit of energy produced (Table M-1), offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a potentially lower effect on total system emissions than offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

As shown in Table M-8, total CO_2e emissions are expected to be slightly higher for steady-flow Alternatives F and G than for the fluctuating-flow alternatives A–E. These increases in total emissions result mainly from relatively higher gas turbine emissions under Alternatives F and G. Higher gas turbine emissions are, in turn, attributable to the lack of peaking power from Glen Canyon Dam under the steady-flow alternatives, which require compensating peaking power from gas turbine peaking plants within the system. As for SO_2 and NO_x, Alternatives F and G have lower CO_2e emissions from steam turbine technologies than Alternative A and other fluctuating-flow alternatives, reflecting relatively greater offsets of baseload coal-fired plants from the steady-flow alternatives. However, total CO_2e emissions are greatest overall for Alternatives F and G because of a more-than-compensating increase in the gas turbine contribution under these alternatives. Alternatives F and G rank highest for CO_2e, but lowest for SO_2 and low for NO_x. This reversal in rank is due to smaller differences in emission factors between gas turbine and stream turbine technologies for CO_2e than for SO_2 and NO_x. CO_2e emission factors are lower for gas turbine technologies by roughly a factor of 2, while SO_2 is

lower by almost 2 orders of magnitude, and NO_x is lower by roughly a factor of 5 for gas turbines than for (coal-fired) steam turbines, as reflected in emission factors shown in Table M-1.

As shown in Table M-8, total system CO_2e emissions are a small fraction of total U.S. GHG emissions, totaling about 0.81% for all LTEMP alternatives.

M.3 REFERENCES

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EPA, 2014, "eGRID," ninth edition with year 2010 data (Version 1.0). Available at http://www.epa.gov/cleanenergy/energy-resources/egrid. Accessed May 23, 2014.

TABLE M-1 Emission Factors by Plant for System Power Generation and Spot Market

Generation Type	Plant Name	EIA Plant No.	Emission Factor (lb/MWh) SO_2	NO_x	CO_2e[a]
System Power Generation					
Combined cycle	Advanced combined-cycle gas turbine[b]	-[c]	0.006	0.048	752
	Desert Basin	55,129	0.005	0.094	1,001
	Front Range	55,283	0.005	0.264	975
	Kyrene #KY7 & #KY7Ae	147	0.005	0.141	932
	Long-term contract (Fort Lupton)[b]	-	0.009	0.069	1,075
	Mesquite	55,481	0.004	0.064	879
	Nebo	56,177	0.005	0.135	890
	Rifle	10,755	0.021	1.026	716
	Santan	8,068	0.004	0.112	843
Composite	Long-term contract (unspecified)[d]	-	0.744	1.068	963
Gas turbine	Advanced simple-cycle gas turbine[b]	-	0.010	0.293	1,141
	Frank Knutson	55,505	0.033	0.394	1,500
	Kyrene KY4-KY6[e]	147	0.005	0.141	932
	Limon	55,504	0.111	0.794	1,714
	Long-term contract (Brush 2)	10,683	0.040	1.950	1,429
	Long-term contract (Coolidge)[b]	-	0.009	0.270	1,053
	Pyramid	7,975	0.042	1.045	1,308
	Rawhide #A-#F[e]	6,761	0.775	1.616	2,049
Internal combustion	Payson	7,408	1.313	19.637	1,473
	Provo	3,686	0.257	17.719	1,493
Steam turbine	Bonanza	1	0.803	3.769	2,099
	Coronado	6,177	3.755	4.044	2,353
	Craig	6,021	0.694	3.035	2,216
	Escalante	87	1.449	3.721	2,449
	Four Corners	2,442	1.588	5.586	2,083
	George Birdsall	493	0.058	3.138	1,948
	Hayden	525	1.495	4.259	2,357
	Hunter	6,165	1.038	3.689	2,248
	Intermountain	6,481	0.765	3.999	2,011
	Kyrene 1 & 2[e]	147	0.005	0.141	932
	Laramie River 1	6,204.1	1.258	2.164	2,461
	Laramie River 2 & 3	6,204.2	1.627	2.890	2,332
	Martin Drake	492	7.428	4.205	2,435
	Navajo	4,941	0.621	2.974	2,179
	Nucla	527	3.859	4.874	2,625
	Rawhide #1[e]	6,761	0.775	1.616	2,049
	Ray D Nixon 1[e]	8,219	4.878	2.391	2,282
	San Juan	2,451	0.847	3.113	2,330
	Springerville	8,223	1.211	1.174	2,026

TABLE M-1 (Cont.)

Generation Type	Plant Name	EIA Plant No.	Emission Factor (lb/MWh)		
			SO_2	NO_x	CO_2e[a]
Spot Market					
	Sales and purchases[f,g]	-	0.0083	0.266	888

[a] GHG emissions are expressed in CO_2e, except for advanced combined cycle, advanced simple cycle, and long-term contract emissions (Coolidge and Fort Lupton), which are expressed as CO_2 and shaded for clarity.

[b] Emission factors were originally given in lb/MMBtu but were converted into lb/MWh using conversion factors (MMBtu/MWh) from the AURORA model outputs described in Appendix K: 6.43 for advanced combined cycle; 9.75 for advanced simple cycle; 9 for Coolidge; and 9.19 for Fort Lupton.

[c] A hyphen denotes "not applicable."

[d] Generation type was not specified, so composite emission factors representative of all types of powerplants currently in operation over the 11 Western Interconnection states were used.

[e] These plants have more than one generation type, and only one plant-wide emission factor for each pollutant was given in the EPA's 2010 eGrid database.

[f] Composite emission factors representative of gas powerplants currently in operation over the 11 Western Interconnection states were used.

[g] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

Sources: EIA (2013); EPA (2014).

TABLE M-2 Power Generation Averaged over the 20-Year LTEMP Period by Alternative

Generation Type	Plant Name	EIA Plant No.	Power Generation (MWh/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation									
Combined cycle	Advanced combined-cycle gas turbine	-[a]	7,620,301	7,623,594	7,617,489	7,620,763	7,622,969	7,605,136	7,609,471
	Desert Basin	55,129	585,800	586,934	590,663	589,933	589,238	588,298	594,677
	Front Range	55,283	919,790	914,735	921,585	924,406	919,148	930,841	925,349
	Kyrene #KY7 & #KY7A	147	46,112	45,923	46,315	47,042	46,657	47,749	46,933
	Long-term contract (Fort Lupton)	-	123,898	121,375	121,530	122,814	120,978	121,286	127,739
	Mesquite	55,481	4,637,436	4,639,304	4,637,048	4,637,704	4,637,659	4,639,378	4,636,160
	Nebo	56,177	205,798	204,042	206,783	206,287	206,392	210,230	209,969
	Rifle	10,755	145,808	145,812	145,755	145,838	145,754	146,621	146,144
	Santan	8,068	1,409,562	1,404,660	1,416,449	1,417,293	1,418,136	1,423,356	1,430,155
	Combined cycle subtotal		**15,694,506**	**15,686,380**	**15,703,618**	**15,712,080**	**15,706,930**	**15,712,895**	**15,726,598**
Composite	**Long-term contract (unspecified)**	-	**1,628,526**	**1,629,588**	**1,628,457**	**1,630,110**	**1,629,858**	**1,632,176**	**1,627,328**
Gas turbine	Advanced simple-cycle gas turbine	-	597,114	587,362	672,023	639,175	647,159	774,061	702,516
	Frank Knutson	55,505	62,101	60,909	62,752	63,133	62,638	70,930	67,843
	Kyrene KY4-KY6	147	938	940	932	936	938	950	962
	Limon	55,504	37,077	36,889	36,664	36,912	36,575	41,589	38,986
	Long-term contract (Brush 2)	10,683	35,169	33,873	34,940	35,592	34,641	36,379	38,201
	Long-term contract (Coolidge)	-	249,994	248,005	247,539	249,364	248,463	248,981	252,243
	Pyramid	7,975	162,140	156,957	163,256	164,392	162,204	172,688	178,097
	Rawhide #A-#F	6,761	4,280	4,267	4,306	4,354	4,278	4,796	4,548
	Gas turbine subtotal		**1,148,814**	**1,129,201**	**1,222,411**	**1,193,859**	**1,196,895**	**1,350,374**	**1,283,395**
Internal combustion	Payson	7,408	1,717	1,713	1,678	1,691	1,679	1,670	1,714
	Provo	3,686	854	850	825	882	869	844	828
	Internal combustion subtotal		**2,571**	**2,563**	**2,503**	**2,573**	**2,548**	**2,514**	**2,542**

TABLE M-2 (Cont.)

Generation Type	Plant Name	EIA Plant No.	Power Generation (MWh/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation (Cont.)									
Steam turbine	Bonanza	7,790	3,589,525	3,589,527	3,589,525	3,589,524	3,589,525	3,589,364	3,589,525
	Coronado	6,177	5,764,907	5,767,009	5,764,236	5,764,829	5,764,453	5,762,531	5,761,006
	Craig	6,021	8,061,885	8,061,806	8,061,979	8,061,745	8,061,885	8,061,388	8,061,713
	Escalante	87	1,783,864	1,783,312	1,782,293	1,783,100	1,783,539	1,775,851	1,781,911
	Four Corners	2,442	1,145,170	1,145,639	1,145,109	1,145,343	1,145,548	1,143,803	1,144,356
	George Birdsall	493	116	115	116	116	114	141	121
	Hayden	525	989,044	989,196	989,115	989,115	989,327	989,267	989,196
	Hunter	6,165	1,514,296	1,514,296	1,514,296	1,514,296	1,514,296	1,514,296	1,514,296
	Intermountain	6,481	5,491,131	5,491,122	5,491,139	5,491,139	5,491,139	5,491,139	5,491,137
	Kyrene 1 & 2	147	1,028	1,034	1,023	1,034	1,027	1,053	1,053
	Laramie River 1	6,204.1	1,039,808	1,039,810	1,039,806	1,039,789	1,039,805	1,039,800	1,039,774
	Laramie River 2 & 3	6,204.2	2,079,620	2,079,620	2,079,620	2,079,620	2,079,620	2,079,620	2,079,620
	Martin Drake	492	1,920,235	1,920,236	1,920,225	1,920,234	1,920,236	1,920,231	1,920,225
	Navajo	4,941	3,741,478	3,741,640	3,741,240	3,741,369	3,741,359	3,740,851	3,740,803
	Nucla	527	753,249	753,276	753,462	753,462	753,504	752,312	752,981
	Rawhide #1	6,761	2,108,554	2,108,554	2,108,554	2,108,554	2,108,554	2,108,554	2,108,554
	Ray D Nixon 1	8,219	1,663,200	1,663,200	1,663,200	1,663,200	1,663,200	1,663,200	1,663,200
	San Juan	2,451	571,214	571,347	571,264	571,231	571,344	570,592	570,934
	Springerville	8,223	6,131,532	6,133,174	6,130,698	6,130,759	6,131,637	6,121,038	6,126,970
	Steam turbine subtotal		**48,349,855**	**48,353,913**	**48,346,900**	**48,348,459**	**48,350,114**	**48,325,031**	**48,337,375**
System subtotal			**66,824,271**	**66,801,645**	**66,903,888**	**66,887,081**	**66,886,345**	**67,022,991**	**66,977,238**
Spot Market									
	Sales (emissions subtracted)[b]	-	−3,753,513	−3,707,051	−3,830,282	−3,784,783	−3,812,913	−3,915,541	−3,872,321
	Purchases (emissions added)[b]	-	2,823,573	2,816,937	2,848,706	2,836,661	2,848,870	2,865,526	2,861,183
Spot market subtotal			**−929,940**	**−890,114**	**−981,576**	**−948,122**	**−964,043**	**−1,050,015**	**−1,011,139**
Total (system + spot market)			**65,894,331**	**65,911,531**	**65,922,312**	**65,938,959**	**65,922,302**	**65,972,976**	**65,966,099**

Footnotes on next page.

TABLE M-2 (Cont.)

[a] A hyphen denotes "not applicable."

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

Data source: AURORA model outputs described in Appendix K.

TABLE M-3 Summary of Potential Impacts of LTEMP Alternatives on Visibility and Regional Air Quality

Air Quality	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Overall summary of impacts	No change from current conditions	Negligible increase in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 emissions and no change in NO_x emissions compared to Alternative A	No change in SO_2 emissions and negligible increase in and NO_x emissions compared to Alternative A	Negligible increase in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 emissions and negligible increase in NO_x emissions compared to Alternative A
Visibility[a]	No change from current conditions	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A
Air Quality in 11-State Western Interconnection Region							
SO_2 emissions (tons/yr)[b]	42,465	42,471	42,463	42,465	42,466	42,448	42,453
	No change from current conditions	Negligible increase (0.01%) compared to Alternative A	Negligible reduction (−0.01%) compared to Alternative A	No change from current conditions from Alternative A	Negligible increase (<0.005%) compared to Alternative A	Negligible reduction (−0.04%) compared to Alternative A	Negligible reduction (−0.03%) compared to Alternative A
NO_x emissions (tons/yr)[b]	78,496	78,501	78,496	78,503	78,500	78,487	78,498
	No change from current conditions	Negligible increase (0.01%) compared to Alternative A	No change from current conditions from Alternative A	Negligible increase (0.01%) compared to Alternative A	Negligible increase (<0.005%) compared to Alternative A	Negligible reduction (−0.01%) compared to Alternative A	Negligible increase (<0.005%) compared to Alternative A

[a] Visibility effects are estimated from expected changes in the emissions of sulfate and nitrate precursors, SO_2 and NO_x.

[b] Total air emissions and percentage change in emissions (compared to Alternative A) from combustion-related powerplants in the Western Interconnection averaged over the 20-year LTEMP period.

Source: EPA (2014).

TABLE M-4 Annual SO_2 Emissions Averaged over the 20-Year LTEMP Period by Alternative

Generation Type	Plant Name	EIA Plant No.	Average Annual SO_2 Emissions (tons/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation									
Combined cycle	Advanced combined-cycle gas turbine	-[a]	24	25	24	25	25	24	24
	Desert Basin	55,129	1	1	1	1	1	1	1
	Front Range	55,283	2	2	2	2	2	2	2
	Kyrene #KY7 & #KY7A	147	0	0	0	0	0	0	0
	Long-term contract (Fort Lupton)	-	1	1	1	1	1	1	1
	Mesquite	55,481	10	10	10	10	10	10	10
	Nebo	56,177	0	0	0	0	0	0	0
	Rifle	10,755	2	2	2	2	2	2	2
	Santan	8,068	3	3	3	3	3	3	3
	Combined cycle subtotal		**44**	**44**	**44**	**44**	**44**	**44**	**44**
Composite	**Long-term contract (unspecified)**	-	**606**	**607**	**606**	**607**	**607**	**608**	**606**
Gas turbine	Advanced simple-cycle gas turbine	-	3	3	3	3	3	4	3
	Frank Knutson	55,505	1	1	1	1	1	1	1
	Kyrene KY4-KY6	147	0	0	0	0	0	0	0
	Limon	55,504	2	2	2	2	2	2	2
	Long-term contract (Brush 2)	10,683	1	1	1	1	1	1	1
	Long-term contract (Coolidge)	-	1	1	1	1	1	1	1
	Pyramid	7,975	3	3	3	3	3	4	4
	Rawhide #A-#F	6,761	2	2	2	2	2	2	2
	Gas turbine subtotal		**13**	**13**	**13**	**13**	**13**	**15**	**14**
Internal combustion	Payson	7,408	1	1	1	1	1	1	1
	Provo	3,686	0	0	0	0	0	0	0
	Internal combustion subtotal		**1**	**1**	**1**	**1**	**1**	**1**	**1**

TABLE M-4 (Cont.)

Generation Type	Plant Name	EIA Plant No.	Average Annual SO_2 Emissions (tons/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation (Cont.)									
Steam turbine	Bonanza	7,790	1,441	1,441	1,441	1,441	1,441	1,441	1,441
	Coronado	6,177	10,822	10,826	10,821	10,822	10,821	10,818	10,815
	Craig	6,021	2,795	2,795	2,795	2,795	2,795	2,795	2,795
	Escalante	87	1,293	1,292	1,291	1,292	1,292	1,287	1,291
	Four Corners	2,442	909	910	909	910	910	908	909
	George Birdsall	493	0	0	0	0	0	0	0
	Hayden	525	739	739	739	739	740	739	739
	Hunter	6,165	786	786	786	786	786	786	786
	Intermountain	6,481	2,099	2,099	2,099	2,099	2,099	2,099	2,099
	Kyrene 1 & 2	147	0	0	0	0	0	0	0
	Laramie River 1	6,204	654	654	654	654	654	654	654
	Laramie River 2 & 3	6,204	1,692	1,692	1,692	1,692	1,692	1,692	1,692
	Martin Drake	492	7,132	7,132	7,132	7,132	7,132	7,132	7,132
	Navajo	4,941	1,161	1,161	1,161	1,161	1,161	1,161	1,161
	Nucla	527	1,453	1,453	1,454	1,454	1,454	1,451	1,453
	Rawhide #1	6,761	817	817	817	817	817	817	817
	Ray D Nixon 1	8,219	4,056	4,056	4,056	4,056	4,056	4,056	4,056
	San Juan	2,451	242	242	242	242	242	242	242
	Springerville	8,223	3,712	3,713	3,712	3,712	3,712	3,706	3,710
	Steam turbine subtotal		**41,805**	**41,810**	**41,802**	**41,804**	**41,805**	**41,785**	**41,792**
System power generation total			**42,469**	**42,474**	**42,467**	**42,469**	**42,470**	**42,452**	**42,457**
Spot Market									
	Sales (emissions subtracted)[b]	-	−16	−15	−16	−16	−16	−16	−16
	Purchases (emissions added)[b]	-	12	12	12	12	12	12	12
Spot market subtotal			**−4**	**−4**	**−4**	**−4**	**−4**	**−4**	**−4**
Total (system + spot market)			**42,465**	**42,471**	**42,463**	**42,465**	**42,466**	**42,448**	**42,453**

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TABLE M-4 (Cont.)

[a] A hyphen denotes "not applicable."

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

TABLE M-5 Annual NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative

Generation Type	Plant Name	EIA Plant No.	Average Annual NO_x Emissions (tons/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation									
Combined cycle	Advanced combined-cycle gas turbine	-[a]	184	184	184	184	184	183	183
	Desert Basin	55,129	28	28	28	28	28	28	28
	Front Range	55,283	122	121	122	122	121	123	122
	Kyrene #KY7 & #KY7A	147	3	3	3	3	3	3	3
	Long-term contract (Fort Lupton)	-	4	4	4	4	4	4	4
	Mesquite	55,481	147	147	147	147	147	147	147
	Nebo	56,177	14	14	14	14	14	14	14
	Rifle	10,755	75	75	75	75	75	75	75
	Santan	8,068	79	79	80	80	80	80	80
	Combined-cycle subtotal		**655**	**654**	**656**	**657**	**656**	**658**	**658**
Composite	**Long-term contract (unspecified)**	-	**869**	**870**	**869**	**870**	**870**	**871**	**869**
Gas turbine	Advanced simple-cycle gas turbine	-	87	86	98	93	95	113	103
	Frank Knutson	55,505	12	12	12	12	12	14	13
	Kyrene KY4-KY6	147	0	0	0	0	0	0	0
	Limon	55,504	15	15	15	15	15	17	15
	Long-term contract (Brush 2)	10,683	34	33	34	35	34	35	37
	Long-term contract (Coolidge)	-	34	33	33	34	34	34	34
	Pyramid	7,975	85	82	85	86	85	90	93
	Rawhide #A-#F	6,761	3	3	3	4	3	4	4
	Gas turbine subtotal		**271**	**265**	**282**	**278**	**277**	**307**	**300**
Internal combustion	Payson	7,408	17	17	16	17	16	16	17
	Provo	3,686	8	8	7	8	8	7	7
	Internal combustion subtotal		**24**	**24**	**24**	**24**	**24**	**24**	**24**

TABLE M-5 (Cont.)

Generation Type	Plant Name	EIA Plant No.	Average Annual NO_x Emissions (tons/yr) A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation (Cont.)									
Steam	Bonanza	7,790	6,764	6,764	6,764	6,764	6,764	6,764	6,764
turbine	Coronado	6,177	11,656	11,661	11,655	11,656	11,655	11,652	11,648
	Craig	6,021	12,236	12,235	12,236	12,235	12,236	12,235	12,235
	Escalante	87	3,319	3,318	3,316	3,318	3,318	3,304	3,315
	Four Corners	2,442	3,199	3,200	3,198	3,199	3,200	3,195	3,196
	George Birdsall	493	0	0	0	0	0	0	0
	Hayden	525	2,106	2,107	2,106	2,106	2,107	2,107	2,107
	Hunter	6,165	2,793	2,793	2,793	2,793	2,793	2,793	2,793
	Intermountain	6,481	10,979	10,979	10,979	10,979	10,979	10,979	10,979
	Kyrene 1 & 2	147	0	0	0	0	0	0	0
	Laramie River 1	6,204.1	1,125	1,125	1,125	1,125	1,125	1,125	1,125
	Laramie River 2 & 3	6,204.2	3,005	3,005	3,005	3,005	3,005	3,005	3,005
	Martin Drake	492	4,037	4,037	4,037	4,037	4,037	4,037	4,037
	Navajo	4,941	5,563	5,563	5,562	5,562	5,562	5,562	5,562
	Nucla	527	1,836	1,836	1,836	1,836	1,836	1,833	1,835
	Rawhide #1	6,761	1,704	1,704	1,704	1,704	1,704	1,704	1,704
	Ray D Nixon 1	8,219	1,989	1,989	1,989	1,989	1,989	1,989	1,989
	San Juan	2,451	889	889	889	889	889	888	889
	Springerville	8,223	3,600	3,601	3,600	3,600	3,600	3,594	3,598
	Steam turbine subtotal		**76,800**	**76,806**	**76,796**	**76,799**	**76,801**	**76,766**	**76,781**
System power generation total			**78,620**	**78,620**	**78,626**	**78,629**	**78,628**	**78,626**	**78,632**
Spot Market									
	Sales (emissions subtracted)[b]	-	−499	−492	−509	−503	−506	−520	−514
	Purchases (emissions added)[b]	-	375	374	378	377	378	381	380
Spot market subtotal			**−124**	**−118**	**−130**	**−126**	**−128**	**−139**	**−134**
Total (system + spot market)			**78,496**	**78,501**	**78,496**	**78,503**	**78,500**	**78,487**	**78,498**

Footnotes on next page.

TABLE M-5 (Cont.)

[a] A hyphen denotes "not applicable."

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

TABLE M-6 Summary of Impacts of LTEMP Alternatives on SO_2 and NO_x Emissions

Generation Type	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Total Glen Canyon Dam power generation relative to Alternative A (MWh/day) (% of Alternative A)	11,650 (100%)	11,616 (99.7%)	11,566 (99.3%)	11,525 (98.9%)	11,571 (99.3%)	11,449 (98.3%)	11,438 (98.2%)
SO_2 Emissions (tons/yr)							
System Power Generation							
Combined cycle	44	44	44	44	44	44	44
Composite[a]	606	607	606	607	607	608	606
Gas turbine	13	13	13	13	13	15	14
Internal combustion	1	1	1	1	1	1	1
Steam turbine	41,805	41,810	41,802	41,804	41,805	41,785	41,792
System subtotal	**42,469**	**42,474**	**42,467**	**42,469**	**42,470**	**42,452**	**42,457**
Spot Market[b]							
Sales (emissions subtracted)	−16	−15	−16	−16	−16	−16	−16
Purchases (emissions added)	12	12	12	12	12	12	12
Spot market subtotal	**−4**	**−4**	**−4**	**−4**	**−4**	**−4**	**−4**
Total (system + spot market)	**42,465**	**42,471**	**42,463**	**42,465**	**42,466**	**42,448**	**42,453**
NO_x Emissions (tons/yr)							
System Power Generation							
Combined cycle	655	654	656	657	656	658	658
Composite[a]	869	870	869	870	870	871	869
Gas turbine	271	265	282	278	277	307	300
Internal combustion	24	24	24	24	24	24	24
Steam turbine	76,800	76,806	76,796	76,799	76,801	76,766	76,781
System subtotal	**78,620**	**78,620**	**78,626**	**78,629**	**78,628**	**78,626**	**78,632**
Spot Market Sales[b]							
Sales (emissions subtracted)	−499	−492	−509	−503	−506	−520	−514
Purchases (emissions added)	375	374	378	377	378	381	380
Spot market subtotal	**−124**	**−118**	**−130**	**−126**	**−128**	**−139**	**−134**
Total (system + spot market)	**78,496**	**78,501**	**78,496**	**78,503**	**78,500**	**78,487**	**78,498**

[a] Unspecified generation type.

[b] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

TABLE M-7 Annual Greenhouse Gas Emissions under LTEMP Alternatives

Generation Type	Plant Name	EIA Plant No.	Annual GHG Emissions (MT/yr CO_2e)[a] A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation									
Combined cycle	Advanced combined-cycle gas turbine	-[b]	2,600,367	2,601,491	2,599,408	2,600,525	2,601,278	2,595,192	2,596,672
	Desert Basin	55,129	265,937	266,452	268,144	267,813	267,498	267,071	269,967
	Front Range	55,283	406,591	404,356	407,384	408,631	406,307	411,476	409,048
	Kyrene #KY7 & #KY7A	147	19,494	19,414	19,580	19,887	19,724	20,186	19,841
	Long-term contract (Fort Lupton)	-	60,427	59,216	59,291	59,907	59,026	59,174	62,270
	Mesquite	55,481	1,849,137	1,849,882	1,848,983	1,849,244	1,849,226	1,849,912	1,848,629
	Nebo	56,177	83,114	82,405	83,512	83,312	83,354	84,904	84,799
	Rifle	10,755	47,363	47,364	47,345	47,372	47,345	47,627	47,472
	Santan	8,068	539,188	537,313	541,823	542,146	542,468	544,465	547,066
	Combined-cycle subtotal		**5,871,619**	**5,867,894**	**5,875,470**	**5,878,837**	**5,876,226**	**5,880,006**	**5,885,763**
Composite	**Long-term contract (unspecified)**	-	**711,604**	**712,068**	**711,574**	**712,296**	**712,186**	**713,199**	**711,081**
Gas turbine	Advanced simple-cycle gas turbine	-	308,968	303,922	347,729	330,732	334,863	400,526	363,507
	Frank Knutson	55,505	42,240	41,430	42,683	42,942	42,605	48,246	46,146
	Kyrene KY4-KY6	147	396	397	394	396	396	402	407
	Limon	55,504	28,833	28,686	28,511	28,704	28,442	32,341	30,317
	Long-term contract (Brush 2)	10,683	22,800	21,960	22,651	23,074	22,458	23,585	24,766
	Long-term contract (Coolidge)	-	119,405	118,455	118,233	119,105	118,674	118,921	120,479
	Pyramid	7,975	96,184	93,109	96,845	97,520	96,222	102,441	105,650
	Rawhide #A-#F	6,761	3,979	3,966	4,003	4,047	3,977	4,458	4,227
	Gas turbine subtotal		**622,805**	**611,925**	**661,049**	**646,520**	**647,637**	**730,920**	**695,498**
Internal combustion	Payson	7,408	1,147	1,145	1,121	1,130	1,122	1,116	1,145
	Provo	3,686	579	576	559	597	588	572	561
	Internal combustion subtotal		**1,726**	**1,721**	**1,680**	**1,728**	**1,711**	**1,688**	**1,706**

TABLE M-7 (Cont.)

Generation Type	Plant Name	EIA Plant No.	Annual GHG Emissions (MT/yr CO_2e)[a] A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation (Cont.)									
Steam turbine	Bonanza	7,790	3,418,218	3,418,220	3,418,218	3,418,217	3,418,218	3,418,064	3,418,218
	Coronado	6,177	6,153,123	6,155,366	6,152,407	6,153,039	6,152,639	6,150,587	6,148,959
	Craig	6,021	8,102,872	8,102,792	8,102,966	8,102,731	8,102,872	8,102,372	8,102,699
	Escalante	87	1,981,912	1,981,299	1,980,168	1,981,064	1,981,551	1,973,010	1,979,743
	Four Corners	2,442	1,081,762	1,082,205	1,081,704	1,081,925	1,082,120	1,080,471	1,080,993
	George Birdsall	493	103	101	103	103	101	124	107
	Hayden	525	1,057,553	1,057,715	1,057,628	1,057,628	1,057,855	1,057,791	1,057,715
	Hunter	6,165	1,544,335	1,544,336	1,544,335	1,544,335	1,544,336	1,544,335	1,544,335
	Intermountain	6,481	5,009,462	5,009,453	5,009,469	5,009,469	5,009,469	5,009,469	5,009,467
	Kyrene 1 & 2	147	435	437	432	437	434	445	445
	Laramie River 1	6,204.1	1,160,583	1,160,585	1,160,581	1,160,562	1,160,580	1,160,574	1,160,546
	Laramie River 2 & 3	6,204.2	2,199,501	2,199,501	2,199,501	2,199,501	2,199,501	2,199,501	2,199,501
	Martin Drake	492	2,120,585	2,120,587	2,120,574	2,120,585	2,120,587	2,120,581	2,120,575
	Navajo	4,941	3,697,248	3,697,409	3,697,013	3,697,141	3,697,131	3,696,629	3,696,581
	Nucla	527	896,805	896,837	897,059	897,059	897,108	895,690	896,486
	Rawhide #1	6,761	1,960,118	1,960,118	1,960,118	1,960,118	1,960,118	1,960,118	1,960,118
	Ray D Nixon 1	8,219	1,721,687	1,721,687	1,721,687	1,721,687	1,721,687	1,721,687	1,721,687
	San Juan	2,451	603,661	603,801	603,714	603,679	603,799	603,004	603,365
	Springerville	8,223	5,634,678	5,636,188	5,633,913	5,633,969	5,634,776	5,625,035	5,630,487
	Steam turbine subtotal		**48,344,640**	**48,348,638**	**48,341,590**	**48,343,248**	**48,344,880**	**48,319,488**	**48,332,026**
System power generation total			**55,552,395**	**55,542,246**	**55,591,363**	**55,582,629**	**55,582,640**	**55,645,301**	**55,626,074**
Spot Market									
	Sales (emissions subtracted)[c]	-	−1,512,509	−1,493,787	−1,543,444	−1,525,109	−1,536,444	−1,577,799	−1,560,383
	Purchases (emissions added)[c]	-	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal			**−374,727**	**−358,679**	**−395,534**	**−382,053**	**−388,469**	**−423,112**	**−407,447**
Total (system + spot market)			**55,177,668**	**55,183,567**	**55,195,829**	**55,200,576**	**55,194,171**	**55,222,189**	**55,218,627**

Footnotes on next page.

TABLE M-7 (Cont.)

[a] To convert from metric tons to tons, multiply by 1.023.

[b] A hyphen denotes "not applicable."

[c] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

TABLE M-8 Summary of Impacts of LTEMP Alternatives on CO_2e Emissions

	CO_2e Emissions (MT/yr)[a,b]						
CO_2e Emissions Source	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
System Power Generation							
Combined cycle	5,871,619	5,867,894	5,875,470	5,878,837	5,876,226	5,880,006	5,885,763
Composite[c]	711,604	712,068	711,574	712,296	712,186	713,199	711,081
Gas turbine	622,805	611,925	661,049	646,520	647,637	730,920	695,498
Internal combustion	1,726	1,721	1,680	1,728	1,711	1,688	1,706
Steam turbine	48,344,640	48,348,638	48,341,590	48,343,248	48,344,880	48,319,488	48,332,026
System subtotal	**55,552,395**	**55,542,246**	**55,591,363**	**55,582,629**	**55,582,640**	**55,645,301**	**55,626,074**
Spot Market[d]							
Sales (emissions subtracted)	−1,512,509	−1,493,787	−1,543,444	−1,525,109	−1,536,444	−1,577,799	−1,560,383
Purchases (emissions added)	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal	**−374,727**	**−358,679**	**−395,534**	**−382,053**	**−388,469**	**−423,112**	**−407,447**
Total emissions (system + spot market)	**55,177,668**	**55,183,567**	**55,195,829**	**55,200,576**	**55,194,171**	**55,222,189**	**55,218,627**
	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Change in total emissions from Alternative A (MT/yr)	0	5,900	18,161	22,908	16,503	44,522	40,960
Change as a percentage of total 11-state GHG emissions[e]	No change from current conditions	0.0005% increase	0.0015% increase	0.0019% increase	0.0013% increase	0.0036% increase	0.0033% increase
Change as a percentage of total U.S. GHG emissions[f]	No change from current conditions	0.00009% increase	0.00027% increase	0.00034% increase	0.00024% increase	0.00065% increase	0.00060% increase

[a] GHG emissions are expressed in carbon dioxide equivalent (CO_2e).

[b] GHG emissions (MT) from combustion-related powerplants in the Western Interconnect averaged over the 20-year LTEMP period.

[c] Unspecified generation type.

[d] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnection. Sales result in a net credit to total Western Interconnection emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnection. Emissions related to these purchases are added to the total emissions in the Western Interconnection.

[e] Total 11-state GHG emissions at 1,226.4 million MT/yr CO_2e in 2010 (see Table 3.15-3).

[f] U.S. total GHG emissions at 6,810.3 million MT/yr CO_2e in 2010 (EPA 2013).

APPENDIX N:

GOVERNMENT-TO-GOVERNMENT AND NATIONAL HISTORIC PRESERVATION ACT CONSULTATION

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APPENDIX N:

GOVERNMENT-TO-GOVERNMENT AND NATIONAL HISTORIC PRESERVATION ACT CONSULTATION

This appendix presents the correspondence pertaining to government-to-government and National Historic Preservation Act of 1966 (NHPA) Section 106 consultation for the Long-Term Experimental Management Program (LTEMP) Environmental Impact Statement (EIS). Attachment 1 provides copies of signed Memorandums of Understanding (MOUs), Attachment 2 provides official correspondence with Tribes, and Attachment 3 contains a copy of the letter to the Arizona State Historic Preservation Officer.

N.1 GOVERNMENT-TO-GOVERNMENT CONSULTATION

As detailed in Chapter 5 of the EIS, both the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) coordinate and consult with all Tribal governments, American Indian communities and organizations, and Tribal individuals whose interests might be directly and substantially affected by activities within their jurisdiction. Both agencies strive to provide Indian Tribes with sufficient opportunities for productive participation in planning and resource management decision-making. In addition, Section 106 of the NHPA requires federal agencies to consult with Indian Tribes on undertakings on Tribal lands and on historic properties of significance to the Tribes that may be affected by an undertaking (36 CFR 800.2 (c)(2)) (see Section 4.8.1). Agency-specific guidance provides additional direction for American Indian consultations (see Section 5.2.3).

On January 21, 2011, an e-mail was sent to Tribes that were previous cooperators on the Glen Canyon Dam EIS (Reclamation 1995)—the Southern Paiute Consortium, the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, and the Pueblo of Zuni—with an invitation to attend the initial "kickoff" meeting for the LTEMP EIS on February 11, 2011. Representatives from the Navajo Nation and the Pueblo of Zuni attended this meeting.

On October 17, 2011, an e-mail was sent to the Southern Paiute Consortium, the Hualapai Tribe, the Hopi Tribe, the Navajo Nation, and the Pueblo of Zuni indicating that Reclamation published in the *Federal Register* a Notice of Intent (NOI) to develop a LTEMP and prepare a LTEMP EIS. In this NOI, the public was notified of upcoming public scoping meetings and provided information on how to participate in the LTEMP public scoping process. A link to the project website and project lead contact information was provided.

On November 4, 2011, an e-mail was sent to the Hopi Tribe, the Southern Paiute Consortium, the Las Vegas Tribe of Paiute Indians, the Moapa Band of Paiute Indians, the Paiute Indian Tribe of Utah, the Havasupai Tribe, the Hualapai Tribe, the Navajo Nation, and the Pueblo of Zuni with an update on the LTEMP process. The e-mail summarized NOI publications and provided contact information for project leads. The e-mail also stated that several Tribes had already indicated their desire to participate as Cooperating Agencies and the joint leads would

soon be formally contacting all potentially interested American Indian Tribes to initiate consultation.

On November 30, 2011, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS. A letter, sent by the joint-lead agencies, provided notification of the intent to prepare the LTEMP EIS, initiated government-to-government consultation, and invited the Tribes to identify concerns related to historic properties, including traditional cultural properties and archaeological sites; natural resources; relevant Indian Trust assets; and other issues of importance.

On December 8, 2011, in accordance with Title 40 *Code of Federal Regulations*, Part 1501.6 (40 CFR 1501.6), concerning the Council on Environmental Quality (CEQ) regulations for implementing the procedural provisions of the National Environmental Policy Act (NEPA), and 43 CFR 46.225, concerning the Department of the Interior's (DOI's) regulations for implementing NEPA, Reclamation and NPS invited 11 Tribes to participate as Cooperating Agencies in the development of the EIS.

A total of 31 Tribes responded to the invitations. Six Tribes agreed to participate as Cooperating Agencies (the Havasupai Tribe, the Hopi Tribe, the Hualapai Tribe, the Kaibab Band of Paiute Indians, the Navajo Nation, the Pueblo of Zuni); three Tribes (the Fort Mojave Tribal Council, Pueblo of Zia, and the Gila River Indian Community) agreed to participate as Consulting Tribes; eight Tribes (Pueblo of Santa Clara, Ute Indian Tribe, Ute Mountain Ute, Pueblo of Nambe, Yavapai Apache, Paiute Indian Tribe of Utah, the Pueblo of Santa Ana, and the Fort Yuma Quechan) declined participation, but asked to remain on the mailing list; and 11 Tribes (Ak Chin Indian Community, Cocopah Indian Tribe, Fort McDowell Yavapai Tribal Council, Jicarilla Apache Nation, Ohkay Owingeh, Southern Ute Tribal Council, the Pueblo of Laguna, the Pueblo of Sandia, Yavapai-Prescott Indian Tribe, Tohono O'odham Nation, and the White Mountain Apache) declined participation in the LTEMP EIS. The joint-leads have yet to receive a response to the request for consultation from the remaining 15 Tribes (Colorado River Indian Tribes, Chemehuevi Tribal Council, Las Vegas Tribe of Paiute Indians, Moapa Band of Paiute Indians, Salt River Pima-Maricopa Indian Community, San Carlos Apache Tribe, San Juan Southern Paiute Tribe, the Pascua Yaqui Tribe, the Pueblo of Acoma, the Pueblo of Cochiti, the Pueblo of Jemez, the Pueblo of Pojoaque, the Pueblo of San Felipe, the Pueblo of Tesuque, and the Tonto Apache Tribe) despite follow-up phone calls and e-mails.

Although the Pueblo of Zia agreed to participate as a Consulting Tribe, there was little participation from the Pueblo. On February 11, 2014, an e-mail was sent to a Tribal representative asking if the Pueblo of Zia would like to remain a Consulting Tribe or be moved to the mailing list. A hard copy of this letter was also sent to the Tribe. No response was received and the joint-leads agreed to move the Pueblo of Zia to the mailing list. A summary of Tribal Participation Status is provided in Table N-1 and a summary of follow-up inquiries is provided in Table N-2.

Beginning in February 2012, the Tribes participating as Cooperating Agencies were invited to monthly conference calls to review progress and to reach agreement on major issues during the preparation of the EIS. Prior to these meetings, Tribes were sent an invitation to

TABLE N-1 Summary of Tribal Participation Status

Participating Tribes	Declined Participation	No Response
Cooperating Agencies	Ak Chin Indian Community	Chemehuevi Tribal Council
The Havasupai Tribe	Chemehuevi Tribal Council	Colorado River Indian Tribes
The Hopi Tribe	Cocopah Indian Tribe	Las Vegas Tribe of Paiute Indians
The Hualapai Tribe	Fort McDowell Yavapai Tribal Council	Moapa Band of Paiute Indians
The Kaibab Band of Paiute Indians	Jicarilla Apache Nation	Salt River Pima-Maricopa Indian Community
The Navajo Nation	Ohkay Owingeh	San Carlos Apache Tribe
The Pueblo of Zuni	Southern Ute Tribal Council	San Juan Southern Paiute Tribe
	The Pueblo of Laguna	The Pascua Yaqui Tribe
Consulting Tribes	The Pueblo of Sandia	The Pueblo of Acoma
The Fort Mojave Tribal Council	Tohono O'odham Nation	The Pueblo of Conchiti
Gila River Indian Community	White Mountain Apache	The Pueblo of Jemez
	Yavapai-Prescott Indian Tribe	The Pueblo of Pojoaque
Mailing List		The Pueblo of San Felipe
Fort Yuma Quechan		The Pueblo of Tesuque
Paiute Indian Tribe of Utah		Tonto Apache Tribe
The Pueblo of Nambe		
The Pueblo of Santa Ana		
The Pueblo of Santa Clara		
The Pueblo of Zia		
Ute Indian Tribe		
Ute Mountain Ute		
Yavapai-Apache		

each meeting as well as a meeting reminder with an agenda, call-in number, and password. Monthly Cooperating Agency meetings are ongoing and will continue to be held throughout the length of the LTEMP.

Cooperating Agency Tribes were invited to sign a MOU defining the relationship and duties of the joint-lead and Cooperating Agencies in completing the NEPA compliance for the LTEMP. A draft copy of the MOU was sent to all Cooperating Agency Tribes on March 6, 2012, and Tribes were encouraged to make revisions and provide comments. Final copies of the MOU were distributed to each Tribe after revisions and comments were returned and incorporated into each MOU. Signed copies were returned to the joint-leads by all Cooperating Agency Tribes. Copies of the MOUs are provided in Attachment 1.

In addition to Cooperating Agency meetings, more than 30 meetings, workshops, and webinars were conducted with stakeholders and Cooperating Agencies to assist in the development of alternatives and performance criteria, explain the Structured Decision Analysis (SDA), conduct swing-weighting exercises, and provide general status updates. A series of Tribal-specific workshops, conference calls, and webinars were also held to identify Tribal resource goals and ways to measure the relative performance of alternatives against those goals. Prior to these meetings, inquiries were sent to Tribes to find a meeting time that would best suit

TABLE N-2 Summary of Tribal Correspondence

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Ak Chin Indian Community	February 2012: Steve Daron, Lake Mead National Recreation Area (LMNRA), attempted phone contact with the Ak Chin Indian Community three times in February. He was unable to reach anyone. May 4, 2012: Steve Daron spoke with Carol Antone and re-sent the November 30 letter. Phone call follow-up, but no response.	July 31, 2012: Letter from Louis J. Manuel, Jr., Chairman indicating that the Ak Chin Indian Community is not interested in participating in the LTEMP process at this time.
Chemehuevi Tribal Council	February 2012: Steve Daron, LMNRA, attempted to call the Chemehuevi Tribal Council three times in February. He was unable to reach anyone.	No response.
Cocopah Indian Tribe	January 23, 2012: John Halliday, DOI, called and was referred from the Chair Office to Tribal Administrator Christopher Nunez. John left him a message regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 25, 2012: Tribal staff member Barbera Mathias called Mr. Halliday and informed him that the Cocopah did not wish to participate in the LTEMP process.
Colorado River Indian Tribes	February 2012: Steve Daron, LMNRA, attempted to call Colorado River Indian Tribes three times in February and received no response. September 24, 2012: Jennifer Abplanalp, Argonne, called and left a message for Mr. Buma requesting an e-mail or mailing address to send LTEMP information.	August 10, 2012: Consulting and Cooperating Tribes meeting was held in Tempe, Arizona. Grant Buma, Acting Director of Water Resources Department, was in attendance. September 24, 2012: Mr. Buma called back with his e-mail address.
Fort McDowell Yavapai Tribal Council	January 23, 2012: John Halliday, DOI, called and left a message for Karen Ray regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday left a message with Ms. Ray asking if the Tribe wished to participate in the LTEMP process. January 27, 2012: Mr. Halliday left a message with Ms. Ray asking if the Tribe wished to participate in the LTEMP process. February 6, 2012: Mr. Halliday called and spoke to Tribal Cultural Representative Gary Loutenhizer. February 14, 2012: Mr. Halliday called and spoke to Mr. Loutenhizer.	February 6, 2012: Mr. Loutenhizer said that he would check with Karen Ray regarding participation in LTEMP and would get back to John soon. February 14, 2014: Mr. Loutenhizer indicated that the Ft. McDowell Yavapai did not want to participate in LTEMP process.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Fort Mojave Tribal Council	December 6, 2013: Steve Daron, LMNRA, spoke with Nora McDowell-Antone and asked if the Fort Mojave were still interested in participating as a consulting Tribe for the LTEMP EIS. January 30, 2014: Mr. Daron spoke with Ms. McDowell-Antone regarding the Fort Mojave participation as a consulting Tribe for the LTEMP EIS.	February 2012: Linda Otero, Director of the Aha Makav Cultural Society, called Steve Daron and indicated that the Fort Mojave were interested in participating in government-to-government consultation. April 24, 2012: Ms. Otero called Mr. Daron to schedule a meeting with the joint-lead agencies for an overview of the project. December 6, 2013: Ms. McDowell-Antone indicated that the Tribe is still interested. January 30, 2014: Ms. McDowell-Antone informed Mr. Daron that Ms. Otero had been temporarily assigned for 3 to 6 months but the Tribe would like to stay in the loop and receive information. Ms. McDowell-Antone requested the most recent documents.
Fort Yuma Quechan Tribe	February 2012: Steven Daron, LMNRA, spoke with John Bathke, Tribal Historic Preservation Officer (THPO), regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. Steve also sent Mr. Bathke an e-mail with information on the LTEMP website. May 8, 2012: Mr. Daron spoke with John Bathke, THPO, regarding LTEMP consultation. May 14, 2012: Mr. Daron sent Mr. Bathke an e-mail with some potential dates for a meeting. May 29, 2012: Mr. Daron informed Mr. Bathke that the LTEMP representatives would be available for a meeting on June 22, as requested. May 30, 2012: Mr. Daron spoke with Mr. Bathke regarding the LTEMP. April 4, 2013: Bruce Verhaaren, Argonne, called the new THPO, Arlene Kingery, Mr. Bathke's replacement, regarding the Tribe's continued involvement in the LTEMP process.	February 15, 2012: John Bathke, THPO, called and left a message for Steven Daron requesting LTEMP consultation. May 8, 2012: Mr. Bathke indicated that the Cultural Committee would like a presentation on the LTEMP project and asked Mr. Daron to provide dates when LTEMP representatives could come give a presentation. May 29, 2012: Mr. Bathke e-mailed Mr. Daron to request a meeting with LTEMP representatives on June 22, 2012, to discuss the LTEMP process. May 30, 2012: Mr. Bathke indicated that the Quechan are more interested in the impacts the project would have on cultural resources because the Tribe has heard that previous releases from Glen Canyon Dam have had impacts on sites. April 4, 2013: Ms. Kingery informed Bruce Verhaaren that the Quechan Cultural Committee had decided that they would no longer like to consult on the LTEMP but would like to remain on the mailing list.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Gila River Indian Community Council	January 9, 2012: Janet Cohen confirmed receipt of the Tribe's interest in consultation. February 2012: Steven Daron, LMNRA, attempted contact with the Gila River Indian Community Council May 14, 2012: Mr. Daron spoke with Larry Benallie, Archaeology Compliance Specialist, regarding the Tribe's participation in the LTEMP process. June 20, 2012: Bruce Verhaaren, Argonne, sent the draft copy of *American Indian Perspectives and Values Related to the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement.*	January 3, 2012: Barnaby Lewis, THPO, sent a letter to John Wessels, NPS, and an e-mail to Ms. Cohen, NPS, indicating the Tribe's interest in consultation. May 14, 2012: Mr. Benallie informed Mr. Daron that the Gila River Indian Community Council did not want to schedule a meeting at this time, but would re-evaluate the decision after the alternatives have been chosen. Mr. Benallie also requested a copy of the draft copy of *American Indian Perspectives and Values Related to the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement* and indicated that the Tribe would like to remain on the mailing list.
Havasupai Tribe	January 23, 2012: E-mail from Janet Cohen, NPS, to Chair and Vice Chair asking the Havasupai what their level of interest is in the project. Ms. Cohen attached a copy of the November and December 2011 letters and asked if they could get back to her by the end of the week regarding their involvement. January 27, 2012: Ms. Cohen tried to call Chairman Watahomigie and the Vice Chair regarding the November and December 2011 LTEMP letters asking if the Tribe wished to participate in the LTEMP process but was unable to reach anyone. January 30, 2012: Ms. Cohen called and spoke to Chairman Watahomigie regarding the November and December 2011 LTEMP letters asking if the Tribe wished to participate in the LTEMP process. Ms. Cohen resent the November and December 2011 letters and asked Chairman Watahomigie to return the Cooperating Agency form. February 7, 2012: Ms. Cohen sent copies of the November and December 2011 letters to the Tribal Secretary as per the Tribe's request. April 8, 2012: Sarah Rinkevich called and spoke with Margaret Vick, Attorney for the Havasupai, asking if they would like to submit a funding proposal and if they were still interested in participating in the LTEMP. July 2012: MOU signed by joint-leads.	January 30, 2012: Chairman Watahomigie said the Tribe is interested in participating but did not specify whether they wanted to be a Cooperating Agency or not. Chairman identified the Tribal secretary (Jaycee Manakaja) as the point of contact to send meeting information, etc. February 27, 2012: Cooperating Agency form returned indicating the Tribe would like to participate as a Cooperating Agency. July 6, 2012: MOU signed. April 8, 2013: Ms. Vick indicated that the Havasupai have not submitted any funding proposal for LTEMP, but she would ask the Chairman if the Havasupai were interested in funding. Ms. Vick indicated that the Havasupai may not be interested in sharing Grand Canyon cultural connections with the federal government but that the engineering and water quality departments may be interested in reviewing the alternatives. September 30, 2015: Havasupai Tribe submitted comments on the LTEMP DEIS.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Havasupai Tribe (Cont.)	December 17, 2014: Preliminary Chapters 1 and 2 sent to Havasupai Tribe for review. April 15, 2015: Preliminary Chapter 3 sent to Havasupai Tribe for review. July 1, 2015: LTEMP DEIS sent to Havasupai Tribe for review.	May 9, 2016: Havasupai Tribe submitted additional comments on the LTEMP DEIS.
Hopi Tribe	January 13, 2012: Janet Cohen, NPS, spoke with Mike Yeatts regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process February 15, 2012: Ms. Cohen spoke with Mr. Yeatts regarding Hopi participation as a Cooperating Agency in the LTEMP process. She asked him to return the Cooperating Agency form to Argonne as soon as possible. She e-mailed another copy of the November 2011 letter and the form to Mr. Yeatts. October 2014: MOU signed by joint-leads December 17, 2014: Preliminary Chapters 1 and 2 sent to Hopi Tribe for review. April 15, 2015: Preliminary Chapter 3 sent to Hopi Tribe for review. July 1, 2015: LTEMP DEIS sent to Hopi Tribe for review.	February 15, 2012: Mr. Yeatts indicated that he will follow up with Leigh Kuwanwiswima, THPO, to see if the Cooperating Agency form had been sent in. June 7, 2013: MOU signed. January 23, 2015: Hopi Tribe submitted comments on preliminary Chapters 1 and 2. September 30, 2015: Hopi Tribe submitted comments on LTEMP DEIS. April 29, 2016: Hopi Tribe submitted additional comments on the LTEMP DEIS.
Hualapai Tribe	November 16, 2012: Rob Billerbeck, NPS, called and spoke with Kerry Christiansen regarding the LTEMP project. January 5, 2012: The November 30, 2011, letter of invitation to become a Cooperating Agency letter was returned to Argonne. The letter was resent via e-mail to Loretta Jackson-Kelly, THPO. Ms. Jackson-Kelly was informed that the deadline for informing the lead-agencies if the Hualapai wished to be a cooperating agency was Friday January 6, 2012, and asked Ms. Jackson-Kelly to let her know if the Hualapai needed more time.	November 16, 2012: Mr. Christiansen expressed that the Hualapai Tribe may be interested in having LTEMP representatives meet with the Hualapai Tribal Council as they felt this has not happened enough on past processes. January 6, 2012: Ms. Jackson-Kelly returned the Cooperating Agency form via fax. The Hualapai would like to be a Cooperating Agency.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Hualapai Tribe (Cont.)	December 16, 2013: Jim May, Argonne, spoke with Peter Bungart and Earlene Havatone, Exec. Director of Grand Canyon West, about the impacts of Glen Canyon Dam releases on the Hualapai's river-running businesses. Mr. May encouraged Ms. Havatone to try to quantify the impacts and to include pictures of the kinds of damage and concerns that the Hualapai have. October 2014: MOU signed by joint-leads. December 17, 2014: Preliminary Chapters 1 and 2 sent to the Hualapai Tribe for review. April 15, 2015: Preliminary Chapter 3 sent to the Hualapai Tribe for review. July 1, 2015: LTEMP preliminary draft EIS sent to the Hualapai Tribe for review.	October 4, 2012: MOU signed. April 8, 2013: Mr. Bungart informed Ms. Rinkevich that the Hualapai already submitted their request for funding. Ms. Jackson-Kelly and he requested a presentation by LTEMP representatives at an open house at the next council meeting on May 3, 2013. August 16, 2013: Mr. Bungart sent a follow-up e-mail in response to a discussion held at the Tribal Values Workshop on Tuesday August 6, 2013, with suggested performance metrics that would be both practical and useful for Hualapai resources of concern. December 16, 2013: Major concerns expressed by Ms. Havatone include bank erosion, difficulty accessing docks, tougher navigation in a narrowing channel, difficulty in accessing the shoreline up steep banks and excessive wear and tear on outboard motors. Ms. Havatone indicated that she had not tried to quantify the effects of the impacts before, but she thought she could. April 16, 2015: The Hualapai Tribe submitted comments on preliminary Chapters 1, 2, and 3. September 30, 2015: The Hualapai Tribe submitted comments on the LTEMP DEIS. May 9, 2016: Hualapai Tribe submitted additional comments on the LTEMP DEIS.
Jicarilla Apache Nation	January 26, 2012: John Halliday, DOI, called Jeffrey Blythe regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 26, 2012: Mr. Blythe indicated that the Jicarilla Apache Nation did not wish to participate in the LTEMP process.
Kaibab Band of Paiute Indians	May/June/July 2012: MOU signed by joint-leads. December 17, 2014: Preliminary Chapters 1 and 2 sent to Kaibab Band of Paiute Indians for review.	February 15, 2011: The Cooperating Agency form as signed and returned. May 2, 2012: MOU signed.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Kaibab Band of Paiute Indians (Cont.)	April 15, 2015: Preliminary Chapter 3 sent to Kaibab Band of Paiute Indians for review. May/June/July 2012: MOU signed by joint-leads. December 17, 2014: Preliminary Chapters 1 and 2 sent to Kaibab Band of Paiute Indians for review. April 15, 2015: Preliminary Chapter 3 sent to Kaibab Band of Paiute Indians for review. July 1, 2015: LTEMP DEIS sent to Kaibab Band of Paiute Indians for review. November 2, 2015: Reclamation informed Charley Bulletts that the joint-leads had not received comments from the Kaibab Band of Paiute Indians as referenced in the September 29, 2015, letter and requested that Mr. Bulletts resend the comments.	January 6, 2015: Mr. Bulletts inquired as to when Chapter 3 would be available for review by Tribal Representatives. February 15, 2011: The Cooperating Agency form as signed and returned. May 2, 2012: MOU signed. January 6, 2015: Mr. Bulletts inquired as to when Chapter 3 would be available for review by Tribal Representatives. September 29, 2015: Kaibab Band of Paiute Indians submitted comments on the LTEMP DEIS. References a letter dated April 8, 2015, regarding comments on preliminary Chapters 1 and 2 that were never received by the joint-lead agencies. November 3, 2015: Mr. Bulletts sent comments on Chapters 1 and 2. Comments received by joint-lead agencies.
Las Vegas Tribe of Paiute Indians	January 23, 2012: Janet Cohen, NPS, sent an e-mail to Kenny Anderson with a copy of the initial November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 27, 2012: Ms. Cohen called Kenny Anderson to follow up on an e-mail containing copies of letters sent on January 23, 2012. February 15, 2012: Ms. Cohen sent an e-mail to Mr. Anderson with a copy of the initial November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. February 22, 2012: Ms. Cohen called Mr. Anderson and left a voicemail indicating that the NPS will have to assume that the Las Vegas Paiute are not interested in this project since they have not indicated otherwise.	January 27, 2012: Mr. Anderson indicated that the Las Vegas Tribe of Paiute Indians are likely interested in some level of consultation and would like to review the letters before saying for sure.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Moapa Band of Paiute Indians	January 23, 2012: Janet Cohen, NPS, sent an e-mail to Chairman Anderson containing copies of the initial November 2011 and December 2011 LTEMP letters asking if the Tribe wished to participate in the LTEMP process. January 27, 2012: Ms. Cohen called Chairman Anderson to follow-up on the e-mail sent out on January 23, 2012. Ms. Cohen asked Chairman Anderson to look at the e-mail and the letters and let the NPS know if the Moapa Band of Paiute Indians is interested in consultation or not. February 15, 2012: Janet Cohen, NPS, sent an e-mail to Chairman Anderson with the November 2011 and December 2011 LTEMP letters attached and asked if the Tribe was interested in consultation. The letter also indicated that if the NPS does not receive a response, the NPS will assume that the Moapa Band of Paiute Indians is not interested in consultation. February 22, 2012: Ms. Cohen called Chairman Anderson and left a voicemail indicating the NPS will have to assume the Moapa are not interested in the project since they have not indicated otherwise.	January 27, 2012: Chairman Anderson indicated he was very backed up on reviewing incoming e-mail and he wasn't sure if he had seen the letters or the e-mail.
Navajo Nation	January 13, 2012: Janet Cohen, NPS, spoke with Jason John regarding the proper contact person for LTEMP. It was confirmed that The Department of Water Resources will represent the Tribe in its Cooperating Agency status. Ms. Cohen will follow up with the Historic Preservation Department in regards to Section 106 and cultural resources. Ms. Cohen provided the web address for the LTEMP project. May 20, 2013: Bruce Verhaaren, Argonne, spoke with Jason John, Navajo Department of Water and Power (NDWP). Bruce advised Mr. John to call Sarah Rinkevich, DOI, to request a meeting. February 11, 2014: Mr. Verhaaren e-mailed a letter to Jason John, NDWP, and Tony Joe, Supervisory Anthropologist, from the joint-leads of the LTEMP EIS concerning the pending MOU between the Navajo Nation, the Bureau of Reclamation, and the NPS regarding the participation of the Navajo Nation as a cooperating agency for the EIS.	February 28, 2011: Letter from Tony Joe of the Navajo Nation with comments on the preliminary draft outline distributed at the kickoff meeting. January 9, 2012: Cooperating Agency form was submitted indicating the Navajo Nation would like to participate in the LTEMP as a Cooperating Agency. May 20, 2013: Mr. John requested a meeting or teleconference to discuss the LTEMP. February 21, 2014: Return receipt confirmation for the February 11, 2014, letter to Mr. John. February 21, 2014: Mr. John sent the joint-leads a letter from the Navajo Nation President Ben Shelly requesting government-to-government consultation.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Navajo Nation (Cont.)	February 13, 2014: A hardcopy of the February 11, 2014, letter was sent to Tony Joe and Jason John.	February 24, 2014: Return receipt confirmation for the February 11, 2014, letter to Tony Joe.
	February 28, 2014: Rob Billerbeck, NPS spoke with Mr. John regarding government-to-government consultation.	February 28, 2014: Mr. John indicated that there may have been a misunderstanding. The Navajo Nation would like LTEMP representatives to explain the LTEMP process before signing the MOU. The Navajo Nation will likely wait until summer for formal government-to-government consultation.
	March 17, 2014: Mr. Billerbeck sent an e-mail to Mr. John in reply to the February 21, 2014, e-mail and attached letter requesting to meet with the project managers of LTEMP. Mr. Billerbeck apologized for not being able to meet on the requested dates and proposed new dates for a meeting and attached some additional information on the LTEMP project for the Navajo to review in advance.	March 17, 2014: Mr. John requested a meeting at 2 p.m. on April 10, 2014, in Window Rock, Arizona.
	October 2014: MOU signed by joint-leads	June 9, 2014: MOU signed.
	December 17, 2014: Preliminary Chapters 1 and 2 sent to the Navajo Nation for review.	October 6, 2015: Navajo Nation submitted comments on the LTEMP DEIS.
	April 15, 2015: Preliminary Chapter 3 sent to the Navajo Nation for review.	May 4 and 5, 2016: Navajo Nation submitted additional comments on the LTEMP DEIS.
	July 1, 2015: LTEMP DEIS sent to the Navajo Nation for review.	
Ohkay Owingeh	January 23, 2012: John Halliday, DOI, called and left a message for Anthony Moquino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 27, 2012: Mr. Moquino indicated that the Tribe did not wish to participate in the LTEMP process.
	January 26, 2012: Mr. Halliday left a message with Mr. Moquino asking if the Tribe wished to participate in the LTEMP process.	
	January 27, 2012: Mr. Halliday spoke with Mr. Moquino and asked if the Tribe would like to participate in the LTEMP process	
Paiute Indian Tribe of Utah	No follow-up needed. Tribe returned form and requested to be added to mailing list.	January 9, 2012: The Cooperating Agency form was returned. The Paiute Indian Tribe of Utah is not interested in being a Cooperating Agency, but would like to remain updated on the LTEMP.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pascua Yaqui Tribe	January 24, 2012: John Halliday, DOI, called and left a message for Chairperson Peter Yucupicio regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and left another message for Chairman Yucupicio. January 27, 2012: Mr. Halliday called and left another message for Chairman Yucupicio. February 6, 2014: Mr. Halliday called and left another message for Chairman Yucupicio. February 14, 2014: Mr. Halliday called and left another message for Chairman Yucupicio.	No response.
Pueblo of Acoma	January 23, 2012: John Halliday, DOI, called and left a message for Theresa Pasquale regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday left another message for Ms. Pasquale. January 27, 2012: Mr. Halliday left another message for Ms. Pasquale. February 14, 2012: Mr. Halliday left another message for Ms. Pasquale.	No response.
Pueblo of Cochiti	January 23, 2012: John Halliday, DOI, called and left a message for Jacob Pecos, Director, Department of Natural Resources, regarding the LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday left another message for Mr. Pecos. January 27, 2012: Mr. Halliday left another message for Mr. Pecos. February 14, 2012: Mr. Halliday left another message for Mr. Pecos.	No response.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of Jemez	January 23, 2012: John Halliday, DOI, called and left a message for Natural Resources Director Christopher Toya regarding the LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	No response.
	January 26, 2012: Mr. Halliday left another message for Mr. Toya.	
	January 27, 2012: Mr. Halliday left another message for Mr. Toya.	
	February 14, 2012: Mr. Halliday left another message for Mr. Toya.	
Pueblo of Laguna	January 23, 2012: John Halliday, DOI, called and was referred from the Governor's Office to Tribal Staff Member Adam Ringia and left a message for him regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 26, 2012: Mr. Ringia indicated that the Pueblo of Laguna does not wish to participate in the LTEMP process.
	January 26, 2012: Mr. Halliday called Mr. Ringia regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	
Pueblo of Nambe	January 23, 2012: John Halliday, DOI, called and left a message for Steve Romero regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 27, 2012: Ms. Carnevale informed Mr. Halliday that she is the new Tribal Environmental Officer. She indicated that the Tribe would like to schedule a consultation meeting.
	January 27, 2012: Mr. Halliday spoke with Nichole Carnevale regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	May 3, 2012: Mary Barger received an e-mail from Ms. Carnevale indicating that the Tribe would not like to actively participate in LTEMP but would like to remain on the mailing list.
Pueblo of Pojoaque	January 24, 2012: John Halliday, DOI, called and left message for Vernon Lujan, THPO, regarding the LTEMP letter asking if the Tribe wished to participate in the LTEMP process	March 29, 2012: Mr. Halliday received a message from Mr. Lujan indicating that the Tribe would like to participate in the LTEMP process.
	January 26, 2012: Mr. Halliday called and left another message for Mr. Lujan.	May 03, 2012: The Pueblo of Pojoaque indicated that they were interested in setting up a meeting and would get back to Ms. Barger, Reclamation, with a date to meet.
	January 27, 2012: Mr. Halliday called and left another message for Mr. Lujan.	
	February 14, 2012: Mr. Halliday called and left another message for Mr. Lujan.	May 14, 2012: Linda was not familiar with the project and gave Ms. Barger Mr. Lujan's cell phone number.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of Pojoaque (Cont.)	May 14, 2012: Ms. Barger called Mr. Lujan to schedule a meeting time and spoke with Linda, a member of his staff. Ms. Barger left Mr. Lujan a message on his cell phone. May 16, 2012: Ms. Barger called and left a voicemail for Mr. Lujan. She offered to put them on the mailing list or schedule a meeting. May 17, 2012: Ms. Barger left another voicemail with Mr. Lujan. May 21, 2012: Ms. Barger called and spoke with Mr. Lujan. May 22, 2012: Adrianne Carr, Argonne, e-mailed a copy of the November 2011 LTEMP letter and the Draft Tribal Consultation Plan to Mr. Lujan for review. May 29, 2012: Ms. Barger called Mr. Lujan to follow-up on the documents sent on May 22 and see if the Pueblo was interested in participating in LTEMP. June 09, 2012: Ms. Barger spoke to Mr. Lujan regarding LTEMP participation. June 19, 2012: Ms. Barger left a message with Mr. Lujan regarding participation in the LTEMP. June 25, 2012: Ms. Barger left a message with Mr. Lujan. She stated that since she has not heard from him, the joint-leads are assuming that the Pueblo of Pojoaque is not interested in meeting on the EIS, and to contact her by June 29 if her assumption was incorrect.	May 21, 2012: Mr. Lujan requested more information so he could decide if the Pueblo of Pojoaque should consult. May 29, 2012: Mr. Lujan indicated that he did not have time to review the project information that Ms. Barger sent. June 9, 2012: Mr. Lujan indicated that he forwarded the information to the Governor's office and was awaiting a recommendation.
Pueblo of San Felipe	January 23, 2012: John Halliday, DOI, called and was referred from the Governor's Office to Tribal Administrator Daryl Candelaria. Mr. Halliday left him a message regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and left another message with Mr. Candelaria. January 27, 2012: Mr. Halliday called and left another message with Mr. Candelaria.	No response.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of San Felipe (Cont.)	February 14, 2012: Mr. Halliday called and left another message with Mr. Candelaria.	
Pueblo of Sandia	January 23, 2012: Mr. Halliday, DOI, called and left a message for Environmental Director Frank Chavez regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and spoke with Mr. Chavez regarding Pueblo of Sandia participation in the LTEMP process.	January 26, 2012: Mr. Chavez indicated the Pueblo of Sandia did not want to participate.
Pueblo of Santa Ana	January 24, 2012: John Halliday, DOI, called and spoke with Tribal Liaison Ben Robbins regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 25, 2012: Mr. Halliday e-mailed copies of the November 2011 letter to Ben. February 06, 2012: Mr. Halliday called and left a message for Mr. Robbins regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. February 14, 2012: Mr. Halliday called and spoke with Mr. Robbins regarding Pueblo of Santa Ana participation in the LTEMP process.	January 24, 2012: Mr. Robbins asked Mr. Halliday to e-mail him another copy of the letter and he would ask the council and get back to John. February 14, 2012: Mr. Robbins indicated that the Tribe did not wish to participate in the LTEMP process, but would like to continue receiving information and updates.
Pueblo of Santa Clara	January 23, 2012: John Halliday, DOI, called to speak with Ben Chavarria, Native American Graves Protection and Repatriation Act (NAGPRA) Contact, regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 24, 2012: Mr. Halliday called and left a message for Mr. Chavarria regarding the Tribe's participation in the LTEMP process. January 26, 2012: Mr. Halliday called and left a message for Mr. Chavarria regarding the Tribe's participation in the LTEMP.	January 23, 2012: Mr. Halliday spoke with a Tribal staff member who informed John that the Tribe was closed for the day and he should call back the next day. January 26, 2012: Mr. Chavarria returned Mr. Halliday's phone call. He informed Mr. Halliday that the Tribe does not wish to participate, but would like to remain on the mailing list.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of Tesuque	January 23, 2012: John Halliday, DOI, called and spoke with Governor Mark Mitchell regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. February 6, 2012: Mr. Halliday left a message for Governor Mitchell regarding the Pueblo's participation in the LTEMP process. February 14, 2012: Mr. Halliday left a message for Governor Mitchell regarding the Pueblo's participation in the LTEMP process.	January 23, 2012: Governor Mitchell informed Mr. Halliday that he would ask the council and get back to him.
Pueblo of Zia	January 23, 2012: John Halliday, DOI, called and left a message for Mr. Peter Pino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and left a message for Mr. Peter Pino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 27, 2012: Mr. Halliday called and left a message for Mr. Peter Pino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. February 6, 2012: Mr. Halliday called and left a message for Mr. Peter Pino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. February 14, 2012: Mr. Halliday called and left a message for Mr. Peter Pino regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. May 3, 2012: Mary Barger spoke with the Pueblo of Zia. They will get back to her on a date for a meeting. May 14, 2012: Ms. Barger spoke with Tribal Administrator Peter Pino and a meeting was scheduled for May 23.	February 29, 2012: Mr. Pino called Mr. Halliday. He said that the Pueblo of Zia would like LTEMP Representatives to come out to the Pueblo and make a presentation on this subject. February 18, 2014: Delivery Confirmation of February 13 letter signed by Tammy L. Pino.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of Zia (Cont.)	April 8, 2013: Sarah Rinkevich, Tribal Liaison, left a message for Mr. Peter Pino regarding the Tribe's participation in LTEMP. February 11, 2014: Bruce Verhaaren, Argonne, sent an e-mail to Governor David Pino regarding the Pueblo of Zia participation in the LTEMP process. The letter indicated that despite many attempts, Argonne and the joint-leads have not received a response from the Pueblo of Zia since January 2013 and advised that they would be moved to the mailing list unless otherwise instructed by February 28, 2014. February 13, 2014: Argonne sent a hardcopy of the above-referenced letter to Governor Pino.	
Pueblo of Zuni	November 10, 2011: Janet Cohen, NPS, presented information about the LTEMP to Kurt Dongoske and members of the Zuni Cultural Resources Advisory Team (ZCRAT). December 13, 2011: Ms. Heffernan met with the Zuni about another matter, but was advised by Mr. Dongoske that the Pueblo of Zuni will be a Cooperating Agency. January 9, 2012: Ms. Cohen confirmed the receipt of the Zuni's request to be a Cooperating Agency with Kurt Dongoske. August/September 2012: MOU signed by joint-leads. April 17, 2014: Bruce Verhaaren, Argonne, informed Mr. Dongoske that a draft copy of Chapter 3 should be available for Tribal review the week of April 21. April 30, 2014: Mr. Verhaaren informed Mr. Dongoske that Chapter 3 is still undergoing review by the joint-leads and he is not sure when the Tribes will be able to view it. May 5, 2014: Verhaaren informed Mr. Dongoske that text submitted by the Pueblo of Zuni was incorporated into the various technical areas of Chapter 3 and that the chapter will be ready for review upon approval of project management.	November 4, 2011: Mr. Dongoske called Beverly Heffernan, Reclamation, with some questions on the general LTEMP process. He asked why there was no public meeting in New Mexico and asked that Ms. Cohen provide information about the project. He indicated that Zuni would want a presentation sooner rather than later by John Wessels, NPS, and Larry Walkoviak, Reclamation. December 22, 2011: Governor Arlen Quetawki, Sr., sent a letter indicating that the Zuni would like to be a Cooperating Agency on the LTEMP. Mr. Quetawki advised that Mr. Dongoske is the primary representative of the Zuni for the LTEMP. The Cooperating Agency form was signed and enclosed. July 26, 2012: MOU signed. March 25, 2014: Mr. Dongoske requested a copy of Chapter 3 so that the ZCRAT could review how the Zuni information had been included. February 7, 2015: Pueblo of Zuni submitted comments on preliminary Chapters 1 and 2. June 24, 2015: Pueblo of Zuni submitted comments on preliminary Chapter 3.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Pueblo of Zuni (Cont.)	December 17, 2014: Preliminary Chapters 1 and 2 sent to Pueblo of Zuni for review.	September 29, 2015: Pueblo of Zuni submitted comments on the LTEMP DEIS.
	April 15, 2015: Preliminary Chapter 3 sent to Pueblo of Zuni for review.	May 4, 2016: Pueblo of Zuni submitted additional comments on the LTEMP DEIS.
	July 1, 2015: LTEMP DEIS sent to Pueblo of Zuni for review.	
Salt River Pima-Maricopa Indian Community	February 2012: Steve Daron, LMNRA, called the Salt River Maricopa Indian Community three times, but there was no response.	No response.
	May 14, 2012: Mr. Daron left a few messages with Shane Antone in the Cultural Resource Department but there was no response.	
San Carlos Apache Tribe	January 24, 2012: John Halliday, DOI, called the Tribal Administration staff regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. Mr. Halliday informed Reclamation about the name and address change of the Tribe.	January 24, 2014: A staff person informed Mr. Halliday that a new letter should be sent to the correct name and address.
	January 26, 2012: A copy of the November 2011 letter was sent to the new address.	February 14, 2012: Chairman Rambler requested that Mr. Halliday re-send the LTEMP letter via e-mail and he would get back to Mr. Halliday.
	January 30, 2012: A copy of the November 2011 letter was sent via e-mail.	No further response.
	February 14, 2012: Mr. Halliday called Chairman Terry Rambler regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. As requested, Mr. Halliday sent an e-mail to Chairman Rambler with the LTEMP letter attached.	
Southern Ute Tribal Council	January 23, 2012: John Halliday, DOI, called and left a message for NAGPRA Coordinator Neil Cloud regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	January 27, 2012: Mr. Naranjo informed Mr. Halliday that the Southern Ute Tribal Council did not wish to participate in the LTEMP process.
	January 26, 2012: Mr. Halliday called and left a message for Mr. Cloud regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Southern Ute Tribal Council (Cont.)	January 27, 2012: Mr. Halliday called and was referred to Mr. Alden Naranjo who was serving as the Acting Tribal NAGPRA representative. Mr. Halliday spoke to Mr. Naranjo regarding the LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	
Tohono O'odham Nation	January 24, 2012: John Halliday, DOI, called and left a message for Dr. Ned Norris, Jr., regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday left another message for Dr. Norris regarding the Tribe's participation in the LTEMP process. January 27, 2012: Mr. Halliday left another message for Dr. Norris regarding the Tribe's participation in the LTEMP process. February 06, 2012: Mr. Halliday left another message for Dr. Norris regarding the Tribe's participation in the LTEMP process.	May 03, 2014: Mary Barger, Reclamation, received an e-mail from Peter Steere, THPO, indicating that the Tribe does not wish to participate in the LTEMP process.
Tonto Apache Tribe	January 24, 2012: John Halliday, DOI, called and left a message for Chairman Ivan Smith regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and left a message for Chairman Smith regarding the Tribe's participation in the LTEMP process. January 27, 2012: Mr. Halliday called and left a message for Chairman Smith regarding the Tribe's participation in the LTEMP process. February 06, 2012: Mr. Halliday called and left a message for Chairman Smith regarding the Tribe's participation in the LTEMP process.	No response.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Ute Indian Tribe	January 23, 2012: John Halliday, DOI, called and left a message for Betsy Chapoose in the Cultural Rights and Protection Office regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and left a message for Ms. Chapoose, regarding the Tribe's participation in the LTEMP process. January 27, 2012: Mr. Halliday called and left a message for Ms. Chapoose, regarding the Tribe's participation in the LTEMP process.	February 1, 2012: Ms. Chapoose returned Mr. Halliday's phone call and informed him that the Tribe did not wish to participate in the LTEMP process, but would like to remain on the mailing list.
Ute Mountain Ute Tribe	February 29, 2012: Rosemary Sucec, Glen Canyon National Recreation Area (GCNRA), called and spoke with Lynn Hartman regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	February 29, 2012: Ms. Hartmann indicated that the Tribe did not wish to participate in the LTEMP process, but would like to remain on the mailing list.
White Mountain Apache	January 23, 2012: John Halliday, DOI, called and left a message for Chairman Ronny Lupe regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process. January 26, 2012: Mr. Halliday called and spoke with Chairman Lupe regarding the Tribe's participation in the LTEMP process. May 3, 2012: Mary Barger, Reclamation, spoke with Mark Altaha, THPO, about a consultation meeting. She also sent a follow-up e-mail to Mr. Altaha with the November 2011 LTEMP letter and requested Mr. Altaha let her know what kind of follow-up would be needed.	January 26, 2012: Mr. Lupe requested that LTEMP representatives meet with the Tribe to talk about the project and asked Mr. Halliday to coordinate the meeting with the Tribal Hydrologist, Cheryl Pailzot. May 3, 2012: Mr. Altaha informed Mary that it was not clear why the Chairman told Mr. Halliday that he wanted a meeting since the project was so far away. Mr. Altaha indicated he would look into the matter and get back to Ms. Barger. May 12, 2012: Mr. Altaha responded to Ms. Barger's e-mail and indicated he would forward her request to Ms. Pailzot as she was scheduled to meet with Chairman Lupe regarding the project. May 15, 2012: Ms. Pailzot e-mailed Ms. Barger and informed her she will recommend to Chairman Lupe that the White Mountain Apache do not need to be cooperators on the EIS.

TABLE N-2 (Cont.)

Tribe	Reclamation and NPS Communications with Tribes	Tribal Comment/Response
Yavapai-Apache Nation	May 15, 2012: Jan Balsom, GCNP, called Christopher Coder regarding the Yavapai-Apache Nation's interest in a meeting to discuss the LTEMP process. September 27, 2012: Bruce Verhaaren, Argonne, sent Christopher an e-mail asking him to confirm that the Yavapai-Apache Nation no longer wished to function as a Cooperating Agency due to the changing circumstances and only a peripheral interest, as stated in an earlier conversation. October 10, 2012: Mr. Verhaaren sent a follow-up e-mail to Christopher Coder asking him to confirm that the Tribe no longer wishes to act as a Cooperating Agency for LTEMP. October 23, 2012: Mr. Verhaaren sent a follow-up e-mail to Christopher Coder asking him to confirm that the Tribes no longer wishes to act as a Cooperating Agency for LTEMP.	January 9, 2012: Mr. Coder, Tribal Archaeologist, returned the Cooperating Agency form indicating that the Yavapai-Apache would like to be a Cooperating Agency. May 15, 2012: Mr. Coder returned Ms. Balsom's call and left a voicemail indicating that the Yavapai-Apache Nation would like to see the final set of alternatives before determining if they would like to have a meeting. October 10, 2012: Mr. Coder responded to Mr. Verhaaren's e-mail and indicated that he will confirm the position of the Yavapai-Apache Nation in regard to LTEMP participation at their next meeting and get back Mr. Verhaaren. October 24, 2012: Mr. Coder sent Mr. Verhaaren an e-mail confirming that the Tribe did not wish to participate as a Cooperating Agency anymore.
Yavapai-Prescott Indian Tribe	February 1, 2012: Steve Daron, LMNRA, called the Tribe and was directed to Greg Glassco. Mr. Daron left a message for Mr. Glassco regarding the November 2011 LTEMP letter asking if the Tribe wished to participate in the LTEMP process.	February 1, 2012: Mr. Glassco sent an e-mail to Mr. Daron indicating that the Tribe does not need to be consulted for LTEMP.

everyone. Every effort was made to hold a meeting when everyone was available; however, due to schedule conflicts there were instances when individuals could not attend and make-up meetings were held for these individuals. Tribes were sent an e-mail invitation prior to each meeting, as well as a meeting reminder with an agenda, call-in number, password, and any pertinent materials needed for review before the meeting. Meeting notes and presentations were distributed shortly after the meetings when requested. Meeting notes and other important documents related to the LTEMP EIS development process were also sent to those Tribes who wished to remain on the mailing list. Reclamation and NPS will continue to provide consultation opportunities for interested Tribes and keep all Tribal entities informed about the NEPA process for the EIS. A list of major face-to-face meetings, webinars, and conference calls involving Tribes is provided in Table N-3.

To date, the joint-leads have held individual Tribal consultation meetings with the Fort Mojave Indian Tribe, the Fort Yuma Quechan, the Havasupai Tribe, the Hualapai Tribe, the Hopi Tribe, the Kaibab Paiute Indian Tribe, the Navajo Nation, the Pueblo of Zia, and the Pueblo of Zuni. During these meetings, the background and overview of LTEMP process and was discussed, as well as specific Tribal concerns related to the LTEMP EIS. A summary of these meetings is provided in Table N-4.

Throughout the early stages of EIS development, many Tribes indicated the need for monetary assistance to be able to fully contribute Tribal knowledge to the EIS. The joint-leads recognized that in some cases it was appropriate to pay a fee for professional services to address the travel costs of Tribal representatives who possess special cultural knowledge or may experience a potential loss of income by being away from their regular jobs to attend a consultation meeting. At the March 14, 2013, Tribal Workshop, the joint-leads requested from the Tribes funding proposals detailing the cost of travel and compensation of Tribal Representatives for their participation in the LTEMP. The joint-leads agreed to fund—to the extent possible—reimbursement of Tribal representatives (elders, or experts not already being paid salaries by the Tribe) to participate LTEMP meetings by invitation and agreement in advance and the cost of deliverables for editing/preparing specific information such as the Affected Environment section of the EIS or requested data or reports regarding affected sites, if those materials are not already publically available. Tasks not funded included review of EIS chapters or drafts and fees for Tribal representatives (such as THPOs) who are being paid by the Tribes to participate in the cooperating agency meetings. Tribes submitted proposals and were funded as appropriate.

Throughout the course of developing the EIS, Cooperating Agency Tribes were asked to review and provide comments on the *Tribal Consultation Plan for the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement, Draft Performance Criteria and Draft Objectives for the Glen Canyon Dam Long-Term Experimental and Management Plan, and the Preliminary Draft Alternatives*. Tribes submitted comments and suggestions and the joint-leads incorporated them as appropriate. Cooperating Agency Tribes were also afforded the opportunity for preliminary review of select chapters of the preliminary DEIS prior to distribution to other Cooperating Agencies. They were also sent revised copies of the DEIS when it was distributed to Cooperating Agencies. The joint-lead agencies also sent responses to the Tribes who submitted comments.

TABLE N-3 Summary of Major Face-to-Face Meetings, Webinars, and Conference Calls Involving Tribes

Date	Meeting	Meeting Type	Location
February 11, 2011	LTEMP EIS Kickoff Meeting	Face-to-Face	Tempe, AZ
February 24, 2011	First Cooperating Agency Meeting	Face-to-Face	Tempe, AZ
April 4–5, 2012	Public Meeting to Discuss Alternatives Development	Face-to-Face	Flagstaff, AZ
August 10, 2012	Meeting with Consulting and Cooperating Tribes	Face-to-Face	Tempe, AZ
January 25, 2013	Tribal Workshop	Face-to-Face	Phoenix, AZ
March 14, 2013	Tribal Participation Workshop	Face-to-Face	Flagstaff, AZ
April 12, 2013	Tribal Representatives Meeting	Conference Call	
April 24, 2013	Tribal Consultation Meeting	Conference Call	
July 11, 2013	Tribal Values Webinar	Webinar	
July 25, 2013	Tribal Values Webinar (make-up)	Webinar	
August 1, 2013	Stakeholder Webinar—Preparation for the August 5 Stakeholder Workshop	Webinar	
August 5, 2013	Stakeholder Workshop—Structured Decision Analysis	Face-to-Face	Flagstaff, AZ
August 21, 2013	Stakeholder Workshop—Follow-up with Tribes	Conference Call	
November 5, 2013	Tribal Values Workshop	Face-to-Face	Flagstaff, AZ
November 19, 2013	Stakeholder Webinar—Alternatives, Performance Metrics, and Modeling	Webinar	
December 3, 2013	Stakeholder Webinar—Socioeconomics	Webinar	
March 18, 2014	Stakeholder Webinar—Swing Weighting	Webinar	
March 31–April 1, 2014	Stakeholder Workshop—Modeling Results, Structured Decision Analysis, and Swing-weighting Exercise	Face-to-Face	Phoenix, AZ
June 23, 2014	Meeting—Discussion of LTEMP EIS Hybrid Alternative Components	Conference Call	
August 12, 2014	Meeting—Update on the LTEMP EIS	Conference Call	
October 6, 2014	Meeting—Discussion of Tribal Input to LTEMP EIS	Conference Call	
October 16, 2014	Meeting—Discussion of the LTEMP Programmatic Agreement	Conference Call	
January 23, 2015	Meeting to discuss Tribal Input on Chapters 1 and 2	Conference Call	
March 27, 2015	Technical Webinar on LTEMP Power Systems and Rate Payer Analyses	Webinar	

TABLE N-3 (Cont.)

Date	Meeting	Meeting Type	Location
December 3, 2015	Meeting—Discussion of the LTEMP Programmatic Agreement	Face-to-Face	Phoenix, AZ
April 21–22, 2016	Meeting—Discussion of the LTEMP Programmatic Agreement	Face-to-Face	Phoenix, AZ
July 28–29, 2016	Meeting—Discussion of the LTEMP Programmatic Agreement	Face-to-Face	Phoenix, AZ
August 9, 2016	Meeting—Discussion of the LTEMP Programmatic Agreement	Webinar	
September 2, 2016	Meeting—Discussion of the Nonative Fish MOA	Webinar	
September 8, 2016	Meeting—Discussion of the LTEMP Programmatic Agreement	Webinar	
September 22, 2016	Meeting—Discussion of the LTEMP Programmatic Agreement	Webinar	

At the start of the LTEMP, a document entitled *American Indian Perspectives and Values Related to the Glen Canyon Dam Long-term Experimental and Management Plan Environmental Impact Statement* was developed for inclusion as a chapter in the LTEMP EIS and distributed to the Cooperating and Consulting Tribes for review. After considering a number of comments received on the document and expressed at Tribal meetings, it was determined that Tribal concerns would best be incorporated throughout the EIS and would not be limited to one section. Instead, a Tribal Resources section (Section 3.9) was added to Chapter 3 (Affected Environment) and Tribal views and concerns were expressed here and incorporated into various resource areas throughout the chapter. Tribes were invited to contribute their own text to Chapter 3 and the Tribal Lands section (Section 1.5.2.3) of Chapter 1. For those Tribes who did not wish to write or did not have the resources to write the section themselves, Argonne National Laboratory (Argonne) provided text that was reviewed by a Tribal representative. To best incorporate Tribal views and concerns, Argonne reviewed meeting notes, ethnographic reports published for the 1995 LTEP EIS, and monitoring reports prepared for Tribal monitoring programs in the Canyon. Argonne requested additional relevant sources from Tribes that would be useful in the preparation of the chapter and information from these sources was incorporated into the EIS. Argonne communicated with Tribes via e-mail and phone during the preparation of Chapter 3 in order to ensure that Tribal views and concerns were being presented correctly.

TABLE N-4 Summary of Individual Tribal Consultation Meetings to Date

Tribe	Date	Attendees	Location
Fort Mojave Indian Tribe	May 4, 2012	Reclamation, NPS, Representatives of the Fort Mojave Indian Tribe	Needles, CA
Fort Yuma Quechan	June 22, 2012	Reclamation, NPS, Representatives of the Fort Yuma Quechan	Near Yuma, AZ
The Havasupai Tribe	November 8, 2013	Reclamation, NPS, DOI Tribal Liaison, Havasupai Tribal Council	Supai Village, AZ
	February 29, 2016	Reclamation, NPS, Havasupai Tribal Council	Grand Canyon, AZ
The Hualapai Tribe	March 5, 2012	Reclamation, Hualapai Tribal Council	Peach Springs, AZ
	May 3, 2013	DOI, Argonne, Hualapai Tribal Council	Peach Springs, AZ
	July 30, 2014	Reclamation, NPS, GCMRC, DOI, Hualapai Tribal Council	Peach Springs, AZ
	February 9, 2016	Reclamation, NPS, Hualapai Tribal Council and Staff	Peach Springs, AZ
The Hopi Tribe	May 16, 2013	DOI, Argonne, Hopi Cultural Resources Advisory Team	Kykotsmovi Village, AZ
	November 18, 2015	Reclamation, NPS, Hopi Tribal Council	Kykotsmovi Village, AZ
Kaibab Paiute Indian Tribe	April 19, 2012	Reclamation, NPS, Kaibab Paiute Indian Tribe Tribal Council	Fredonia, AZ
	July 22, 2013	DOI, Representatives of the Southern Paiute Consortium	Pipe Springs, AZ
	October 22, 2013	DOI, Director of the Southern Paiute Consortium, University of Arizona's Anthropology Department	Tucson, AZ
	January 21, 2016	Reclamation, NPS, DOI, Kaibab Paiute Indian Tribe Tribal Council	Pipe Springs, AZ
Navajo Nation	April 17, 2013	DOI, Representatives from the Navajo Nation	Conference Call
	April 10, 2014	Reclamation, NPS, DOI, Representatives of the Navajo Nation	Flagstaff, AZ
	November 4, 2015	Reclamation, NPS, DOI, Representatives of the Navajo Nation	Window Rock, AZ

TABLE N-4 (Cont.)

Tribe	Date	Attendees	Location
	April 5, 2016	Reclamation, NPS, DOI, Tribal Liason, Representatives of the Navajo Nation including President Begaye	Window Rock, AZ
Pueblo of Zia	May 23, 2012	Reclamation, NPS, Representatives from the Pueblo of Zia	Zia Pueblo, NM
Pueblo of Zuni	June 12, 2012	Reclamation, NPS, Pueblo of Zuni Tribal Council	Zuni Pueblo, NM
	May 17, 2013	DOI, Zuni Cultural Resources Advisory Team (ZCRAT)	Zuni Pueblo, NM
	October 25, 2013	Reclamation, NPS, DOI, Kurt Dongoske	Conference Call
	October 10, 2014	Reclamation, NPS, DOI, Pueblo of Zuni ZCRAT	Zuni Pueblo, NM
	August 18, 2015	Reclamation, DOI, NPS, FWS, Pueblo of Zuni ZCRAT	Zuni Pueblo, NM
	July 27, 2016	Reclamation, NPS, DOI, Pueblo of Zuni ZCRAT	Zuni Pueblo, NM

On April 2, 2014, after a stakeholder workshop presenting modeling results and explaining SDA, Mike Runge (DOI), sent the LTEMP swing-weighting exercise and a summary consequence table to Stakeholders, including Tribes, to complete and be used as input to be considered in the EIS. A follow-up webinar where Stakeholders could ask questions regarding swing weighting was held on April 4, 2014, but no Tribal representatives were in attendance. Participation in the swing-weighting exercise was voluntary and some Tribes chose not to participate. Others returned their results and the results were incorporated into the EIS.

Chapters 1 and 2 of the preliminary LTEMP DEIS were sent to Tribes for review in December 2014. Chapter 3 of the LTEMP DEIS was sent to Tribes in for review in April 2015. A full copy of the LTEMP DEIS was sent to all Cooperating Agencies, including Tribes, in June 2015. Tribes were encouraged to provide comments during all three comment periods. Comments were received from the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and Pueblo of Zuni.

A listing of individual Tribal consultation meetings is provided in Table N-4, and an index of Tribal government consultation and coordination is provided in Table N-5. Table N-5 includes a page number reference to copies of correspondence that are located in Attachment 2.

TABLE N-5 Index of Project Tribal Government Consultation and Coordination Correspondence

Date	Originating Agency/ Tribal Government	Recipient Organization	Page[a]
Multiple Tribes			
November 30, 2011	NPS, Reclamation	Various Tribes	N-74
December 8, 2011	NPS, Reclamation	Various Tribes	N-79
Ak-Chin Indian Community			
July 31, 2012	Louis Manuel Jr., Chairman, Ak-Chin Indian Community	John Wessels, Regional Director, NPS	N-83
Gila River Indian Community			
January 3, 2012	Barnaby Lewis, THPO, Gila River Indian Community	John Wessels, Regional Director, NPS	N-84
Havasupai Tribe			
February 27, 2012	Havasupai Tribe	NPS/Reclamation	N-85
June 21, 2012	Don Watahomigie, Chairman Havasupai Tribe	Kirk LaGory, Argonne	N-86
August 9, 2012	Adrianne Carr, Argonne; NPS; Reclamation	Don Watahomigie, Chairman Havasupai Tribe	N-88
August 29, 2012	Margaret Vick, Attorney for Havasupai	Kirk LaGory, Argonne	N-90
August 30, 2012	Kirk LaGory, Argonne	Margaret Vick, Attorney for Havasupai	N-95
Hopi Tribe			
August 27, 2013	Mike Yeatts, Hopi Cultural Preservation Office (HCPO)	Kirk LaGory, Argonne; NPS; Reclamation	N-96
Hualapai Tribe			
January 6, 2012	Hualapai Tribe	NPS/Reclamation	N-99
June 28, 2012	Peter Bungart, Hualapai Dept. of Cultural Resources	Kirk LaGory, Argonne	N-100
August 9, 2012	Adrianne Carr, Argonne, on behalf of NPS/Reclamation	Loretta Jackson-Kelly, Director, Dept. of Hualapai Cultural Resources and Peter Bungart, Hualapai Dept. of Cultural Resources	N-103
Navajo Nation			
February 28, 2011	Tony Joe, Jr., Historic Preservation Department, Navajo Nation	NPS/Reclamation	N-106
January 9, 2012	Navajo Nation	NPS/Reclamation	N-108
July 17, 2012	Adrianne Carr, Argonne, on behalf of NPS/Reclamation	Jason John, Navajo Department of Water and Power and Alan Downer, THPO	N-109
August 28, 2013	Tony Joe, Jr., Historic Preservation Department, Navajo Nation	Kirk LaGory, Argonne	N-111
February 11, 2014	Bruce Verhaaren, Argonne, on behalf of NPS/Reclamation	Jason John, Navajo Department of Water and Power and Tony Joe, Jr., Historic Preservation Department, Navajo Nation	N-114

TABLE N-5 (Cont.)

Date	Originating Agency/ Tribal Government	Recipient Organization	Page[a]
February 21, 2014	Delores Martinez and Laurinda M., Navajo Nation	Bruce Verhaaren, Argonne	N-117
	Jason John, Navajo Department of Water and Power and Ben Shelly, President Navajo Nation	Glen Knowles, Reclamation; Rob Billerbeck, NPS; and Bruce Verhaaren, Argonne	N-118
February 28, 2014	Rob Billerbeck, NPS	Jason John, Navajo Department of Water and Power	N-120
March 17, 2014	Rob Billerbeck, NPS	Jason John, Navajo Department of Water and Power	N-121
June 2, 2014	Rob Billerbeck, NPS and Glen Knowles, Reclamation	Walter Phelps, Council Delegate, Navajo Nation	N-125
June 3, 2014	Walter Phelps, Council Delegate, Navajo Nation	Rob Billerbeck, NPS and Glen Knowles, Reclamation	N-125
Paiute Indian Tribe of Utah			
January 9, 2012	Paiute Indian Tribe of Utah	NPS/Reclamation	N-126
Pueblo of Zuni			
December 22, 2011	Arlen Quetawki, Sr., Governor, Pueblo of Zuni	Larry Walkoviak, Regional Director, Reclamation and John Wessels, Regional Director NPS	N-127
White Mountain Apache			
May 15, 2012	Cheryl Pailzote, Water Resources Director, White Mountain Apache Tribe	Mary Barger, Reclamation	N-129
Yavapai-Apache Nation			
January 9, 2012	Yavapai-Apache Nation	NPS/Reclamation	N-130
October 10, 2012	Bruce Verhaaren, Argonne	Chris Coder, Tribal Archaeologist, Yavapai-Apache Nation	N-131
	Chris Coder, Tribal Archaeologist, Yavapai-Apache Nation	Bruce Verhaaren and Adrianne Carr, Argonne	N-132
October 23, 2012	Bruce Verhaaren, Argonne	Chris Coder, Tribal Archaeologist, Yavapai-Apache Nation	N-133
October 24, 2012	Chris Coder, Tribal Archaeologist, Yavapai-Apache Nation	Bruce Verhaaren, Argonne	N-134

[a] Page number in Appendix N, Attachment 2.

N.2 CONSULTATION WITH THE STATE HISTORIC PRESERVATION OFFICE (SHPO)

This section presents the interactions that occurred as part of the NHPA Section 106 review for the LTEMP EIS. A brief overview of the consultation process with State Historic Preservation Officers (SHPOs) is provided below.

On June 12, 2014, the joint-leads sent a letter to the Arizona State SHPO notifying him of the intent to complete the LTEMP EIS. The letter provided a review of the LTEMP to date with a draft description of the proposed Area of Potential Effect. The letter also indicated the desire to consult with the SHPO pursuant to Section 106 of the NHPA. A copy of this letter was also sent to the Advisory Council on Historic Preservation and all Cooperating Agencies. The SHPO's office responded on July 18, 2014, indicating they look forward to working with the joint-leads on the Programmatic Agreement. A copy of these letters is provided in Attachment 3.

N.3 REFERENCE

Reclamation (Bureau of Reclamation), 1995, *Operation of Glen Canyon Dam: Colorado River Storage Project, Arizona, Final Environmental Impact Statement*, U.S. Department of the Interior, Bureau of Reclamation, Salt lake City, Utah, March. Available at http://www.usbr.gov/uc/library/envdocs/eis/gc/gcdOpsFEIS.html. Accessed February 19, 2015.

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ATTACHMENT N.1

(a) Havasupai Tribe

Memorandum of Understanding
Between
the Bureau of Reclamation and the National Park Service
and
the Havasupai Tribe
for the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan for the Operation of Glen Canyon Dam

I. Introduction and Purpose

Pursuant to the National Environmental Policy Act (NEPA), the Department of the Interior (Department), through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), is preparing an environmental impact statement (EIS) for a Long Term Experimental and Management Plan (LTEMP) for the operation of Glen Canyon Dam. Reclamation and the NPS are the joint lead or "joint-lead agencies" for the completion of this EIS. The Havasupai Tribe hereafter "the cooperating agency", in addition to other parties, has agreed to serve as a cooperating agency for the completion of the LTEMP EIS. The purpose of this Memorandum of Understanding (MOU) is to outline the roles and responsibilities of the joint-lead and the cooperating agency (hereinafter collectively referred to alternatively as "agencies" or "parties") in accordance with 43 CFR § 46.225(d).

II. Background

The LTEMP process is intended to develop and implement a structured, long term experimental and management plan, to determine the need for potential future modifications to Glen Canyon Dam operations, and to determine whether to establish an Endangered Species Act (ESA) Recovery Implementation Program for endangered fish species below Glen Canyon Dam. Revised dam operations and other actions under the jurisdiction of the Secretary of the Interior will be considered within alternatives of the EIS, in keeping with the scope of the Grand Canyon Protection Act (GCPA). The NEPA process will document and evaluate impacts of the alternatives described in the EIS.

III. Purpose of this MOU

This MOU defines the relationship and duties of the joint-lead and the cooperating agency in completing NEPA compliance for the LTEMP, and how the parties will cooperate during the NEPA process.

By signing this MOU, the parties agree that this MOU provides the framework to fulfill compliance requirements for NEPA.

IV. Agency Designee

The cooperating agency will designate a primary point of contact (and alternate if desired) for the EIS by sending correspondence at the time of signing of this agreement to the joint-lead agencies with the contacts name and information. The cooperating agency may change its point

of contact at any time by providing written notice to the joint-lead agencies and the other cooperating agencies.

V. Authority

The authority of the joint-lead and the cooperating agency to participate in this agreement is provided by the National Environmental Policy Act, 42 U.S.C. §§ 4321 *et seq.* NEPA allows agencies to be designated as a cooperating agency when that agency has jurisdiction by law or special expertise (40 CFR § 1501.6 and 40 CFR§ 1508.5). Activities contemplated under this MOU are specifically authorized under:

A. Title I of NEPA;

B. "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," 40 CFR §§ 1500-1508, Council on Environmental Quality (in particular 40 CFR § 1501.6, Cooperating Agencies);

C. Department of the Interior NEPA Implementing Procedures in the Departmental Manual at 43 CFR § Part 46, Cooperating Agencies (40 CFR §1501.6).

VI. Joint-lead Agency Responsibilities

Reclamation and the NPS will be joint-leads for this effort because Reclamation has primary responsibility for operation of Glen Canyon Dam and the NPS has primary responsibility for managing Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area.

The NPS and Reclamation, as joint-leads for the completion of the LTEMP EIS, shall:

A. Jointly be responsible for the preparation, quality, content and overall direction of the EIS and for ensuring the appropriate participation of cooperating agencies in developing the EIS.

B. Jointly be responsible for identifying the purpose and need for the project, scope of analysis, and decisions to be made. In coordination with the Department, the joint-lead agencies will make the final decision on the content of all EIS-related documents, including the preferred alternative and the Record of Decision to be signed by the Secretary of the Interior.

C. Jointly oversee the execution and administration of contracts or cooperative agreements with mutually agreed upon federal, state or local agencies, or tribal governments or mutually agreed upon private contractors to develop information for inclusion in the EIS.

D. Jointly conduct cooperating agency meetings, and provide advance information for discussions at these meetings, as necessary during the preparation of the EIS. Meeting dates and locations will be jointly agreed upon and may be chosen to coincide with the

dates of Adaptive Management Working Group meetings to minimize travel costs and maximize collaboration.

E. Ensure that cooperating agency proposals and substantive comments (including divergent views) within their jurisdiction or technical expertise are appropriately documented and considered in the EIS.

F. Provide advance copies (normally 30 days) of the preliminary draft and preliminary final EIS and related compliance documents for review by cooperating agencies.

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B. Participate in the scoping process.

C. Assume, on request of the lead agencies, responsibility for developing information and preparing environmental analyses including portions of the environmental impact statement concerning which the cooperating agency has special expertise.

D. Make available staff support at the lead agencies' request to enhance the latter's interdisciplinary capability.

E. Normally use their own funds.

F. The cooperating agency may in response to a lead agencies' request for assistance in preparing the environmental impact statement reply that other program commitments preclude any involvement or the degree of involvement requested in the action that is the subject of the environmental impact statement.

G. Provide comments in a timely manner (normally within 30 days of receipt) of draft documents when requested. One consolidated set of comments for the cooperating agency will be provided in the format specified by the joint-lead agencies.

H. As appropriate and practicable, attend cooperating agency meetings and public meetings and hearings on the EIS process.

I. Retain the right to comment on all issues related to the EIS through the normal EIS public review and comment process.

expand, or substitute for those provisions or regulations. This MOU does not impose legally-binding requirements on the Parties, nor does it create a legal right of action for the Parties or any third party.

J. **AGENCY AND PARTNERSHIP.** Unless expressly provided by law, personnel or volunteers of one party shall not be considered to be agents, partners or employees of the other party for any purpose, and no joint venture or principal-agent relationship shall be deemed to exist. The personnel and volunteers of one party are not entitled to any of the benefits that any other party provides for its employees or volunteers.

K. **LIABILITY.** To the extent authorized by law, on behalf of itself, its officers, directors, members, employees, agents, and representatives, each party agrees that it will be responsible for its own acts and omissions and the results thereof and that it shall not be responsible for the acts or omissions of other parties, nor the results thereof. To the extent authorized by law, each party therefore agrees that it will assume the risk and liability to itself, its agents, employees, and volunteers for any injury to or death of persons or loss or destruction of property resulting in any manner from the conduct of the party's own operations and/or the operations of its agents, employees, and/or volunteers under this MOU. To the extent authorized by law, each party further releases and waives all claims against the other party for compensation for any loss, cost, damage, expense, personal injury, death, claim, or other liability arising out of the performance of this MOU.

L. **NONDISCRIMINATION.** This MOU is subject to all Federal statutes relating to nondiscrimination. These include, but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352); and (b) Title IX of the Education Amendments of 1972 (20 U.S.C. 1681-1683 and 1685-1686).

XI. Effective Dates, Amendment and Termination

A. This MOU will become effective on the date of the last signature and may be subsequently amended through written agreement of all signatories. The joint-lead agencies or the cooperating agency may terminate their cooperative status by providing 30 days written notice of termination to the other party. Otherwise, the cooperative status will terminate when a Record of Decision is issued or the EIS is terminated.

XII. Signatures

The parties hereto have executed this Memorandum of Understanding as of the dates shown below.

BUREAU OF RECLAMATION

Date July 9, 2012

Larry Walkoviak
Regional Director
Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Date 7/11/2012

Herbert C. Frost
Associate Director for Natural Resources, Stewardship and Science
National Park Service

for

Date 7/20/12

John Wessels
Regional Director
Intermountain Region
National Park Service

Date 7/25/12

Christine Lehnertz
Regional Director
Pacific West Region
National Park Service

THE HAVASUPAI TRIBE

Date 7-6-12

Don E. Watahomigie, Chairman

(b) Hopi Tribe

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the Bureau of Reclamation and the National Park Service
and
the Hopi Tribe
for the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan for the Operation of Glen Canyon Dam

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E. Ensure that cooperating agency proposals and substantive comments (including divergent views) within their jurisdiction or technical expertise are appropriately documented and considered in the EIS.

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E. Normally use their own funds.

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H. As appropriate and practicable, attend cooperating agency meetings and public meetings and hearings on the EIS process.

I. Retain the right to comment on all issues related to the EIS through the normal EIS public review and comment process.

J. Promptly advise the joint-lead agencies of concerns related to the EIS process.

VIII. Shared Responsibilities of all Parties

A. Reclamation and NPS may meet separately with any one or more cooperating agencies to discuss specific topics.

B. It is understood that the respective agencies are normally responsible for their own costs with regard to completion of tasks outlined herein, such as attendance at meetings, assembling data, analyzing effects, and providing input with regard to sections of the EIS subject to section VII.F. Funding requests from tribal governments with a demonstrated need will be considered on a case by case basis by the joint-lead agencies.

C. All parties agree that because of the need for timely completion of NEPA compliance, work will proceed as expeditiously as possible, including data gathering, analysis, and document review. However, all parties agree that sufficient time must be allowed to ensure thorough document review. It is anticipated that the parties will be given a minimum of 30 days to review the preliminary draft EIS and a minimum of 30 days to review the draft final EIS.

IX. Resolution of Disputes

Reclamation and NPS are responsible for all decisions involving the EIS and will make all final decisions on disputes arising during the NEPA process. The joint-lead agencies will document the nature of any dispute and the resolution of the dispute. Documentation of resolution will be made available to appropriate parties.

X. Standard Conditions:

A. AUTHORITIES. Nothing in this MOU shall be construed to extend the jurisdiction or decision-making authority of any party to this MOU beyond that which exists under current laws and regulations. Nothing in this MOU shall be construed as limiting or affecting the authority or legal responsibility of any party, or as binding any party to perform beyond the respective authority of each, or to require any party to assume or expend any specific sum of money. The provisions of this MOU are subject to the laws of the United States; and the regulations of the Department of the Interior, as they may be applicable. Nothing in this MOU shall be construed as affecting the decision-making requirements of any party or impairing the independent judgment of each party regarding policy decisions.

B. RELEASE OF INFORMATION. Except as required by court order or ruling, the joint - lead agencies and the cooperating agency will not release any pre-decisional material or working information or documents to the public other than through an approved Freedom of Information Act request or comparable tribal or state law-based process, or unless the agency or agencies have already disseminated the specific materials or documents to the public. The

agencies agree to inform each other if it is determined that there is a legal requirement to release any such information, and that information will include expected release date of the information.

C. **LEGAL RIGHTS AND REMEDIES.** Nothing in this MOU shall be construed to alter the legal rights and remedies that each party would otherwise have. No party waives any legal rights or defenses by entering into this MOU or participating in the process contemplated hereby. This MOU is not a Federal contract, rule, or regulation. This MOU shall not be construed as or interpreted to be final Federal agency action.

D. **SEVERABILITY.** Should any portion of this MOU be judicially determined to be illegal or unenforceable, the remainder of the MOU shall continue in full force and effect, and any party may renegotiate the terms affected by the severance.

E. **THIRD PARTY BENEFICIARY RIGHTS.** The parties do not intend to create in any other individual or entity the status of third party beneficiary, and this MOU shall not be construed so as to create such status. The rights, duties and obligations contained in this MOU shall operate only among the parties to this MOU, and shall inure solely to the benefit of the parties to this MOU. The provisions of this MOU are intended only to assist the parties in determining and performing their obligations under this MOU.

F. **NON-FUND OBLIGATION DOCUMENT.** This MOU is neither a fiscal nor a funds obligation document. Any endeavor or transfer of anything of value involving reimbursement or contribution of funds between the parties to this instrument will be handled in accordance with applicable laws, regulations, and procedures including those for Government procurement and printing. Such endeavors will be outlined in separate agreements that shall be made in writing by representatives of the parties and shall be independently authorized by appropriate rules, policies, and statutory authority. This MOU does not provide such authority. Specifically, this MOU does not establish authority for noncompetitive award to the cooperator of any contract or other agreement. Nothing herein constitutes a binding commitment to fund any of the proceedings encompassed by the MOU. Any specific cost sharing or funding shall be executed separately through other funding mechanisms, as deemed necessary and appropriate by each of the signatories.

G. **PARTICIPATION IN SIMILAR ACTIVITIES WITH OTHER ENTITIES.** This MOU in no way restricts any of the parties from participating in similar activities with other public or private agencies, organizations, and individuals.

H. **ENDORSEMENT.** Nothing in this MOU may be interpreted to imply that the United States, the Department of the Interior, the NPS, the Bureau of Reclamation, or the cooperating agency endorses any product, service or policy of the other parties. No party will take any action or make any statement that suggests or implies such an endorsement.

I. **STATUTES AND REGULATIONS.** The provisions of any statutes and/or regulations cited in this MOU contain legally binding requirements. The MOU itself does not alter, expand, or substitute for those provisions or regulations. This MOU does not impose legally-

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Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Date 10/10/2014

Raymond M. Sauvajot
Acting Associate Director for Natural Resources, Stewardship and Science
National Park Service

Date 10/1/14

Sue E. Masica
Regional Director
Intermountain Region
National Park Service

Date 03 October 2014

Christine Lehnertz
Regional Director
Pacific West Region
National Park Service

THE HOPI TRIBE

Date 6.7.13

Leroy Ned Shingoitewa, Chairman

(c) Hualapai Tribe

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C. **SOVEREIGNTY.** Participation by a tribe in this National Environmental Policy Act process does not diminish the Tribe's rights to protect its sovereignty under their constitutional authorities and in consideration of applicable law.

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H. **PARTICIPATION IN SIMILAR ACTIVITIES WITH OTHER ENTITIES.** This MOU in no way restricts any of the parties from participating in similar activities with other public or private agencies, organizations, and individuals.

I. **ENDORSEMENT.** Nothing in this MOU may be interpreted to imply that the United States, the Department of the Interior, the NPS, the Bureau of Reclamation, or the

cooperating agency endorses any product, service or policy of the other parties. No party will take any action or make any statement that suggests or implies such an endorsement.

J. **STATUTES AND REGULATIONS.** The provisions of any statutes and/or regulations cited in this MOU contain legally binding requirements. The MOU itself does not alter, expand, or substitute for those provisions or regulations. This MOU does not impose legally-binding requirements on the Parties, nor does it create a legal right of action for the Parties or any third party.

K. **AGENCY AND PARTNERSHIP.** Unless expressly provided by law, personnel or volunteers of one party shall not be considered to be agents, partners or employees of the other party for any purpose, and no joint venture or principal-agent relationship shall be deemed to exist. The personnel and volunteers of one party are not entitled to any of the benefits that any other party provides for its employees or volunteers.

L. **LIABILITY.** To the extent authorized by law, on behalf of itself, its officers, directors, members, employees, agents, and representatives, each party agrees that it will be responsible for its own acts and omissions and the results thereof and that it shall not be responsible for the acts or omissions of other parties, nor the results thereof. To the extent authorized by law, each party therefore agrees that it will assume the risk and liability to itself, its agents, employees, and volunteers for any injury to or death of persons or loss or destruction of property resulting in any manner from the conduct of the party's own operations and/or the operations of its agents, employees, and/or volunteers under this MOU. To the extent authorized by law, each party further releases and waives all claims against the other party for compensation for any loss, cost, damage, expense, personal injury, death, claim, or other liability arising out of the performance of this MOU.

M. **NONDISCRIMINATION.** This MOU is subject to all Federal statutes relating to nondiscrimination. These include, but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352); and (b) Title IX of the Education Amendments of 1972 (20 U.S.C. 1681-1683 and 1685-1686).

XI. Effective Dates, Amendment and Termination

A. This MOU will become effective on the date of the last signature and may be subsequently amended through written agreement of all signatories. The joint-lead agencies or the cooperating agency may terminate their cooperative status by providing 30 days written notice of termination to the other party. Otherwise, the cooperative status will terminate when a Record of Decision is issued or the EIS is terminated.

XII. Signatures
The parties hereto have executed this Memorandum of Understanding as of the dates shown below.

BUREAU OF RECLAMATION

Date 7/21/14

Larry Walkoviak
Regional Director
Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Date 10/10/2014

Raymond M. Sauvajot
Acting Associate Director for Natural Resources, Stewardship and Science
National Park Service

Date 10/1/14

Sue E. Masica
Regional Director
Intermountain Region
National Park Service

Date 03October 2014

Christine Lehnertz
Regional Director
Pacific West Region
National Park Service

THE HUALAPAI TRIBE

Date 10/3/12

Sherry J. Counts
Chairwoman
The Hualapai Tribe

Date 10.04.2012

Loretta Jackson-Kelly
Director for the Department of Cultural Resources
The Hualapai Tribe

(d) Kaibab Band of Paiute Indians

Memorandum of Understanding
Between
the Bureau of Reclamation and the National Park Service
and
the Kaibab Band of Paiute Indians
for the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan for the Operation of Glen Canyon Dam

I. Introduction and Purpose

Pursuant to the National Environmental Policy Act (NEPA), the Department of the Interior (Department), through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), is preparing an environmental impact statement (EIS) for a Long Term Experimental and Management Plan (LTEMP) for the operation of Glen Canyon Dam. Reclamation and the NPS are the joint lead or "joint-lead agencies" for the completion of this EIS. The Kaibab Band of Paiute Indians hereafter "the cooperating agency", in addition to other parties, has agreed to serve as a cooperating agency for the completion of the LTEMP EIS. The purpose of this Memorandum of Understanding (MOU) is to outline the roles and responsibilities of the joint-lead and the cooperating agency (hereinafter collectively referred to alternatively as "agencies" or "parties") in accordance with 43 CFR § 46.225(d).

II. Background

The LTEMP process is intended to develop and implement a structured, long term experimental and management plan, to determine the need for potential future modifications to Glen Canyon Dam operations, and to determine whether to establish an Endangered Species Act (ESA) Recovery Implementation Program for endangered fish species below Glen Canyon Dam. Revised dam operations and other actions under the jurisdiction of the Secretary of the Interior will be considered within alternatives of the EIS, in keeping with the scope of the Grand Canyon Protection Act (GCPA). The NEPA process will document and evaluate impacts of the alternatives described in the EIS.

III. Purpose of this MOU

This MOU defines the relationship and duties of the joint-lead and the cooperating agency in completing NEPA compliance for the LTEMP, and how the parties will cooperate during the NEPA process.

By signing this MOU, the parties agree that this MOU provides the framework to fulfill compliance requirements for NEPA.

IV. Agency Designee

The cooperating agency will designate a primary point of contact (and alternate if desired) for the EIS by sending correspondence at the time of signing of this agreement to the joint-lead agencies with the contacts name and information. The cooperating agency may change its point

of contact at any time by providing written notice to the joint-lead agencies and the other cooperating agencies.

V. Authority

The authority of the joint-lead and the cooperating agency to participate in this agreement is provided by the National Environmental Policy Act, 42 U.S.C. §§ 4321 *et seq.* NEPA allows agencies to be designated as a cooperating agency when that agency has jurisdiction by law or special expertise (40 CFR § 1501.6 and 40 CFR§ 1508.5). Activities contemplated under this MOU are specifically authorized under:

A. Title I of NEPA;

B. "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," 40 CFR §§ 1500-1508, Council on Environmental Quality (in particular 40 CFR § 1501.6, Cooperating Agencies);

C. Department of the Interior NEPA Implementing Procedures in the Departmental Manual at 43 CFR § Part 46, Cooperating Agencies (40 CFR §1501.6).

VI. Joint-lead Agency Responsibilities

Reclamation and the NPS will be joint-leads for this effort because Reclamation has primary responsibility for operation of Glen Canyon Dam and the NPS has primary responsibility for managing Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area.

The NPS and Reclamation, as joint-leads for the completion of the LTEMP EIS, shall:

A. Jointly be responsible for the preparation, quality, content and overall direction of the EIS and for ensuring the appropriate participation of cooperating agencies in developing the EIS.

B. Jointly be responsible for identifying the purpose and need for the project, scope of analysis, and decisions to be made. In coordination with the Department, the joint-lead agencies will make the final decision on the content of all EIS-related documents, including the preferred alternative and the Record of Decision to be signed by the Secretary of the Interior.

C. Jointly oversee the execution and administration of contracts or cooperative agreements with mutually agreed upon federal, state or local agencies, or tribal governments or mutually agreed upon private contractors to develop information for inclusion in the EIS.

D. Jointly conduct cooperating agency meetings, and provide advance information for discussions at these meetings, as necessary during the preparation of the EIS. Meeting dates and locations will be jointly agreed upon and may be chosen to coincide with the

dates of Adaptive Management Working Group meetings to minimize travel costs and maximize collaboration.

E. Ensure that cooperating agency proposals and substantive comments (including divergent views) within their jurisdiction or technical expertise are appropriately documented and considered in the EIS.

F. Provide advance copies (normally 30 days) of the preliminary draft and preliminary final EIS and related compliance documents for review by cooperating agencies.

VII. Cooperating Agency Responsibilities

Federal, state, and local agencies, and tribal governments with appropriate expertise or jurisdiction have been invited to participate as cooperating agencies. Reclamation and NPS may, at any time during the course of the EIS project, invite additional agencies to participate in the process.

The cooperating agency, subject to sufficient appropriations to carry out the following responsibilities, shall:

A. Participate in the NEPA process at the earliest possible time.

B. Participate in the scoping process.

C. Assume, on request of the lead agencies, responsibility for developing information and preparing environmental analyses including portions of the environmental impact statement concerning which the cooperating agency has special expertise.

D. Make available staff support at the lead agencies' request to enhance the latter's interdisciplinary capability.

E. Normally use their own funds.

F. The cooperating agency may in response to a lead agencies' request for assistance in preparing the environmental impact statement reply that other program commitments preclude any involvement or the degree of involvement requested in the action that is the subject of the environmental impact statement.

G. Provide comments in a timely manner (normally within 30 days of receipt) of draft documents when requested. One consolidated set of comments for the cooperating agency will be provided in the format specified by the joint-lead agencies.

H. As appropriate and practicable, attend cooperating agency meetings and public meetings and hearings on the EIS process.

I. Retain the right to comment on all issues related to the EIS through the normal EIS public review and comment process.

J. Promptly advise the joint-lead agencies of concerns related to the EIS process.

VIII. Shared Responsibilities of all Parties

A. Reclamation and NPS may meet separately with any one or more cooperating agencies to discuss specific topics.

B. It is understood that the respective agencies are normally responsible for their own costs with regard to completion of tasks outlined herein, such as attendance at meetings, assembling data, analyzing effects, and providing input with regard to sections of the EIS subject to section VII.F. Funding requests from tribal governments with a demonstrated need will be considered on a case by case basis by the joint-lead agencies.

C. All parties agree that because of the need for timely completion of NEPA compliance, work will proceed as expeditiously as possible, including data gathering, analysis, and document review. However, all parties agree that sufficient time must be allowed to ensure thorough document review. It is anticipated that the parties will be given a minimum of 30 days to review the preliminary draft EIS and a minimum of 30 days to review the draft final EIS.

IX. Resolution of Disputes

Reclamation and NPS are responsible for all decisions involving the EIS and will make all final decisions on disputes arising during the NEPA process. The joint-lead agencies will document the nature of any dispute and the resolution of the dispute. Documentation of resolution will be made available to appropriate parties.

X. Standard Conditions:

A. **AUTHORITIES.** Nothing in this MOU shall be construed to extend the jurisdiction or decision-making authority of any party to this MOU beyond that which exists under current laws and regulations. Nothing in this MOU shall be construed as limiting or affecting the authority or legal responsibility of any party, or as binding any party to perform beyond the respective authority of each, or to require any party to assume or expend any specific sum of money. The provisions of this MOU are subject to the laws of the United States; and the regulations of the Department of the Interior, as they may be applicable. Nothing in this MOU shall be construed as affecting the decision-making requirements of any party or impairing the independent judgment of each party regarding policy decisions.

B. **RELEASE OF INFORMATION.** Except as required by court order or ruling, the joint - lead agencies and the cooperating agency will not release any pre-decisional material or working information or documents to the public other than through an approved Freedom of Information Act request or comparable tribal or state law-based process, or unless the agency or agencies have already disseminated the specific materials or documents to the public. The

agencies agree to inform each other if it is determined that there is a legal requirement to release any such information, and that information will include expected release date of the information.

C. **LEGAL RIGHTS AND REMEDIES.** Nothing in this MOU shall be construed to alter the legal rights and remedies that each party would otherwise have. No party waives any legal rights or defenses by entering into this MOU or participating in the process contemplated hereby. This MOU is not a Federal contract, rule, or regulation. This MOU shall not be construed as or interpreted to be final Federal agency action.

D. **SEVERABILITY.** Should any portion of this MOU be judicially determined to be illegal or unenforceable, the remainder of the MOU shall continue in full force and effect, and any party may renegotiate the terms affected by the severance.

E. **THIRD PARTY BENEFICIARY RIGHTS.** The parties do not intend to create in any other individual or entity the status of third party beneficiary, and this MOU shall not be construed so as to create such status. The rights, duties and obligations contained in this MOU shall operate only among the parties to this MOU, and shall inure solely to the benefit of the parties to this MOU. The provisions of this MOU are intended only to assist the parties in determining and performing their obligations under this MOU.

F. **NON-FUND OBLIGATION DOCUMENT.** This MOU is neither a fiscal nor a funds obligation document. Any endeavor or transfer of anything of value involving reimbursement or contribution of funds between the parties to this instrument will be handled in accordance with applicable laws, regulations, and procedures including those for Government procurement and printing. Such endeavors will be outlined in separate agreements that shall be made in writing by representatives of the parties and shall be independently authorized by appropriate rules, policies, and statutory authority. This MOU does not provide such authority. Specifically, this MOU does not establish authority for noncompetitive award to the cooperator of any contract or other agreement. Nothing herein constitutes a binding commitment to fund any of the proceedings encompassed by the MOU. Any specific cost sharing or funding shall be executed separately through other funding mechanisms, as deemed necessary and appropriate by each of the signatories.

G. **PARTICIPATION IN SIMILAR ACTIVITIES WITH OTHER ENTITIES.** This MOU in no way restricts any of the parties from participating in similar activities with other public or private agencies, organizations, and individuals.

H. **ENDORSEMENT.** Nothing in this MOU may be interpreted to imply that the United States, the Department of the Interior, the NPS, the Bureau of Reclamation, or the cooperating agency endorses any product, service or policy of the other parties. No party will take any action or make any statement that suggests or implies such an endorsement.

I. **STATUTES AND REGULATIONS.** The provisions of any statutes and/or regulations cited in this MOU contain legally binding requirements. The MOU itself does not alter, expand, or substitute for those provisions or regulations. This MOU does not impose legally-

binding requirements on the Parties, nor does it create a legal right of action for the Parties or any third party.

J. **AGENCY AND PARTNERSHIP.** Unless expressly provided by law, personnel or volunteers of one party shall not be considered to be agents, partners or employees of the other party for any purpose, and no joint venture or principal-agent relationship shall be deemed to exist. The personnel and volunteers of one party are not entitled to any of the benefits that any other party provides for its employees or volunteers.

K. **LIABILITY.** To the extent authorized by law, on behalf of itself, its officers, directors, members, employees, agents, and representatives, each party agrees that it will be responsible for its own acts and omissions and the results thereof and that it shall not be responsible for the acts or omissions of other parties, nor the results thereof. To the extent authorized by law, each party therefore agrees that it will assume the risk and liability to itself, its agents, employees, and volunteers for any injury to or death of persons or loss or destruction of property resulting in any manner from the conduct of the party's own operations and/or the operations of its agents, employees, and/or volunteers under this MOU. To the extent authorized by law, each party further releases and waives all claims against the other party for compensation for any loss, cost, damage, expense, personal injury, death, claim, or other liability arising out of the performance of this MOU.

L. **NONDISCRIMINATION.** This MOU is subject to all Federal statutes relating to nondiscrimination. These include, but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352); and (b) Title IX of the Education Amendments of 1972 (20 U.S.C. 1681-1683 and 1685-1686).

XI. Effective Dates, Amendment and Termination

A. This MOU will become effective on the date of the last signature and may be subsequently amended through written agreement of all signatories. The joint-lead agencies or the cooperating agency may terminate their cooperative status by providing 30 days written notice of termination to the other party. Otherwise, the cooperative status will terminate when a Record of Decision is issued or the EIS is terminated.

XII. Signatures

The parties hereto have executed this Memorandum of Understanding as of the dates shown below.

BUREAU OF RECLAMATION

Larry Walkoviak — Date 5/22/2012
Regional Director
Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Herbert C. Frost — Date 7/11/2012
Associate Director for Natural Resources Stewardship and Science
National Park Service

John Wessels — Date 6/21/12
Regional Director
Intermountain Region
National Park Service

Christine Lehnertz — Date 07/05/12
Regional Director
Pacific West Region
National Park Service

THE KAIBAB BAND OF PAIUTE INDIANS

Manuel Savala, Chairman — Date May 2, 2012

(e) Navajo Nation

Memorandum of Understanding
Between
the Bureau of Reclamation and the National Park Service
and
the Navajo Nation
for the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan for the Operation of Glen Canyon Dam

I. Introduction and Purpose

Pursuant to the National Environmental Policy Act (NEPA), the Department of the Interior (Department), through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), is preparing an environmental impact statement (EIS) for a Long Term Experimental and Management Plan (LTEMP) for the operation of Glen Canyon Dam. Reclamation and the NPS are the joint lead or "joint-lead agencies" for the completion of this EIS. The Navajo Nation hereafter "the cooperating agency", in addition to other parties, has agreed to serve as a cooperating agency for the completion of the LTEMP EIS. The purpose of this Memorandum of Understanding (MOU) is to outline the roles and responsibilities of the joint-lead and the cooperating agency (hereinafter collectively referred to alternatively as "agencies" or "parties") in accordance with 43 CFR § 46.225(d).

II. Background

The LTEMP process is intended to develop and implement a structured, long term experimental and management plan, to determine the need for potential future modifications to Glen Canyon Dam operations, and to determine whether to establish an Endangered Species Act (ESA) Recovery Implementation Program for endangered fish species below Glen Canyon Dam. Revised dam operations and other actions under the jurisdiction of the Secretary of the Interior will be considered within alternatives of the EIS, in keeping with the scope of the Grand Canyon Protection Act (GCPA). The NEPA process will document and evaluate impacts of the alternatives described in the EIS.

III. Purpose of this MOU

This MOU defines the relationship and duties of the joint-lead and the cooperating agency in completing NEPA compliance for the LTEMP, and how the parties will cooperate during the NEPA process.

By signing this MOU, the parties agree that this MOU provides the framework to fulfill compliance requirements for NEPA.

IV. Agency Designee

The cooperating agency will designate a primary point of contact (and alternate if desired) for the EIS by sending correspondence at the time of signing of this agreement to the joint-lead agencies with the contacts name and information. The cooperating agency may change its point

of contact at any time by providing written notice to the joint-lead agencies and the other cooperating agencies.

V. Authority

The authority of the joint-lead and the cooperating agency to participate in this agreement is provided by the National Environmental Policy Act. 42 U.S.C. §§ 4321 *et seq.* NEPA allows agencies to be designated as a cooperating agency when that agency has jurisdiction by law or special expertise (40 CFR § 1501.6 and 40 CFR§ 1508.5). Activities contemplated under this MOU are specifically authorized under:

A. Title I of NEPA;

B. "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," 40 CFR §§ 1500-1508. Council on Environmental Quality (in particular 40 CFR § 1501.6, Cooperating Agencies);

C. Department of the Interior NEPA Implementing Procedures in the Departmental Manual at 43 CFR § Part 46. Cooperating Agencies (40 CFR §1501.6).

D. Section 106 of the National Historic Preservation Act, as amended. 16 U.S.C. §§ 470 *et seq.*

E. Applicable tribal consultation policies of the joint-lead agencies and the Department of the Interior, and Executive Order 13175 (Nov. 6, 2000).

F. Resolution No. NABIMY-33-14_ of the Naabik'kyati' Committee. Navajo Nation Council, pursuant to 2 N.N.C. § 301(B)(15).

VI. Joint-lead Agency Responsibilities

Reclamation and the NPS will be joint-leads for this effort because Reclamation has primary responsibility for operation of Glen Canyon Dam and the NPS has primary responsibility for managing Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area.

The NPS and Reclamation, as joint-leads for the completion of the LTEMP EIS, shall:

A. Jointly be responsible for the preparation, quality, content and overall direction of the EIS and for ensuring the appropriate participation of cooperating agencies in developing the EIS.

B. Jointly be responsible for identifying the purpose and need for the project, scope of analysis, and decisions to be made. In coordination with the Department, the joint-lead agencies will make the final decision on the content of all EIS-related documents,

including the preferred alternative and the Record of Decision to be signed by the Secretary of the Interior.

C. Jointly oversee the execution and administration of contracts or cooperative agreements with mutually agreed upon federal, state or local agencies, or tribal governments or mutually agreed upon private contractors to develop information for inclusion in the EIS.

D. Jointly conduct cooperating agency meetings, and provide advance information for discussions at these meetings, as necessary during the preparation of the EIS. Meeting dates and locations will be jointly agreed upon and may be chosen to coincide with the dates of Adaptive Management Working Group meetings to minimize travel costs and maximize collaboration.

E. Ensure that cooperating agency proposals and substantive comments (including divergent views) within their jurisdiction or technical expertise are appropriately documented and considered in the EIS.

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The cooperating agency, subject to sufficient appropriations to carry out the following responsibilities, shall:

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B. Participate in the scoping process.

C. Assume, on request of the lead agencies, responsibility for developing information and preparing environmental analyses including portions of the environmental impact statement concerning which the cooperating agency has special expertise.

D. Make available staff support at the lead agencies' request to enhance the latter's interdisciplinary capability.

E. Normally use their own funds.

F. The cooperating agency may in response to a lead agencies' request for assistance in preparing the environmental impact statement reply that other program commitments preclude any involvement or the degree of involvement requested in the action that is the subject of the environmental impact statement.

G. Provide comments in a timely manner (normally within 30 days of receipt) of draft documents when requested. One consolidated set of comments for the cooperating agency will be provided in the format specified by the joint-lead agencies.

H. As appropriate and practicable, attend cooperating agency meetings and public meetings and hearings on the EIS process.

I. Retain the right to comment on all issues related to the EIS through the normal EIS public review and comment process, as well as through the independently required tribal consultation process.

J. Promptly advise the joint-lead agencies of concerns related to the EIS process.

VIII. Shared Responsibilities of all Parties

A. Reclamation and NPS may meet separately with any one or more cooperating agencies to discuss specific topics.

B. It is understood that the respective agencies are normally responsible for their own costs with regard to completion of tasks outlined herein, such as attendance at meetings, assembling data, analyzing effects, and providing input with regard to sections of the EIS subject to section VII.F. Funding requests from tribal governments with a demonstrated need will be considered on a case by case basis by the joint-lead agencies.

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Reclamation and NPS are responsible for all decisions involving the EIS and will make all final decisions on disputes arising during the NEPA process. The joint-lead agencies will document the nature of any dispute and the resolution of the dispute. Documentation of resolution will be made available to appropriate parties.

X. Standard Conditions:

A. AUTHORITIES. Nothing in this MOU shall be construed to extend the jurisdiction or decision-making authority of any party to this MOU beyond that which exists under current laws and regulations. Nothing in this MOU shall be construed as limiting or affecting the authority or legal responsibility of any party, or as binding any party to perform beyond the

respective authority of each. , or to otherwise violate any applicable law, regulation or policy or to require any party to assume or expend any specific sum of money. The provisions of this MOU are subject to the laws of the United States; and the regulations of the Department of the Interior, as they may be applicable. Nothing in this MOU shall be construed as affecting the decision-making requirements of any party or impairing the independent judgment of each party regarding policy decisions.

B. **RELEASE OF INFORMATION.** Except as required by court order or ruling, the joint - lead agencies and the cooperating agency will not release any pre-decisional material or working information or documents to the public other than through an approved Freedom of Information Act request or an approved request made under the Navajo Nation Privacy Act, or unless the agency or agencies have already disseminated the specific materials or documents to the public. The agencies agree to inform each other if it is determined that there is a legal requirement to release any such information, and that information will include expected release date of the information.

C. **LEGAL RIGHTS AND REMEDIES.** Nothing in this MOU shall be construed to alter the legal rights and remedies that each party would otherwise have. No party waives any legal rights or defenses by entering into this MOU or participating in the process contemplated hereby, including that nothing herein shall be construed as a waiver, express or implied, of any party's sovereign immunity. This MOU is not a Federal contract, rule, or regulation. This MOU shall not be construed as or interpreted to be final Federal agency action.

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K. LIABILITY. To the extent authorized by law, on behalf of itself, its officers, directors, members, employees, agents, and representatives, each party agrees that it will be responsible for its own acts and omissions and the results thereof and that it shall not be responsible for the acts or omissions of other parties, nor the results thereof. To the extent authorized by law, each party therefore agrees that it will assume the risk and liability to itself, its agents, employees, and volunteers for any injury to or death of persons or loss or destruction of property resulting in any manner from the conduct of the party's own operations and/or the operations of its agents, employees, and/or volunteers under this MOU, in accordance with applicable law, including the Navajo Sovereign Immunity Act, as amended. To the extent authorized by law, each party further releases and waives all claims against the other party for compensation for any loss, cost, damage, expense, personal injury, death, claim, or other liability arising out of the performance of this MOU.

L. NONDISCRIMINATION. This MOU is subject to all Federal statutes relating to nondiscrimination, as applicable to the parties. These include, but are not limited to: (a) Title VI of the Civil Rights Act of 1964 (P.L. 88-352); and (b) Title IX of the Education Amendments of 1972 (20 U.S.C. 1681-1683 and 1685-1686).

XI. Effective Dates, Amendment and Termination

A. This MOU will become effective on the date of the last signature and may be subsequently amended through written agreement of all signatories. The joint-lead agencies or the cooperating agency may terminate their cooperative status by providing 30 days written

notice of termination to the other party. Otherwise, the cooperative status will terminate when a Record of Decision is issued or the EIS is terminated.

B. This MOU may be executed in separate counterparts, and such counterparts when executed shall constitute an original.

XII. Signatures

The parties hereto have executed this Memorandum of Understanding as of the dates shown below.

BUREAU OF RECLAMATION

Date June 18, 2014

Larry Walkoviak
Regional Director
Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Date 10/10/2014

Raymond M. Sauvajot, Ph.D.
Acting Associate Director
Natural Resource Stewardship and Science
National Park Service

for

Date July 16, 2014

Sue Masica
Regional Director
Intermountain Region
National Park Service

Date 03 October 2014

Christine Lehnertz
Regional Director
Pacific West Region
National Park Service

THE NAVAJO NATION

Date JUN 09 2014

Ben Shelly, President

(f) Pueblo of Zuni

Memorandum of Understanding
Between
The Bureau of Reclamation and the National Park Service
And
The Pueblo of Zuni
For the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan for the Operation of Glen Canyon Dam

I. Introduction and Purpose

Pursuant to the National Environmental Policy Act (NEPA), the Department of the Interior (Department), through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), is preparing an environmental impact statement (EIS) for a Long Term Experimental and Management Plan (LTEMP) for the operation of Glen Canyon Dam. Reclamation and the NPS are the joint lead or "joint-lead agencies" for the completion of this EIS. The Pueblo of Zuni hereafter "the cooperating agency", in addition to other parties, has agreed to serve as a cooperating agency for the completion of the LTEMP EIS. The purpose of this Memorandum of Understanding (MOU) is to outline the roles and responsibilities of the joint-lead and the cooperating agency (hereinafter collectively referred to alternatively as "agencies" or "parties") in accordance with 43 CFR § 46.225(d).

II. Background

The LTEMP process is intended to develop and implement a structured, long term experimental and management plan, to determine the need for potential future modifications to Glen Canyon Dam operations, and to determine whether to establish an Endangered Species Act (ESA) Recovery Implementation Program for endangered fish species below Glen Canyon Dam. Revised dam operations and other actions under the jurisdiction of the Secretary of the Interior will be considered within alternatives of the EIS, in keeping with the scope of the Grand Canyon Protection Act (GCPA). The NEPA process will document and evaluate impacts of the alternatives described in the EIS.

III. Purpose of this MOU

This MOU defines the relationship and duties of the joint-lead and the cooperating agency in completing NEPA compliance for the LTEMP, and how the parties will cooperate during the NEPA process.

By signing this MOU, the parties agree that this MOU provides the framework to fulfill compliance requirements for NEPA.

IV. Agency Designee

The cooperating agency will designate a primary point of contact (and alternate if desired) for the EIS by sending correspondence at the time of signing of this agreement to the joint-lead agencies with the contacts name and information. The cooperating agency may change its point

of contact at any time by providing written notice to the joint-lead agencies and the other cooperating agencies.

V. Authority

The authority of the joint-lead and the cooperating agency to participate in this agreement is provided by the National Environmental Policy Act, 42 U.S.C. §§ 4321 *et seq.* NEPA allows agencies to be designated as a cooperating agency when that agency has jurisdiction by law or special expertise (40 CFR § 1501.6 and 40 CFR§ 1508.5). Activities contemplated under this MOU are specifically authorized under:

A. Title I of NEPA;

B. "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," 40 CFR §§ 1500-1508, Council on Environmental Quality (in particular 40 CFR § 1501.6, Cooperating Agencies);

C. Department of the Interior NEPA Implementing Procedures in the Departmental Manual at 43 CFR § Part 46, Cooperating Agencies (40 CFR §1501.6).

VI. Joint-lead Agency Responsibilities

Reclamation and the NPS will be joint-leads for this effort because Reclamation has primary responsibility for operation of Glen Canyon Dam and the NPS has primary responsibility for managing Grand Canyon National Park, Glen Canyon National Recreation Area, and Lake Mead National Recreation Area.

The NPS and Reclamation, as joint-leads for the completion of the LTEMP EIS, shall:

A. Jointly be responsible for the preparation, quality, content and overall direction of the EIS and for ensuring the appropriate participation of cooperating agencies in developing the EIS.

B. Jointly be responsible for identifying the purpose and need for the project, scope of analysis, and decisions to be made. In coordination with the Department, the joint-lead agencies will make the final decision on the content of all EIS-related documents, including the preferred alternative and the Record of Decision to be signed by the Secretary of the Interior.

C. Jointly oversee the execution and administration of contracts or cooperative agreements with mutually agreed upon federal, state or local agencies, or tribal governments or mutually agreed upon private contractors to develop information for inclusion in the EIS.

D. Jointly conduct cooperating agency meetings, and provide advance information for discussions at these meetings, as necessary during the preparation of the EIS. Meeting dates and locations will be jointly agreed upon and may be chosen to coincide with the

dates of Adaptive Management Working Group meetings to minimize travel costs and maximize collaboration.

E. Ensure that cooperating agency proposals and substantive comments (including divergent views) within their jurisdiction or technical expertise are appropriately documented and considered in the EIS.

F. Provide advance copies (normally 30 days) of the preliminary draft and preliminary final EIS and related compliance documents for review by cooperating agencies.

VII. Cooperating Agency Responsibilities

Federal, state, and local agencies, and tribal governments with appropriate expertise or jurisdiction have been invited to participate as cooperating agencies. Reclamation and NPS may, at any time during the course of the EIS project, invite additional agencies to participate in the process.

The cooperating agency, subject to sufficient appropriations to carry out the following responsibilities, shall:

A. Participate in the NEPA process at the earliest possible time.

B. Participate in the scoping process.

C. Assume, on request of the lead agencies, responsibility for developing information and preparing environmental analyses including portions of the environmental impact statement concerning which the cooperating agency has special expertise.

D. Make available staff support at the lead agencies' request to enhance the latter's interdisciplinary capability.

E. Normally use their own funds.

F. The cooperating agency may in response to a lead agencies' request for assistance in preparing the environmental impact statement reply that other program commitments preclude any involvement or the degree of involvement requested in the action that is the subject of the environmental impact statement.

G. Provide comments in a timely manner (normally within 30 days of receipt) of draft documents when requested. One consolidated set of comments for the cooperating agency will be provided in the format specified by the joint-lead agencies.

H. As appropriate and practicable, attend cooperating agency meetings and public meetings and hearings on the EIS process.

I. Retain the right to comment on all issues related to the EIS through the normal EIS public review and comment process.

J. Promptly advise the joint-lead agencies of concerns related to the EIS process.

VIII. Shared Responsibilities of all Parties

A. Reclamation and NPS may meet separately with any one or more cooperating agencies to discuss specific topics.

B. It is understood that the respective agencies are normally responsible for their own costs with regard to completion of tasks outlined herein, such as attendance at meetings, assembling data, analyzing effects, and providing input with regard to sections of the EIS subject to section VII.F. Funding requests from tribal governments with a demonstrated need will be considered on a case by case basis by the joint-lead agencies.

C. All parties agree that because of the need for timely completion of NEPA compliance, work will proceed as expeditiously as possible, including data gathering, analysis, and document review. However, all parties agree that sufficient time must be allowed to ensure thorough document review. It is anticipated that the parties will be given a minimum of 30 days to review the preliminary draft EIS and a minimum of 30 days to review the draft final EIS.

IX. Resolution of Disputes

Reclamation and NPS are responsible for all decisions involving the EIS and will make all final decisions on disputes arising during the NEPA process. The joint-lead agencies will document the nature of any dispute and the resolution of the dispute. Documentation of resolution will be made available to appropriate parties.

X. Standard Conditions:

A. AUTHORITIES. Nothing in this MOU shall be construed to extend the jurisdiction or decision-making authority of any party to this MOU beyond that which exists under current laws and regulations. Nothing in this MOU shall be construed as limiting or affecting the authority or legal responsibility of any party, or as binding any party to perform beyond the respective authority of each, or to require any party to assume or expend any specific sum of money. The provisions of this MOU are subject to the laws of the United States; and the regulations of the Department of the Interior, as they may be applicable. Nothing in this MOU shall be construed as affecting the decision-making requirements of any party or impairing the independent judgment of each party regarding policy decisions.

B. RELEASE OF INFORMATION. Except as required by court order or ruling, the joint - lead agencies and the cooperating agency will not release any pre-decisional material or working information or documents to the public other than through an approved Freedom of Information Act request or comparable tribal or state law-based process, or unless the agency or agencies have already disseminated the specific materials or documents to the public. The

agencies agree to inform each other if it is determined that there is a legal requirement to release any such information, and that information will include expected release date of the information.

C. **LEGAL RIGHTS AND REMEDIES.** Nothing in this MOU shall be construed to alter the legal rights and remedies that each party would otherwise have. No party waives any legal rights or defenses by entering into this MOU or participating in the process contemplated hereby. This MOU is not a Federal contract, rule, or regulation. This MOU shall not be construed as or interpreted to be final Federal agency action.

D. **SEVERABILITY.** Should any portion of this MOU be judicially determined to be illegal or unenforceable, the remainder of the MOU shall continue in full force and effect, and any party may renegotiate the terms affected by the severance.

E. **THIRD PARTY BENEFICIARY RIGHTS.** The parties do not intend to create in any other individual or entity the status of third party beneficiary, and this MOU shall not be construed so as to create such status. The rights, duties and obligations contained in this MOU shall operate only among the parties to this MOU, and shall inure solely to the benefit of the parties to this MOU. The provisions of this MOU are intended only to assist the parties in determining and performing their obligations under this MOU.

F. **NON-FUND OBLIGATION DOCUMENT.** This MOU is neither a fiscal nor a funds obligation document. Any endeavor or transfer of anything of value involving reimbursement or contribution of funds between the parties to this instrument will be handled in accordance with applicable laws, regulations, and procedures including those for Government procurement and printing. Such endeavors will be outlined in separate agreements that shall be made in writing by representatives of the parties and shall be independently authorized by appropriate rules, policies, and statutory authority. This MOU does not provide such authority. Specifically, this MOU does not establish authority for noncompetitive award to the cooperator of any contract or other agreement. Nothing herein constitutes a binding commitment to fund any of the proceedings encompassed by the MOU. Any specific cost sharing or funding shall be executed separately through other funding mechanisms, as deemed necessary and appropriate by each of the signatories.

G. **PARTICIPATION IN SIMILAR ACTIVITIES WITH OTHER ENTITIES.** This MOU in no way restricts any of the parties from participating in similar activities with other public or private agencies, organizations, and individuals.

H. **ENDORSEMENT.** Nothing in this MOU may be interpreted to imply that the United States, the Department of the Interior, the NPS, the Bureau of Reclamation, or the cooperating agency endorses any product, service or policy of the other parties. No party will take any action or make any statement that suggests or implies such an endorsement.

I. **STATUTES AND REGULATIONS.** The provisions of any statutes and/or regulations cited in this MOU contain legally binding requirements. The MOU itself does not alter, expand, or substitute for those provisions or regulations. This MOU does not impose legally-

XII. Signatures

The parties hereto have executed this Memorandum of Understanding as of the dates shown below.

BUREAU OF RECLAMATION

Larry Walkoviak — Date August 3, 2012
Regional Director
Upper Colorado Region
Bureau of Reclamation

NATIONAL PARK SERVICE

Herbert C. Frost — Date 9/6/2012
Associate Director for Natural Resources, Stewardship and Science
National Park Service

John Wessels — Date 8/13/12
Regional Director
Intermountain Region
National Park Service

for Christine Lehnertz — Date 8/29/12
Regional Director
Pacific West Region
National Park Service

THE PUEBLO OF ZUNI

Arlen Quetawki Sr., Governor — Date 07-26-12
For:

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ATTACHMENT N.2

(a) Multiple Tribes

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street
Salt Lake City, UT 84138

NATIONAL PARK SERVICE
Intermountain Region Office
12795 Alameda Parkway
Denver, CO 80225

November 30, 2011

Bernadine Jones, Chairwoman
The Havasupai Tribe
PO BOX 10
Supai, AZ 86435

Dear Ms. Jones,

The Department of the Interior, through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) as co-lead agencies, intend to prepare an Environmental Impact Statement (EIS) under the provisions of the National Environmental Policy Act (NEPA) for a Long-Term Experimental and Management Plan (LTEMP) for Glen Canyon Dam operations. A primary function of the LTEMP, which will be developed based on tribal and public input and the latest science, will be to review the results of experiments that have been successfully completed and use this information to guide development of future experimental and management actions. Through the LTEMP EIS, alternatives will be developed and evaluated that consider potential future modifications to Glen Canyon Dam operations and other resource management and protection actions.

The Department's decision to develop the LTEMP is a component of its efforts to continue to comply with the ongoing requirements and obligations established by the Grand Canyon Protection Act of 1992 (Pub. L. 102-575) (GCPA) to protect, mitigate adverse impacts to, and improve the conditions for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, while continuing to comply with the Law of the River. Although the GCPA does not apply to the Lake Mead National Recreation Area, effects to the resources at Lake Mead will be considered in the LTEMP EIS. Enclosed please find a map of the project area.

The purpose of this letter is to initiate government-to-government consultation on the LTEMP under Section 106 of the National Historic Preservation Act of 1966 (NHPA), as amended, and other relevant authorities. Through consultation, you will have opportunities to identify concerns related to historic properties, including traditional cultural properties and archaeological sites, natural resources, Indian trust assets as appropriate, and other issues of importance to your tribe. The NPS and Reclamation intend to follow 36 CFR 800.8(c), and use the process and documentation required for the preparation of all NEPA documents to comply with Section 106 in lieu of the procedures set forth in Sections 800.3 through 800.6.

The NPS and Reclamation began the NEPA Public Scoping process for this EIS with publication of the Notice of Intent in the Federal Register on July 6, 2011. We recently completed seven initial public scoping meetings; the deadline for receiving public comments on the scope of the EIS is January 31, 2012. More information can be found on the project website at http://ltempeis.anl.gov/.

Effects of the operations of Glen Canyon Dam have been evaluated for more than 20 years. The 1995 EIS for Glen Canyon Dam operations and the subsequent Glen Canyon Dam Adaptive Management Program have allowed us to better understand the relationship of water releases and downstream effects. The LTEMP EIS will draw on the research and knowledge we have acquired, and continue to acquire, to determine how the dam is operated for the next 20 years.

If you are interested in consulting on the LTEMP, please contact us at your earliest convenience and identify a point of contact for communication. If you would like to schedule meetings with us, please let us know as we plan to schedule these meetings by the end of January 2012, and conduct them as soon as is practicable. We will provide opportunities to meet and consult with you throughout the EIS process. Please contact Jan Balsom at (928) 638-7758 or Janet Cohen at (928) 638-7445, Grand Canyon National Park, or Keith Waldron, Bureau of Reclamation, at (801) 524-3816 at your earliest convenience.

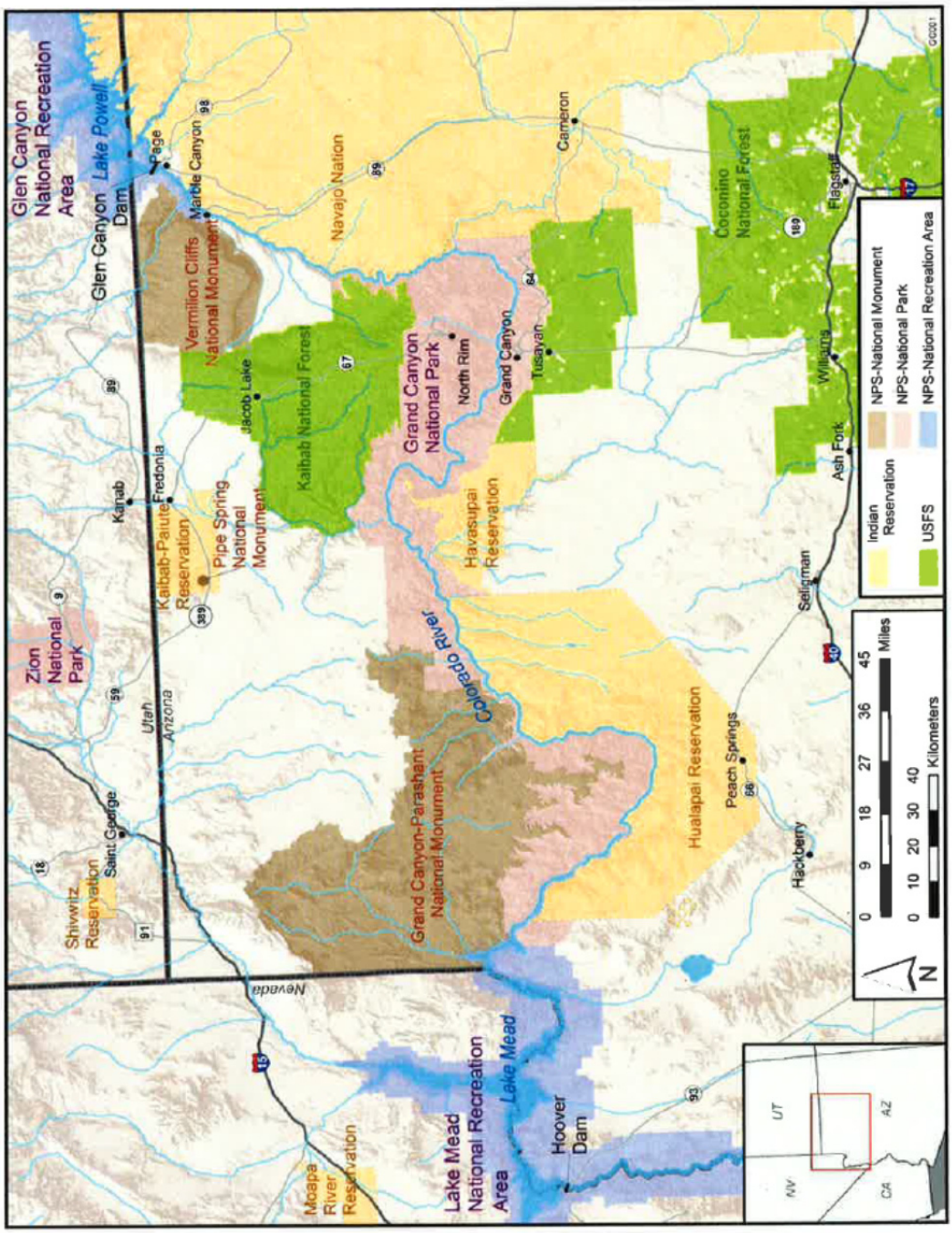
Sincerely,

Larry Walkoviak
Regional Director
Upper Colorado Region
Bureau of Reclamation

John Wessels
Regional Director
Intermountain Region
National Park Service

Enclosure: Project area map

cc: GRCA: Superintendent Uberuaga, Martha Hahn, Jan Balsom, Janet Cohen
LAKE: Superintendent Dickenson, Kent Turner, Steve Daron
GLCA: Superintendent Brindle, Brian Carey, Chris Hughes, Rosemary Sucec
IMR/WASO: Rob Billerbeck, Tammy Whittington, Karen Breslin, Chris Turk, Bert Frost, Pat Walsh
BOR: Beverley Heffernan, Glen Knowles, Keith Waldron
DOI: Jane Lyder, Lori Caramanian
Travis Hamidreek, Natural Resources


Glen Canyon National Recreation Area
Lake Powell
Glen Canyon Dam
Page
Marble Canyon
Vermilion Cliffs National Monument
Navajo Nation
Cameron
Coconino National Forest
Flagstaff
Jacob Lake
Kaibab National Forest
Grand Canyon National Park
North Rim
Grand Canyon
Tusayan
Williams
Ash Fork
Kanab
Fredonia
Kaibab-Paiute Reservation
Pipe Spring National Monument
Havasupai Reservation
Zion National Park
Utah
Arizona
Colorado River
Seligman
Hualapai Reservation
Peach Springs
Hackberry
Saint George
Shivwitz Reservation
Grand Canyon-Parashant National Monument
Nevada
Lake Mead National Recreation Area
Lake Mead
Hoover Dam
Moapa River Reservation
NPS-National Monument
NPS-National Park
NPS-National Recreation Area
Indian Reservation
USFS
Miles
Kilometers
N
UT
AZ
NV
CA

List of Recipients

Name	2ndName	Tribe	Add1	Add2	City	Cc1	Cc2	Cc3
Louis Manuel, Jr., Chairperson		Ak Chin Indian Community	42507 W. Peters & Nail Road		Maricopa, AZ 85138			
Charles Wood, Chairperson		Chemehuevi Tribal Council	PO BOX 1976		Chemehuevi Valley, CA 92362			
Cara MacDonald	Director of Cultural Resources	Chemehuevi Tribal Council	PO BOX 1976		Chemehuevi Valley, CA 92363			
Sherry Cordova, Chairperson		Cocopah Indian Tribe	County 15th & Avenue G		Somerton, AZ 85350			
H. Jill McCormick	Cultural Resources Manager	Cocopah Indian Tribe	Co. 15th St. & Ave. G		Somerton, AZ 85350			
Eldred Enas, Chairman		Colorado River Indian Tribes	26600 Mohave Road		Parker, AZ 85344			
Clinton Pattea, President		Fort McDowell Yavapai Tribal Council	PO BOX 17779		Fountain Hills, AZ 85268			
Karen Ray	Cultural Development Office		PO BOX 17779		Fountain Hills, AZ 85268			
Timothy Williams, Chairperson		Fort Mojave Tribal Council	500 Merriman Avenue		Needles, CA 92363			
William R. Rhodes, Governor		Gila River Indian Community Council	PO BOX 97		Sacatone, AZ 85147			
Bernadine Jones, Chairwoman		The Havasupai Tribe	PO BOX 10		Supai, AZ 86435			
Travis Hamidreek	Natural Resources	The Havasupai Tribe	PO BOX 10		Supai, AZ 86435			
Leroy Ned Shingoitewa, Chairman		The Hopi Tribe	PO BOX 123		Kykotsmovi, AZ 86039			
Leigh Kuwanwisiwma	Cultural Preservation Officer	The Hopi Tribe	PO BOX 123		Kykotsmovi, AZ 86039			
Mike Yeatts	Tribal Archaeologist	The Hopi Tribe	PO BOX 123		Kykotsmovi, AZ 86039			
Louise Benson, Chairwoman		The Hualapai Tribe	PO BOX 179		Peach Springs, AZ 86434			
Loretta Jackson-Kelly	Tribal Historic Preservation Officer	The Hualapai Tribe	PO BOX 300		Peach Springs, AZ 86434			
Lee Pasata, President		Jicarilla Apache Nation	PO BOX 507		Dulce, NM 87528			

1

Manuel Savala, Chairman		Kaibab Band of Paiute Indians	Tribal Affairs Building	HC-65, Box 2	Pipe Spring, AZ 86022			
Charley Bullets	Cultural Resource Director	Kaibab Band of Paiute Indians	Tribal Affairs Building	HC-65, Box 2	Pipe Spring, AZ 86022			
Tonia Means, Chairperson		Las Vegas Tribe of Paiute Indians	One Paiute Drive		Las Vegas, NV 89106			
Ramona Salazar		Las Vegas Tribe of Paiute Indians	One Paiute Drive		Las Vegas, NV 89106			
Kenny Anderson		Las Vegas Tribe of Paiute Indians	One Paiute Drive		Las Vegas, NV 89106			
William Anderson, Chairman		Moapa Band of Paiute Indians	PO BOX 340		Moapa, NV 89025			
Deanna Domingo	Cultural Committee	Moapa Band of Paiute Indians	PO BOX 340		Moapa, NV 89025			
Ben Shelly, President		The Navajo Nation	PO Box 7440		Window Rock, AZ 86515			
Alan Downer	Historic Preservation Officer	The Navajo Nation	PO BOX 4950		Window Rock, AZ 86515			
Tony Joe	Supervisory Anthropologist	The Navajo Nation	Division of Natural Resources	PO BOX 4950	Window Rock, AZ 86515			
Jeff Cole	Navajo Fish and Game Department	The Navajo Nation	PO Box 1480		Window Rock, AZ 86515			
Stanley M. Pollack	Assistant Attorney General	Department of Justice	The Navajo Nation	P.O. Drawer 2010	Window Rock, AZ 86515			
Ron Lovato, Governor		Ohkay Owingeh	PO BOX 1099		San Juan Pueblo, NM 87566			
Jeannine Borchardt, Chairperson		Paiute Indian Tribe of Utah	440 North Paiute Drive		Cedar City, UT 84720			
Dorena Martineau		Paiute Indian Tribe of Utah	440 North Paiute Drive		Cedar City, UT 84720			
Peter Yucupicio, Chairperson		The Pascua Yaqui Tribe	7474 S. Camino de Oeste		Tucson, AZ 85746			
Randall Vicente, Governor		The Pueblo of Acoma	PO BOX 309		Acoma, NM 87034			

Robert B. Pecos, Governer		The Pueblo of Cochiti	PO BOX 70		Cochiti, NM 87072			
Michael Toledo, Jr., Governor		The Pueblo of Jemez	PO BOX 100		Jemez Pueblo, NM 87024			
Richard B. Luarkie, Governor		The Pueblo of Laguna	PO BOX 194		Laguna, NM 87026			
Ernest Mirabel, Governor		The Pueblo of Nambe	Route 1	Box 117-BB	Santa Fe, NM 87501			
George Rivera, Governor		The Pueblo of Pojoaque	7800 Cities of Gold Road		Santa Fe, NM 87506			
Raymond Sandoval, Jr., Governor		The Pueblo of San Felipe	PO BOX 4339		San Felipe, NM 87001			
Malcolm Montoya, Governor		The Pueblo of Sandia	481 Sandia Loop		Bernalillo, NM 87004			
Lawrence Montoya, Governor		The Pueblo of Santa Ana	2 Dove Road		Santa Ana Pueblo, NM 87004			
Walter Dashend, Governor		The Pueblo of Santa Clara	PO BOX 580		Espanola, NM 87532			
Mark Mitchell, Governor		The Pueblo of Tesuque	RR 42	Box 360-T	Santa Fe, NM 87506			
Marcellus Medina		The Pueblo of Zia	135 Capitol Square Drive		Zia Pueblo, NM 87053			
Arlen P. Quetawki, Sr., Governor		The Pueblo of Zuni	PO BOX 339		Zuni, NM 87327			
Kurt Dongoske	Zuni Heritage and Historic Preservation Office	The Pueblo of Zuni	PO BOX 339		Zuni, NM 87327			
Mike Jackson, Sr., President		Fort Yuma Quechan Tribe	PO BOX 1899		Yuma, AZ 85366			
Pauline Jose	Cultural Preservation Committee	Fort Yuma Quechan Tribe	PO BOX 1899		Yuma, AZ 85366			
Keeney Escalanti Sr.	Vice President	Fort Yuma Quechan Tribe	PO BOX 1899		Yuma, AZ 85366			
Diane Enos, President		Salt River Pima-Maricopa Indian Community	10005 E. Osborn		Scottsdale, AZ 85256			
Shane Anton	Cultural Resources Dept.	Salt River Pima-Maricopa Indian Community	10005 E. Osborn		Scottsdale, AZ 85256			

Mary Kim Titla, Chairwoman		San Carlos Apache Tribe	PO BOX 1240		San Carlos, AZ 85550			
Lee Choe	Interim Chair	San Juan Southern Paiute Tribe	PO Box 1989		Tuba City, AZ 86045			
Kelly Youngbear, Superintendent		Southern Paiute Agency	BIA	PO BOX 720	St. George, UT 84771			
Matthew J. Box, Chairman		Southern Ute Tribal Council	PO BOX 737		Ignacio, CO 81137			
Neil Cloud	NAGPRA Coordinator	Southern Ute Tribal Council	PO BOX 737		Ignacio, CO 81137			
Ned Norris, Jr.		Tohono O'odham Nation	PO BOX 837		Sells, NM 85634			
Ivan Smith, Chairman		Tonto Apache	Tonto Apache Reservation #30		Payson, AZ 85541			
Richard Jenks, Chairman		Ute Indian Tribe	PO BOX 190		Ft. Duchesne, UT 84026-0190			
Ms. Betsy Chapoose	Cultural Rights and Protection Office	Ute Indian Tribe	PO BOX 190		Ft. Duchesne, UT 84026-0190			
Gary Hayes, Chairman		Ute Mountain Ute Tribe	P. O. Box JJ		Towaco, CO 81334			
Terry Knight, Sr.		Tribal Historic Preservation Officer	Ute Mountain Ute Tribe	PO BOX 468	Towaco, CO 81334			
Ronnie Lupe, Chairman		White Mountain Apache	PO BOX 700		Whiteriver, AZ 85941			
Mark T. Altaha	Historic Preservation Office	White Mountain Apache	PO BOX 507		Fort Apache, AZ 85926			
David Kwail, Chairman		Yavapai-Apache Nation	2400 W. Datsi Street		Camp Verde, AZ 86322			
Chris Coder		Yavapai-Apache Nation	2400 W. Datsi Street		Camp Verde, AZ 86322			
Ernest Jones, Sr., President		Yavapai-Prescott Indian Tribe	530 E. Merritt		Prescott, AZ 86301			
Linda Ogo	Cultural Research Committee	Yavapai-Prescott Indian Tribe	530 E. Merritt		Prescott, AZ 86301			

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street
Salt Lake City, UT 84138

NATIONAL PARK SERVICE
Intermountain Region Office
12795 Alameda Parkway
Denver, CO 80225

December 8, 2011

Bernadine Jones
Chairwoman
The Havasupai Tribe
PO BOX 10
Supai, AZ 86435

Dear Chairwoman Jones:

The Department of the Interior, through the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) as co-lead agencies, intends to prepare an Environmental Impact Statement (EIS) under the provisions of the National Environmental Policy Act (NEPA) for a Long-Term Experimental and Management Plan (LTEMP) for Glen Canyon Dam operations. A primary function of the LTEMP, which will be developed based on cooperator, tribal, and public input and the latest science, will be to review the results of experiments that have been successfully completed and use this information to guide development of future experimental and management actions. The LTEMP is intended to develop and implement a structured, long-term experimental and management plan, to determine the need for potential future modifications to Glen Canyon Dam operations, and to determine whether to establish an Endangered Species Act Recovery Implementation Program for endangered fish species below Glen Canyon Dam.

The Department's decision to develop the LTEMP is a component of its efforts to continue to comply with the ongoing requirements and obligations established by the Grand Canyon Protection Act of 1992 (Pub. L. 102-575) (GCPA) to protect, mitigate adverse impacts to, and improve the conditions for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, while continuing to comply with the Law of the River. Although the GCPA does not apply to the Lake Mead National Recreation Area, effects to the resources at Lake Mead will be considered in the LTEMP EIS. Enclosed, please find a map of the project area.

Effects of the operations of Glen Canyon Dam have been evaluated for more than 20 years. The 1995 EIS for Glen Canyon Dam operations and the subsequent Glen Canyon Dam Adaptive Management Program have allowed us to better understand the relationship of water releases and downstream effects. The LTEMP EIS will draw on this existing research and knowledge to determine how the dam will be operated in the future.

In accordance with 40 CFR 1501.6 of the Council on Environmental Quality's (CEQ) regulations for implementing the procedural provisions of NEPA, and 43 CFR 46.225 of the Department of

the Interior's regulations for implementation of NEPA, the NPS and Reclamation are inviting the Havasupai Tribe to be a cooperating agency in the LTEMP EIS process. Your participation in the LTEMP EIS process will assist us in making a more informed decision. Participation as a cooperating agency does not imply that your agency supports the proposed project.

The scope of your agency's involvement as a cooperating agency should include those areas, resources, or issues under its jurisdiction or within its area of expertise. Should your agency choose to assume cooperating status, your specific responsibilities as a cooperating agency will include:

- Participation in the NEPA scoping and environmental review process including draft document review.
- Providing comments on the project's purpose and need, goals and objectives, methodologies, and range of alternatives.
- Providing comment on project coordination and project schedule.
- Providing (upon request of the co-lead agencies) information and assistance with the preparation of environmental analyses (portions of the NEPA documents relevant to your agency's jurisdiction or area of special expertise).
- Providing staff support at the lead agencies' request to enhance the agencies' interdisciplinary capability.
- Using your agency's own funds for participation.

An email was sent from Anne Castle, Assistant Secretary of the Department of the Interior, on January 21, 2011, to determine preliminary interest from potential cooperating agencies. An initial meeting with potential cooperators was held on February 11, 2011, to address questions and concerns related to this process. To follow up on these initial contacts, we now ask that you formally let us know if you would like to participate as a cooperating agency in the development of the LTEMP EIS. Should the Havasupai Tribe choose to decline cooperating agency status in part or in whole, we ask that you confirm this in writing. We have enclosed a form to facilitate your response to this cooperating agency invitation and ask that you complete and return this form, or otherwise respond in writing, not later than Friday, January 6, 2012.

At this time we are tentatively planning cooperator meetings in Phoenix sometime in February 2012. We will arrange for phone-in capability for all cooperating agency meetings. If you have any questions, please contact the EIS project managers, Beverley Heffernan, Bureau of Reclamation, at (801) 524-3712, or Rob Billerbeck, National Park Service, at (303) 987-6789. We look forward to working with you in developing the LTEMP EIS.

Sincerely,

Larry Walkoviak
Regional Director
Upper Colorado Region
Bureau of Reclamation

John Wessels
Regional Director
Intermountain Region
National Park Service

Enclosures: Response Form and Project Area Map

3

cc: GRCA: Superintendent Uberuaga, Martha Hahn, Jan Balsom,
LAKE: Superintendent Dickenson, Kent Turner,
GLCA: Superintendent Brindle, Brian Carey, Chris Hughes,
IMR/WASO: Rob Billerbeck, Tammy Whittington, Karen Breslin, Chris Turk, Bert Frost, Pat Walsh
BOR: Beverley Heffernan, Glen Knowles
DOI: Jane Lyder, Lori Caramanian

List of Recipients

Name	2ndName	Tribe	Add1	Add2	City	Cc1	Cc2	Cc3
Bernadine Jones, Chairwoman		The Havasupai Tribe	PO BOX 10		Supai, AZ 86435			
Leroy Ned Shingoitewa, Chairman		The Hopi Tribe	PO BOX 123		Kykotsmovi, AZ 86039			
Louise Benson, Chairwoman		The Hualapai Tribe	PO BOX 179		Peach Springs, AZ 86434			
Manuel Savala, Chairman		Kaibab Band of Paiute Indians	Tribal Affairs Building	HC-65, Box 2	Pipe Spring, AZ 86022			
Tonia Means, Chairperson		Las Vegas Tribe of Paiute Indians	One Paiute Drive		Las Vegas, NV 89106			
William Anderson, Chairman		Moapa Band of Paiute Indians	PO BOX 340		Moapa, NV 89025			
Ben Shelly, President		The Navajo Nation	PO Box 7440		Window Rock, AZ 86515			
Jeannine Borchardt, Chairperson		Paiute Indian Tribe of Utah	440 North Paiute Drive		Cedar City, UT 84720			
Arlen P. Quetawki, Sr., Governor		The Pueblo of Zuni	PO BOX 339		Zuni, NM 87327			
Lee Choe	Interim Chair	San Juan Southern Paiute Tribe	PO Box 1989		Tuba City, AZ 86045			
David Kwail, Chairman		Yavapai-Apache Nation	2400 W. Datsi Street		Camp Verde, AZ 86322			

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

Please return this form by January 6, 2012, to indicate your interest in participating as a cooperating agency in the development of a Long-Term Experimental and Management Plan and Environmental Impact Statement for the Glen Canyon Dam.

A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

_____ Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: _____

Contact: _____

Title: _____

Office: _____

Address: _____

_____

_____

Direct Phone: _____

Office Phone: _____

Mobile Phone: _____

Fax: _____

Email: _____

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

(b) Ak-Chin Indian Community

AK-CHIN INDIAN COMMUNITY
Community Government
42507 W. Peters & Nall Road • Maricopa, Arizona 85138 • Telephone: (520) 568-1000 • Fax: (520) 568-1001

July 31, 2012

John Wessels, Regional Director
National Park Service
Intermountain Region Office
12795 Alameda Parkway
Denver, CO 80225

Re: Long-Term Experimental and Management Plan for Glen Canyon Dam operations

Dear Mr. Wessels:

The Ak-Chin Indian Community did receive your letter regarding your intentions to prepare an Environmental Impact Statement (EIS) under the provisions of the National Environmental Policy Act (NEPA) for a Long-Term Experimental and Management Plan (LTEMP) for Glen Canyon Dam operations.

Based on the location of this project, we would defer consultation to Native American Tribes that are located closer to the project area. The Ak-Chin Indian Community has no comments at this time.

Thank you for informing the Ak-Chin Indian Community about this project. If you should have any questions, please contact Mrs. Caroline Antone, Cultural Resources Manager at (520) 568-1372 or Mr. Gary Gilbert, Cultural Resources Technician II, at (520) 568-1369.

Sincerely,

Louis J. Manuel Jr., Chairman
Ak-Chin Indian Community

(c) Gila River Indian Community

GILA RIVER INDIAN COMMUNITY
POST OFFICE BOX 2140, SACATON, AZ 85147

TRIBAL HISTORIC PRESERVATION OFFICE
(520) 562-7162
Fax: (520) 562-5083

January 3, 2012

John Wessels, Regional Director
National Park Service
Intermountain Region Office
12795 Alameda Parkway
Denver, Colorado 80225

RE: Department of the Interior, Bureau of Reclamation and National Park Service Co-Lead Agencies, Environmental Impact Statement (EIS) Preparation Long Term Experimental and Management Plan (LTEMP) Glen Canyon Dam Operations

Dear Mr. Wessels,

The Gila River Indian Community Tribal Historic Preservation Office (GRIC-THPO) has received your letter initiating government-to-government consultation regarding the preparation of an EIS for operations at the Glen Canyon Dam. The GRIC-THPO would be an interested consulting entity and we can be reached at the address listed on the letterhead. The proposed project area is within the ancestral lands of the Four Southern Tribes (Gila River Indian Community; Salt River Pima-Maricopa Indian Community; Ak-Chin Indian Community and the Tohono O'Odham Nation).

Thank you for consulting with the GRIC-THPO on this project. If you have any questions please do not hesitate to contact me or Archaeological Compliance Specialist Larry Benallie, Jr. at 520-562-7162.

Respectfully,

Barnaby V. Lewis
Tribal Historic Preservation Officer
Gila River Indian Community

(d) Havasupai Tribe

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

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A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

✓ Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: Havasupai Tribe
Contact: Don Watahomigie
Title: Chairman
Office: Havasupai Tribal Council
Address: Box 10
Supai, AZ 86435

Direct Phone: 928-660-0023
Office Phone: 928-448-2731 → main Tribal office # Tribal Secretary is Joycee Manakaja
Mobile Phone:
Fax: 928-448-2551
Email: htchair@havasupai-nsn.gov

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

HAVASUPAI TRIBAL COUNCIL
P.O. BOX 10 • SUPAI, ARIZONA 86435
(928) 448-2731 • FAX (928) 448-2551

June 21, 2012

Kirk E. LaGory, Ph.D.
Environmental Science Division
Argonne National Laboratory
9700 s. Cass Ave., Building 240
Argonnc, Ill. 60439

Sent via email to lagory@anl.gov and via mail

Re: Comments on Preliminary Draft LTEMP Alternatives

Dr. LaGory,

We thank the NPS and BoR for the opportunity to work on the LTEMP EIS process as a cooperating agency. We have reviewed the Preliminary Draft Alternatives distributed for Cooperating Agency Review on June 7, 2012 and have the following comments.

The Havasupai Tribe supports operation of Glen Canyon Dam in a way that is closest to natural conditions prior to construction of the dam. The Havasupai have resided in the study area since time immemorial. Significant religious, cultural and historical sites are located in that part of the river corridor that is within their aboriginal territory.

As a matter of form and in recognition of the Secretary's trust responsibility to the Tribe, the Havasupai request that in the lists of considerations "Indian Tribal interests" be listed before ESA. (see page 2)

The Havasupai Tribe requests that the following actions be added to the Elements Potentially Common to All Alternatives:

1. Protection of burial sites and artifacts from erosion and exposure from high flows. In previous flood events burial sites and artifacts of the Havasupai located along the river have been exposed.

2. Timely notice to the Havasupai of changes in flow regimes. Numerous people access the river corridor through the Havasupai Reservation and their safety depends on adequate notice from the Tribe of potential hazards within the River Corridor.
3. River flow regimes should not disrupt the flow of springs close to the river.

Draft Alternative #1, Condition-Dependent Adaptive Strategy is not developed sufficiently to provide comments. The decision tree process cannot be evaluated without knowing the conditions and triggers that will prompt different decisions to be made.

Draft Alternative #3, No Action, includes modifications in the current Adaptive Management Plan as required by other decisions. In order to provide a baseline for comparison of Alternatives and comparison of the decisions under this EIS to the current Adaptive Management Plan, the No Action alternative should describe in detail current conditions. If the current conditions will change prior to implementation of the LTEMP this should be explained in detail so that comparisons may be made and cumulative impacts determined.

Thank you for the opportunity to participate in this process. We look forward to working with you.

Sincerely,

Don Watahomigie, Chairman

From: Carr, Adrianne E.
Sent: Thursday, August 09, 2012 3:38 PM
To: 'Don E. Watahomigie (htchair@havasupai-nsn.gov)'; 'Jaycee Manakaja (htsec1@havasupai-nsn.gov)'
Cc: 'Margaret Vick'; Heffernan, Beverley; Knowles, Glen; Billerbeck, Rob P.; LaGory, Kirk E.
Subject: Response to Havasupai Tribe's comments on June 7 LTEMP Alternatives document

Please find the responses to the Havasupai Tribe's comments on the preliminary draft LTEMP Alternatives document for cooperating agencies.

Very best regards,
Adrianne

Adrianne Carr, Ph.D.
Hydrologist
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Avenue, EVS-240
Argonne, IL 60439

630-252-1572 (office)
650-799-2625 (mobile)
adrianne@anl.gov

Response to Havasupai Tribal Council Comments Received on Preliminary Draft Alternatives

Thank you for your comments, your input is appreciated and helpful for the development of this EIS. Regarding your comment about the order of the tribal trust responsibilities in relation to ESA in the "Need" statement, we did not intend to imply any priority in the listing of items. Both responsibilities are important for this EIS.

Regarding the elements that you mentioned in your letter:

1. Impacts to burial sites and artifacts will be considered in the LTEMP EIS. As a part of compliance with both the NHPA and the GCPA, a goal of alternatives developed for the EIS will be to protect and where possible improve sites. In the context of your comment, we know that if additional sediment in certain areas would help reduce the likelihood of unwanted exposure of burials or other sites, this would be a desirable outcome.

2. The recently signed MOA for the High Flow Experiment Protocol EA provides that there will be at a minimum a 30-day notice for any high flow experiment. We expect to propose similar steps for any new actions under the LTEMP EIS.

3. The EIS team plans to examine impacts to all resources. We would like further explanation as to what the Havasupai mean by "disrupt the flow of springs close to the river." There has been research on these groundwater-fed springs, but we want to make sure that we understand your concerns before responding to this comment.

Draft Alternative #1. Thank you for your comment. We agree that the draft alternatives documented dated June 7, 2012, did not contain sufficient information for full evaluation, but we did want to circulate it for cooperating agency anyway in order to maximize cooperators' opportunities for input on the development of alternatives.

Draft Alternative #3. We agree that the EIS should fully describe current conditions and this will be appropriately captured in the 'affected environment' section of the EIS. The no action alternative is by definition how the Glen Canyon Dam will be operated in the future should none of the LTEMP EIS action alternatives be selected for implementation. This means that 'no action' would be continued operation under the 1996 ROD plus implementation of the HFEP and nonnative fish control in accordance with the two recently issued Findings of No Significant Impact.

From: Margaret Vick [mailto:mjvick@gmail.com]
Sent: Wednesday, August 29, 2012 9:18 PM
To: LaGory, Kirk E.
Cc: Tribal Chair; htvchair@havasupai-nsn.gov; Uberuaga, David V.; Balsom, Janet R.; Heffernan, Beverley; Amy Heuslein; Carr, Adrianne E.
Subject: Havasupai Comments on Tribal Perspectives and Process

Dr. LaGory,

Please find attached two documents: the comments and revised text from the Havasupai Tribe for the section titled Tribal Perspectives and my comments as attorney for the Havasupai Tribe on the EIS process for incorporating tribal input.

The Havasupai Tribal Council discussed the draft section on Tribal Perspectives at several different tribal council meetings. They want to point out to the consultants drafting these documents that the Havasupai do not share a common origin story with other Pai tribes. It should also be noted that the exclusive aboriginal territory of the Havasupai as determined by the Indian Claims Commission was from the Colorado River on the north to the Little Colorado River on the east to the San Francisco Peaks, south to Bill Williams Mountain and on the west to the Aubry Cliffs. Other tribes now claim areas within the Havasupai aboriginal territory but the Havasupai do not support this and the ICC found otherwise.

The attached statement of the Havasupai relationship to the affected area is the only statement that has been approved for inclusion.

Thank you for your cooperation.

Best regards,

Margaret Vick

Margaret J. Vick, JSD
Margaret J. Vick, PLC
140 E. Rio Salado Pkwy, #607
Tempe, AZ 85281
USA
+1 602.814.7666
mjvick@gmail.com

Margaret J. Vick, PLC

140 E. Rio Salado Pkwy #607
Tempe, AZ 85281

602 814 7666
mjvick@gmail.com

August 27, 2012

Kirk E. LaGory PhD
Argonne National Laboratory
9700 s. Cass ave., Building 240
Argonne, Il 60439

Sent via email: lagory@anl.gov

Re: Tribal consultation and incorporation of information in the LTEMP EIS

Dear Dr. LaGory,

I represent the Havasupai Tribe and provide these comments on the process for inclusion of data and information from Tribes in the LTEMP EIS. This letter incorporates my comments made at the LTEMP Tribal Consultation meeting in Tempe on August 10, 2012.

1. Draft "American Indian Perspectives and Values Related to the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement," prepared by Jennifer Abplanalp and Burce Verhaaren, Argonne National Laboratory.

The EIS for operations of Glen Canyon Dam is not the appropriate document to discuss tribal religious practices, religious origins for Native Americans, regional religious connections or other matters not related to the federal action at issue, the operations of Glen Canyon Dam. Information written by a consultant based on third party publications is suspect to many tribal members and should not be re-published in this document.

The Grand Canyon National Park and the Bureau of Reclamation, the co-lead agencies are both within the Department of Interior and have long standing relationships with the Tribes and Native Americans within the affected region. Those Tribes for whom the operations of Glen Canyon Dam may be of concern have been identified as potential cooperating agencies and the process includes them in tribal consultations. Each Tribe's religious, cultural and historical connection to the Grand Canyon and surrounding area does not need to be, and cannot be, written into a Tribal Perspectives section of this EIS and remain consistent with those beliefs.

Tribal governments have limited resources to participate in federal EIS processes. Those resources are better used for the substantive issues of concern to the EIS, not refuting third party information published in books and reports.

The descriptions of individual Tribal histories in the Tribal Perspectives section as circulated for comment, do not include tribal perspectives on the operations of Glen Canyon Dam and should be deleted from the EIS.

2. Use of Tribal Comments.

The authorized representatives of Tribes will present data, information and comments on many different aspects of the EIS. The Tribal input must be given the same consideration, weight and prominence as other input on the substantive topics. An EIS that reproduces Tribal input in its own section or attaches it as an appendix relegates this input to a class of information separate from "scientific" information. The Decision Maker and the public providing comments on the EIS should have all information on a topic presented in a manner that permits a comprehensive and comparative review.

For example, at the consultation meetings representatives of the Zuni Tribe expressed concerns over the treatment of fish within the Colorado River in particular efforts to control the rainbow trout population. This information should be included in the section on fish, not in a separate Tribal or Zuni section.

The Havasupai Tribe requested notification of high-flow releases in sufficient time to warn hikers within Havasu Canyon. This is a safety concern for recreational users and should be included in the appropriate section.

Appropriate references and attribution to Tribal input may be included in the text similar to other citations. For example, references might look like this: Havasupai, 2012a, Letter from Chairman, Havasupai Tribe, August 10, 2012, on file.

3. Cultural Resources.

The Grand Canyon Protection Act requires that the Secretary operate Glen Canyon Dam "in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources…." Tribal governments and Native Americans have worked with the NPS for decades to identify and protect religious and cultural resources within GCNP and Glen Canyon. The natural environment of the Grand Canyon is significant to Native Americans. The resources are well known to the NPS.

This EIS process should not require a new listing or cultural resources through separate identification of sites, a separate listing or Tribal specific descriptions of locations, their uses or the importance of cultural resources. Consultations with Tribal government

representatives and with Native Americans may be used for clarification and to avoid omissions and is important to the process. However, the requirements of federal law, the Grand Canyon Protection Act and the trust obligation of the Secretary require an analysis of impacts to all cultural resources already known to the Department of Interior. Tribes are not required to submit separate listings for this EIS.

If you have any questions or would like to discuss these comments, please contact me.

Best regards,

Margaret J. Vick, JSD

Cc via email: Don Watahomigie, Chairman
Matthew Putesoy, Vice Chairman
David Uberuaga, Supt. GCNP
Jan Balsom, GCNP
Beverly Heffernon, BoR
Amy Heuslein, BIA
Adrianne E. Carr, Argonne

August 29, 2012

Comments of the Havasupai Tribe on:

AMERICAN INDIAN PERSPECTIVES AND VALUES
RELATED TO THE GLEN CANYON DAM
LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN
ENVIRONMENTAL IMPACT STATEMENT

Prepared by
Jennifer Abplanalp and Bruce Verhaaren
Environmental Science Division
Argonne National Laboratory

The Havasupai Tribe requests that if the section titled American Indian Perspectives is included in a Draft EIS for LTEMP that the sections related to the Pai be revised to delete all references to the Havasupai making clear that the discussion of origins currently in the draft does not apply to Havasupai. The section on the Havasupai Tribe should be limited to the statements set forth below.

Havasupai

The Havasupai Reservation consists of 188,077 acres of canyon and plateau along the western portion of the Grand Canyon's south rim. In 1975, the Grand Canyon National Park Enlargement Act (PL 93-620) restored 185,000 acres to the Havasupai reservation and identified 95,300 acres of traditional use lands within Grand Canyon National Park that were made available for traditional Havasupai practices. The Havasupai Traditional Use Lands are north of the reservation from the plateau to the Colorado River and extend from approximately river mile 116 to river mile 165. (P.L. 93-620)

The Havasupai Tribe and tribal members have a history interwoven with that of Grand Canyon National Park since creation of the Park from within the Havasupai aboriginal territory. Members of the Havasupai Tribe have access to locations of importance within Grand Canyon National Park guaranteed by the 1919 Act to Establish Grand Canyon National Park, (40 Stat. 1175, 1919) and the 1975 Grand Canyon Enlargement Act, (88 Stat. 2089, 1975).

The Havasupai view everything in and around the Grand Canyon as sacred in all aspects of their cultural, spiritual, and traditional life (Reclamation 1995). The Havasupai were signatories to the 1994 PA, yet, chose not to participate in the GCDAMP. The Tribe works closely with the NPS for protection of cultural sites, historic locations and water resources. They are also members of the Native Voices on the Colorado River, a group that works with Grand Canyon Colorado River Outfitters to increase understanding of tribal relationships with Grand Canyon from their own perspective (NVCR 2012).

From: LaGory, Kirk E.
Sent: Thursday, August 30, 2012 10:20 AM
To: Margaret Vick
Cc: Tribal Chair; htvchair@havasupai-nsn.gov; Uberuaga, David V.; Balsom, Janet R.; Heffernan, Beverley; Amy Heuslein; Carr, Adrianne E.; Billerbeck, Rob P.
Subject: RE: Havasupai Comments on Tribal Perspectives and Process

Margaret:

I received your email, the attached Havasupai Tribe comments on the tribal perspectives section, and your letter regarding the EIS process. I will pass this information on to the joint-lead agencies for their consideration in developing the EIS.

Thank you.

Kirk LaGory

~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Kirk E. LaGory, Ph.D.
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Ave., Building 240
Argonne, Illinois 60439

Office: 630-252-3169
Cell: 630-564-3169
Fax: 630-252-6090
~~~~~~~~~~~~~~~~~~~~~~~~~~~~

(e) Hopi Tribe

-----Original Message-----
From: Mike [mailto:Michael.Yeatts@nau.edu]
Sent: Tuesday, August 27, 2013 5:48 PM
To: LaGory, Kirk E.
Cc: Rinkevich, Sarah; Kurt Dongoske; Bulletts, Charley; Tony Joe; Bungart, Peter; Loretta Jackson-Kelly; Leigh Kuwanwisiwma
Subject: Re: Fwd: REMINDER: Comments on LTEMP Performance Metrics and Models

Attached are some comments on the LTEMP performance metrics from the Hopi Tribe-

Mike Yeatts
HCPO

Hopi comments on Draft LTEMP
Performance Metrics (01, August, 2013)

General Comment:
An aspect that is still lacking an adequate integration of tribal values overall in the performance measures. Nine goals were developed by the tribes for consideration as additional goals to those that were developed by the agencies. Of these, five were discarded (not by the tribes) as not being useful for discriminating among the alternatives. Of the four remaining ones, only two were addressed within the final performance metrics, and only partially at that. Looking again at the overall suite of tribal goals and expanding on the performance metrics should be a first start at revising the performance metrics. The following comments will provide some specific thoughts on better addressing the tribal values.

1) Archaeological and Cultural Resources
The performance metric currently only addresses an (unknown) subset of the archaeological sites. This measure is probably unlikely to measure the overall impacts/benefits to the full suite of archeological sites and certainly does not get at non-archeological historic properties (eg. TCPs).

For the archeological sites, going back to the Park's monitoring data should provide some other measures with regard to site impacts, flow patterns, visitor effects, etc. Prioritization of sites for treatment was based on this information in the past – hopefully this data can also be used going forward into the future.

For the TCP's the only mechanism I can see to adequately address them is to have specific culturally focused performance metrics under <u>each</u> of the resource categories for which there is a tribal value. In addition, the "ecosystem health" goal needs to be added as something separate from the "natural processes" goal. This is in effect getting at the overall integrity of the Grand Canyon as a TCP. It may be some type of a summation of the individual resource goal (from a tribal perspective). This could be in effect a summation that is calculated from the other data rather than being directly entered.

Finally, from the description of the GLCA penalized flow index, this really doesn't get at historic properties in a systematic manner – it seems to primarily capture recreational issues. Instead, there needs to be a performance measure that gets at site stability throughout the system and not just in Glen Canyon. I do agree that using the aeolian deposition completely ignores the Glen Canyon stretch (and likely most of the sites in Grand Canyon.

2) Sanctity of Life
Measurement of trout removal actions get at one portion of this concept, but do not get at the positive aspects of enhancing opportunities for life. For instance, increasing

habitat for culturally valued birds or animals. As with TCPs, it may be appropriate to add a measure that is the sum of tribal value measures in each of the other specific resource categories.

3) Natural Processes
As currently measured, this is a limited, arbitrary measure of "natural processes" and definitely does not measure system health. In order to be somewhat more rigorous, at a minimum, what is being taken as the "natural pattern" needs to be better defined. Why is only flow and water temperate being used? Why not sediment load, number of species in the riparian zone, percent of the CRE covered by vegetation, number of people present in the canyon, fish species composition, etc? All of these are part of the natural processes. As currently used, this measure is misleading and should either be expanded on or dropped. With what is currently being measured, the desired direction is wrong from the standpoint of Hopi values for the current ecosystem (with a dam in place).

4) Riparian Vegetation
To get at the Hopi values, a metric that looks at marsh habitats might be appropriate as a proxy for on aspect of the canyon as a TCP. In addition, a measure of the "value" of the vegetation as habitat for birds and other animal life would be helpful in addressing the both TCP aspects and sanctity of life. Both the type and coverage may have substantially different carrying capacities and species compositions.

5) Non-native Aquatic Species
Aquatic (or other) parasites that only effect non-native species might be considered a positive development.

6) Recreation
Use of crowding at the head of rapids because of "low" flows is really not an effective measure of wilderness, particularly at the flows that are being considered (if flows below 5,000cfs were in alternatives then there would be more of an issue, particularly with motor boats – though wilderness and motor boat has its own issue).

Also, for the Hopi, anything that increases the amount of recreation, distributes it more broadly throughout the year, or puts more people at greater numbers of places throughout the canyon would be viewed as negative, not positive.

7) Trout Fishery
Increasing the angler catch rate would seem to imply more trout, which might be viewed as not positive some tribes. Similarly with the trout abundance index.

(f) Hualapai Tribe

Jan 06 2012 9:00AM NATURAL RESOURCES 9287692309 page 2

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

Please return this form by January 6, 2012, to indicate your interest in participating as a cooperating agency in the development of a Long-Term Experimental and Management Plan and Environmental Impact Statement for the Glen Canyon Dam.

A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

XX Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: Hualapai Tribe
Contact: Loretta Jackson-Kelly
Title: THPO/Director of Cultural Resources
Office: Cultural Resources Department
Address: P.O. Box 310
Peach Springs, AZ 86434

Direct Phone: 928-769-2234
Office Phone: 928-769-2223
Mobile Phone: 928-380-4429
Fax: 928-769-2736
Email: loriac@frontiernet.net

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

From: Peter Bungart [mailto:pbungart@circaculture.com]
Sent: Thursday, June 28, 2012 2:11 PM
To: LaGory, Kirk E.
Cc: 'Loretta Jackson-Kelly'
Subject: RE: LTEMP Preliminary Draft Alternatives

Kirk,
Attached are two documents submitted on behalf of the Hualapai Tribe for the LTEMP EIS preliminary draft alternatives: one is a comment letter and the other a Track Changes version of the alternatives document that was sent out for review. We hope you find the comments useful.
Sincerely,
Peter

Peter Bungart
Hualapai Dept. of Cultural Resources
PO Box 310
Peach Springs AZ 86434
928.769.2223 (office)
928.606.8393 (cell)
-

Hualapai Department of Cultural Resources
P.O. Box 310
Peach Springs, Arizona 86434
Office: 928.769.2223 FAX: 928.769.2235

Kirk E. LaGory, Ph.D.
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Ave., Building 240
Argonne, Illinois 60439

June 27, 2012

In reading the preliminary draft alternatives, it was striking that the various kinds of input resulting from the breakout sessions at the April 2012 LTEMP meeting in Flagstaff were apparently not integrated into this document in any tangible way. It appears the preparers narrowed the focus of the alternatives simply toward managing flows using various protocols that will affect sediment movement and native and non-native fish survival.

We understand that this document outlines preliminary draft alternatives for the LTEMP EIS, but aside from the quote in the *Purpose* section, there is absolutely no acknowledgement of the importance of tribal perspectives or values. This is disheartening, especially considering the past several years of working together, more or less successfully, on the GCDAMP. If the expectation is that tribal concerns will be brought to light later through NEPA consultation, then this approach will surely devolve into an unsatisfactory process. Consider that federal agencies have managed the area undergoing study for a few generations, yet the tribes have called the place home for countless centuries. We urge the preparers to engage the tribes more proactively and more inclusively as soon as possible.

Likewise, there is little reference to the GCPA, or explanations of how each of the preliminary draft alternatives meet its requirements or, conversely, have the potential to adversely affect river corridor resources. It would be helpful if predicted or expected

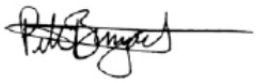
outcomes vis a vis the GCPA were provided in the discussion of alternatives, especially since it is a key component of the EIS.

The various alternatives all seem conceptually very linear, and perhaps overly simplistic in the suggested implementations of proposed actions. There seems to be three main ingredients: flows, fish, and sand. Each alternative seems to be simply variations on a theme, without regard to how their outcome may affect the values of different stakeholders. In addition, although the Colorado River ecosystem and ecological concerns are mentioned in passing, there is little to inform the reader how the various alternatives may actually affect the broader ecosystem, or even most of its components (aside from fish). This seems to be a document mainly concerned with complying with the Endangered Species Act rather than the Grand Canyon Protection Act.

Other comments and suggested language are included in the attached Track Changes version of the Preliminary Draft Alternatives.

If you have any questions, comments, or suggestions please feel free to call Loretta Jackson-Kelly or Peter Bungart at (928) 769-2223. Thank you for your consideration.

Sincerely,



Peter Bungart, Senior Archaeologist
Hualapai Department of Cultural Resources

From: Carr, Adrianne E.

Sent: Thursday, August 09, 2012 3:43 PM

To: Loretta Jackson-Kelly (lorjac@frontiernet.net); Peter Bungart

Cc: Knowles, Glen; Heffernan, Beverley; Billerbeck, Rob P.; LaGory, Kirk E.; Abplanalp, Jennifer Marie; Verhaaren, Bruce T.

Subject: Response to Hualapai Tribe's comments on June 7 LTEMP Alternatives document

Please find the responses to the Hualapai Tribe's comments on the preliminary draft LTEMP Alternatives document for cooperating agencies.

Very best regards,

Adrianne

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Adrianne Carr, Ph.D.

Hydrologist

Environmental Science Division

Argonne National Laboratory

9700 S. Cass Avenue, EVS-240

Argonne, IL 60439

Response to Hualapai Tribe Comments Received on Preliminary Draft Alternatives –

Thank you for your letter dated June 27, 2012 with comments on the LTEMP preliminary alternatives and the process. Your feedback helps us adjust our process and produce a better EIS. Below are our responses to the concerns raised in your letter.

Comment regarding alternatives structured around flows:

As the co-lead agencies worked on developing more detailed alternatives out of the concepts which came out of the April workshop, we did incorporate input received in the breakout sessions and continue to take the results of that workshop into account as we develop the alternatives.

Comment regarding incorporation of tribal perspectives and values in document:

The co-lead agencies place great importance on the input from tribes and we appreciate your feedback. If there are specific ideas on how to be better involved tribes, then we would welcome those specific suggestions. To date we have offered to meet with tribes through the tribal consultation process, and have met with the Hualapai and a number of other tribes. We have also offered additional consultation meetings with the intent of seeking input and feedback from tribes on the draft alternatives, above and beyond the opportunity provided through the cooperating agency relationship. We have also scheduled a meeting with just tribal representatives on August 10th in Phoenix, prior to the cooperating agencies meeting, as another opportunity for face to face dialogue about the LTEMP EIS process and the alternatives. We have also provided draft text for a tribal perspectives section of the EIS, and are continuing to coordinate with tribes on development of that draft, or alternate information from each tribe. As stated in that draft document, our intent is to provide to each interested tribe the opportunity to communicate their values and perspectives in the EIS.

If the Hualapai feel that there are additional steps we can take to enhance your participation in development of the EIS, we urge you to communicate that information to the joint lead project managers.

Concern about Grand Canyon Protection Act (GCPA) and potential effects of the alternatives:

We appreciate the comments regarding Hualapai concerns about the potential effects of the alternatives. At this time we are in the alternatives development phase and it would be premature at this early point in the process to attempt a description of effects or outcomes of the alternatives. The analysis of effects of alternatives to all resources will be undertaken during the process of preparing the draft EIS. At a public forum to be scheduled after the alternatives are developed, there will be presentations to articulate the scientific basis for each flow regime (and non-flow actions) included in the alternatives. As noted above, we would welcome more

discussion with tribes on what input they would like to provide for this public meeting and we hope to discuss that further at the meeting with interested tribes on August 10th.

Concern about the focus on flow, fish, sediment vs. the Grand Canyon Protection Act (GCPA).

Compliance with the GCPA is one of the main reasons that the LTEMP EIS is being prepared. The Secretary of the Interior has noted that revisiting resource conditions, and applying the knowledge we have gained since the ROD was signed in 1996, will help us to better achieve the requirements and goals of the GCPA. Accordingly, the GCPA is referenced within the purpose and need of this process which will inform the range of alternatives and the evaluation of impacts. We have also developed resource goals (based on the DFCs and other relevant documents) to inform this evaluation that consider specific resources as well as tribal values.

Response numbers here correspond to comment numbers in the June 7, 2012 draft alternatives document submitted with the June 27 letter.

1. Tribal Involvement in Alternative Development. Please see the response to the second comment in your letter, above. We have received input on the alternatives from tribes, cooperating agencies and the public at the April 4-5, 2012 meeting and via other communications. In addition to our ongoing Government to Government consultation with interested tribes, the Hualapai and other tribes who are serving as cooperating agencies have many additional opportunities to inform the EIS development process, including our monthly cooperating agency calls and the upcoming cooperating agency meeting on August 10. Prior to the meeting with all cooperators on August 10, we have scheduled a meeting with interested tribes on August 10, 2012 in Phoenix as an additional opportunity for face-to-face participation specifically to focus on tribal values and concerns.

2. Sediment Augmentation - We appreciate your concern about the engineering solution proposed to increase sediment with the goal of trying to improve downstream resources. Infrastructure additions and other alternative elements are still being considered. It is understood that sediment augmentation and other infrastructure proposals would require in-depth analysis and may require separate and additional NEPA.

3. Other Types of Knowledge - The EIS team has also recently offered additional meetings with tribes, and is planning a meeting on August 10 to discuss alternatives and seek feedback from tribes on alternatives. Recognizing the ongoing GCDAMP effort to improve consideration of tribal ecological knowledge, we would like to discuss additional approaches to incorporating tribal knowledge into the EIS process. We have also shared with Hualapai and other interested tribes the first draft of tribal perspectives write-ups for eventual inclusion in the EIS, and we do need feedback on that draft from the tribes as soon as possible.

(g) Navajo Nation

February 28, 2011

Bureau of Reclamation
Environmental Resources Division
125 South State Street, Room 7218
Salt Lake City, UT 84138

To Whom It May Concern:

The Historic Preservation Department – Traditional Culture Program (HPD-TCP) is submitting the following comments on behalf of the Navajo Nation. HPD-TCP has provided the following comments for the Glen Canyon Dam Long Term Experimental and Management Plan Preliminary Draft Outline.

The Glen Canyon Dam Adaptive Management Program (AMP) was implemented as a result of the Record of Decision on the Operation of Glen Canyon Dan Final Environmental Impact Statement to comply with consultation requirements of the Grand Canyon Protection Act (Pub. L.102-575) of 1992. The Amp includes a Federal advisory committee, the Adaptive Management Work Group (AMWG), a technical work group (TWG), a Grand Canyon Monitoring and Research Center, and independent review panels. The AMWG makes recommendations to the Secretary of the Interior concerning Glen Canyon Dam operations and other management actions to protect resources downstream of Glen Canyon Dam consistent with the Grand Canyon Protection Act. The TWG is a subcommittee of the AMWG and provides technical advice and recommendations to the AMWG.

Recommendations:

1. The Navajo Nation is in support of the removal of Non-Native fish from the Grand Canyon. The Nation recommends the removal of Non-Native fish be done about a half mile from the confluence of the Little Colorado River and the Colorado River up and down stream.
.
2. The Navajo Nation supports the lethal removal of Non-Native Fish outside the half a mile buffer from the confluence. The disposal of the Non-Native fish is something the Nation supports. The lethal extermination of the Non-Native fish outside the areas of concern and has no objections with the lethal eradication of the Non-Native fish as long as it is away from the confluence.

Concerns:

1. Operations conducted by the Bureau of Reclamation and National Park Service

negatively effect the sacredness of the Grand Canyon. Local Navajo families refuse to conduct ceremonies near the river due to the Non-Natives consideration of the river as a place of recreation.

2. Navajo communities have no access to the river because of the constant flow of river trips and scientific research. Navajo tribal members hesitate to conduct offerings and ceremonies because of fear their prayers will not be answered.

If the Bureau of Reclamation (BOR) and the National Park Service (NPS) want to consult with the Nation on any of the raised concerns, we would be more than happy to accommodate.

The Navajo Nation appreciates the opportunity to comment on such a complicated issue. If you have any questions or comments, do not hesitate to call Tony Joe at (928) 871-7750.

Sincerely,

Tony H. Joe, Jr.
Historic Preservation Department

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

Please return this form by January 6, 2012, to indicate your interest in participating as a cooperating agency in the development of a Long-Term Experimental and Management Plan and Environmental Impact Statement for the Glen Canyon Dam.

A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

X Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: NAVAJO DEPARTMENT OF WATER RESOURCES

Contact: JOHN LEEPER

Title: BRANCH MANAGER

Office: WATER MANAGEMENT BRANCH

Address: PO BOX 678
FORT DEFIANCE ARIZ 86504

Direct Phone: 928 729 4501

Office Phone: 928 729 4004

Mobile Phone: 928 349 1101

Fax: 928 729 4126

Email: JOHNLEEPER@NAVAJO-NSN.GOV

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

From: Carr, Adrianne E.
Sent: Tuesday, July 17, 2012 5:52 PM
To: 'Jason John'; 'Alan Downer'
Cc: Abplanalp, Jennifer Marie; Carr, Adrianne E.; Bert Frost; Heffernan, Beverley; Brian Carey; Christine Landrum; Uberuaga, David V.; Denise Shultz; Halliday, John D (John_Halliday@ios.doi.gov); Jack Schmidt; Balsom, Janet R.; Jane Lyder; Cohen, Janet; John Wessels; Karen Breslin; Turner, Kent; Knowles, Glen; LaGory, Kirk E.; Caramanian, Lori L.; Anderson, Mark; Mark_Wondzell@nps.gov; Hahn, Martha Gail; Oltrogge, Maureen; Boyles, Michael John; Michael Whiteman-Jones; Billerbeck, Rob P.; Rod Smith; Sucec, Rosemary Jean; Daron, Steve; Melis, Theodore Steven; Brindle, Todd; Dickinson, William
Subject: LTEMP: Responses to Comments on Purpose, Need, and Objectives

Dear Cooperator:

Attached to this email are the responses to your comments on the LTEMP purpose, need, and objectives from the project team.

Very best regards,
Adrianne

Adrianne Carr, Ph.D.
Hydrologist
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Avenue, EVS-240
Argonne, IL 60439

Response to Comments by Navajo on Purpose, Need, and Objectives

We thank you for your comments on the purpose, need, and objectives of the Glen Canyon Dam LTEMP. The joint lead EIS team carefully reviewed these comments and concerns. Some changes were incorporated if they substantially helped to clarify purpose, need, and objectives. However, NEPA provides that the purpose and need statements should "briefly specify the underlying purpose and need," and the level of detail suggested in many comments would contravene the direction that the purpose and need statements be concise.

Purpose

- Resources of importance to Indian Tribes are not specifically listed in the GCPA; but the EIS team feels it is important to include them based on public comments, AMWG desired future conditions, and agency goals for this project. Consistent with input received, we reworded this sentence to be clearer about the intent of this statement by adding "including those" before "of importance to Indian Tribes."

Need

- No comments were received.

Objectives

- We did not make the suggested change of "Protect the interests and perspectives of the Indian Tribes" from the original "Respect the interests and perspectives of the Indian Tribes" in the fifth objective. The EIS will contain a section on tribal perspectives, which will be developed in consultation with the tribes to ensure interests and perspectives are accurately portrayed. Achieving the objective of respecting tribal interests and perspectives will depend on government-to-government consultation, which will be an important part of the LTEMP EIS process.

From: Tony Joe [mailto:tony@navajohistoricpreservation.org]
Sent: Wednesday, August 28, 2013 2:53 PM
To: LaGory, Kirk E.; Sarah Rinkevich
Subject: Metrix

Kirk.

Navajo Historic Preservation Department's comments. The official letter with signature will be sent via mail.

Tony

--
Tony H. Joe, Jr.
Supervisory Anthropologist
Traditional Culture Program
928-871-7750

THE
NAVAJO
NATION

Ben Shelly
PRESIDENT

Rex Lee Jim
VICE PRESIDENT

August 28, 2013

Kirk E. LaGory, Ph.D.
Senior Program Manager
Ecological Resources and Systems
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Ave., Building 240
Argonne, Illinois 60439

Dear Mr. LaGory,

The Navajo Historic Preservation Department is in response to the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP EIS) Performance Metrix.

The tribes were invited to Flagstaff, AZ on March 14-15, 2013 for their input. At this meeting federal officials labeled the meeting as "Tribal Values". The tribes along with representatives from the National Park Service were in attendance. It was more of a brainstorming about tribal concerns. The tribes gave suggestions and all of the tribe's issues and concerns were written on a flip chart. On March 15, 2013, the tribes developed nine goals we thought would be included in the Performance Metrix, in addition to the agencies goals. I am concerned eight of the tribal values were not considered. The following comments are in reference to concerns we have.

1. **Archaeological and Cultural Resources**
   The anticipation for windblown deposits seems to be dependent upon hope. We support the idea of wind deposits covering up cultural resources but I think more evidence needs to be shared with the interested parties. Only a few archaeological sites might benefit and overall there is no specific sites mentioned that will yield positive benefits. The Grand Canyon river corridor exhibits archaeological sites that are not mentioned or considered.

2. **Natural Processes**
   The Nation supports native habitat improvement. Native fish and plant species need some attention to recreate the natural beauty of the Grand and Glen Canyon. I suggest more studies and more emphasis on re-establishing native fish and plant species. The eradication of non-Native plants species should be a goal.

3. **Humpback Chub**

HISTORIC PRESERVATION DEPARTMENT P.O. BOX 4950 WINDOW ROCK, ARIZONA 86515 928.871.7198 (v) 928.871.7886 (fax)

Humpback Chub research is supported by the Nation. I would like to see more studies on other native fish population.

4. **Other Native Fish**
   More research needs to be conducted on other native fish. The Nation would like to be consulted on studies past and present on these species. A map showing projects that are occurring on other native fish be of recommendation so we can have a better understanding of locations for the 2014 boat trip initiated by Navajo.

5. **Recreation**
   The cultural resources will be impacted by the heavy flow of the visitor experience each year. This is an issue for the Nation.

If you have any questions, do not hesitate to contact me at 928-871-7750. Thank you for honoring our request.

Sincerely,

Tony H. Joe, Jr.
Supervisory Anthropologist
Traditional Culture Program
Historic Preservation Department

Cc TCP 13-251 Glen Canyon Long-Term Experimental and Management Plan

From: Verhaaren, Bruce T.
Sent: Tuesday, February 11, 2014 11:16 AM
To: tony@navajohistoricpreservation.org; 'Jason John (jasonjohn@navajo-nsn.gov)'
Cc: Knowles, Glen; Billerbeck, Rob P.; Balsom, Janet R.; barger, mary; Sarah_Rinkevich@fws.gov; LaGory, Kirk E.
Subject: LTEMP MOU

Tony and Jason,

Please find attached a letter from the joint leads of the LTEMP EIS concerning the pending MOU between the Navajo Nation, the Bureau of Reclamation, and the National Park Service regarding the participation of the Navajo Nation as a cooperating agency for the EIS.

I will try to contact you by telephone later in the week regarding the status of the MOU. Please feel free to contact the joint leads or me if you have questions regarding the MOU. I should be back in the office Thursday, February 13.

Best Regards,

Bruce Verhaaren, Ph.D.
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Office: 630 252-3240
Fax: 630 252-4624
bverhaaren@anl.gov

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street
Salt Lake City, UT 84138

NATIONAL PARK SERVICE
Intermountain Region Office
12795 Alameda Parkway
Denver, CO 80225

Jason John
Navajo Department of Water Resources
P.O. Box 678
Fort Defiance, AZ 86504

Tony Joe
Historic Preservation Department
P.O. Box 4950
Window Rock, AZ 86515

Dear Mr.John and and Mr. Joe,

We are writing regarding the pending Memorandum of Understanding (MOU) between the Bureau of Reclamation (Reclamation) and the National Park Service (NPS) and the Navajo Nation for the Environmental Impact Statement (EIS) for Adoption of a Long Term Experimental and Management Plan (LTEMP) for the Operation of Glen Canyon Dam.

Reclamation and NPS first extended an invitation to the Navajo Nation to become a cooperating agency for the LTEMP EIS in a letter dated December 8, 2011. In January 2012, John Leeper of the Navajo Department of Water Resources returned the invitation form indicating an interest in the Navajo Nation becoming a cooperating agency. A draft MOU outlining the roles and responsibilities of Reclamation, NPS, and the cooperating agencies was emailed to representatives of the Navajo Nation on March 6, 2012. Suggested revisions were provided by Alan Downer of the Navajo Nation Historic Preservation Department on March 22, 2012. A revised MOU was sent to Dr. Downer and to Jason John of the Department of Water Resources on April 11, 2012 with a request that it be signed and returned.

We are aware that Navajo procedures require an MOU to be reviewed and approved by legislative committees and ultimately by the legislature as a whole before it can be signed and returned. It is our understanding that the committees involved have requested an additional work session to determine whether being a cooperating agency would impact current negotiations regarding Navajo water rights.

Sections of the EIS are currently being drafted. Signing and returning the MOU will facilitate the Navajo Nation's role as a cooperating agency in reviewing drafted sections. We request that the MOU be signed by February 21, 2012. If the Navajo Nation chooses not to act as a cooperating agency please notify the LTEMP EIS team in writing. If Navajo Nation chooses not to act as a cooperating agency, we will still conduct government to government consultation with the Navajo Nation.

To return the signed MOU you may scan it in and return via email, send by fax, or send via postal mail. The fax number is 630-252-6090, and the mailing address is as follows:

Kirk LaGory
Argonne National Laboratory
9700 S. Cass Avenue, EVS-240
Argonne, IL 60439

Please feel free to contact us if you need any additional information regarding the LTEMP EIS and MOU. We look forward to hearing from you.

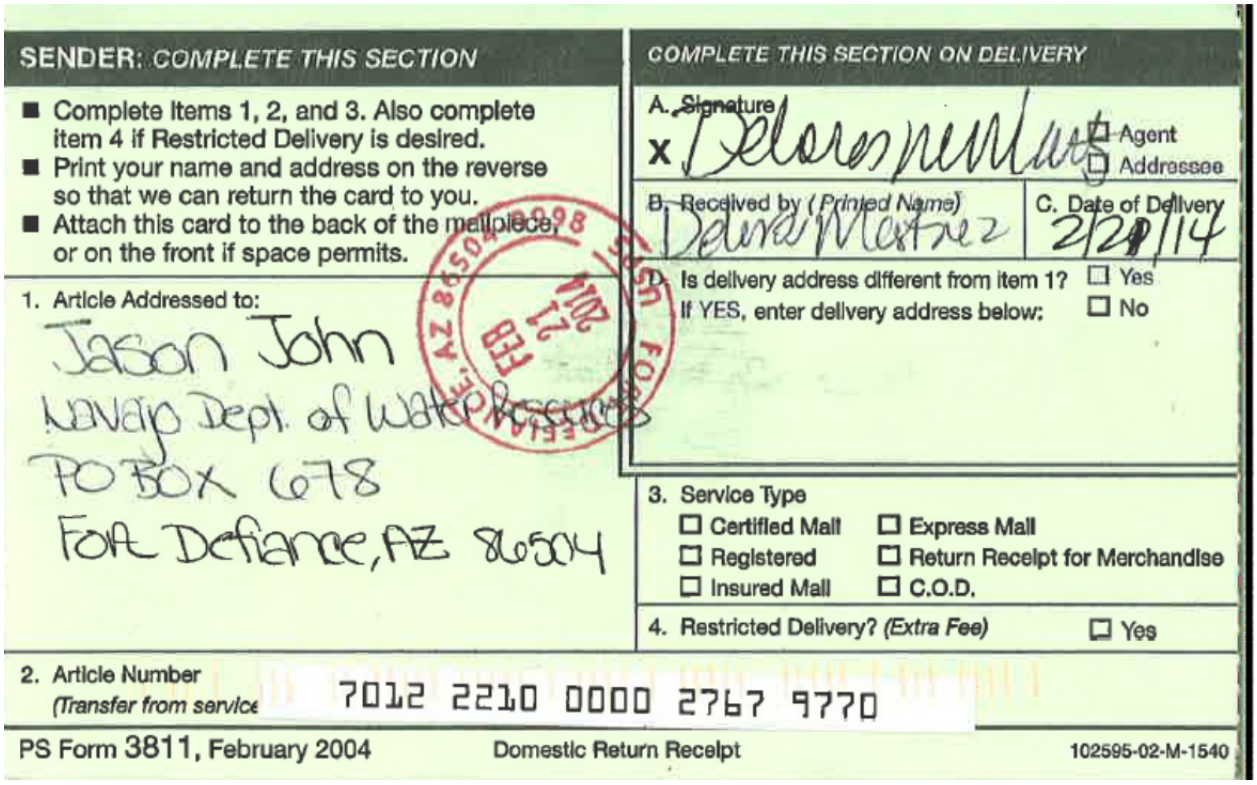
Sincerely,

2/10/14

Glen Knowles
Chief, Adaptive Management Group
Environmental Resources Division
Upper Colorado Region
Bureau of Reclamation

2/6/2014

Rob Billerbeck
Colorado River Coordinator
Resource Stewardship and Science
Intermountain Region
National Park Service



SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
Jason John
Navajo Dept. of Water Resources
PO Box 678
Fort Defiance, AZ 86504

COMPLETE THIS SECTION ON DELIVERY

A. Signature
x Delores Manuelito
☐ Agent
☐ Addressee

B. Received by (Printed Name) Delora Manuelito
C. Date of Delivery 2/28/14

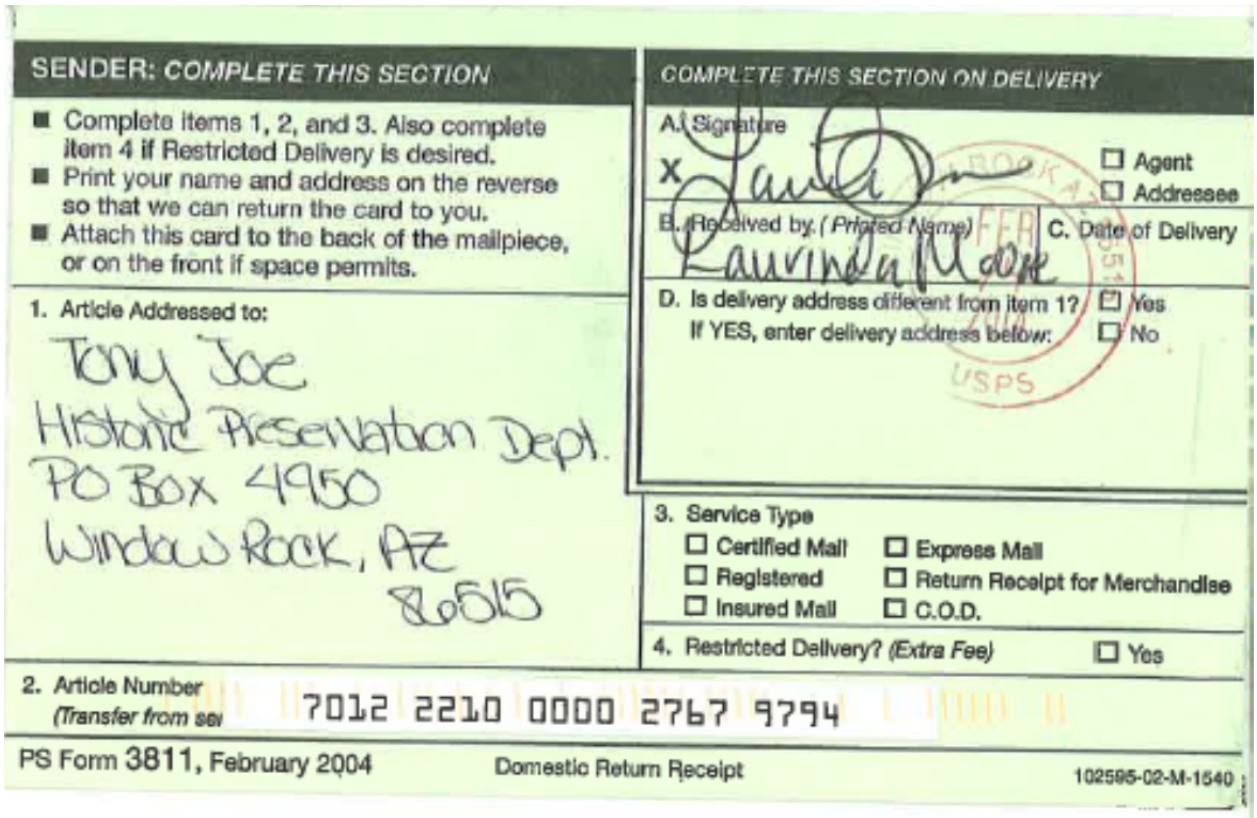
D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service) 7012 2210 0000 2767 9770

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540



SENDER: COMPLETE THIS SECTION

- Complete items 1, 2, and 3. Also complete item 4 if Restricted Delivery is desired.
- Print your name and address on the reverse so that we can return the card to you.
- Attach this card to the back of the mailpiece, or on the front if space permits.

1. Article Addressed to:
Tony Joe
Historic Preservation Dept.
PO Box 4950
Window Rock, AZ
86515

COMPLETE THIS SECTION ON DELIVERY

A. Signature
x Laurie Moore
☐ Agent
☐ Addressee

B. Received by (Printed Name) Laurie Moore
C. Date of Delivery

D. Is delivery address different from item 1? ☐ Yes
If YES, enter delivery address below: ☐ No

3. Service Type
☐ Certified Mail ☐ Express Mail
☐ Registered ☐ Return Receipt for Merchandise
☐ Insured Mail ☐ C.O.D.

4. Restricted Delivery? (Extra Fee) ☐ Yes

2. Article Number (Transfer from service) 7012 2210 0000 2767 9794

PS Form 3811, February 2004 Domestic Return Receipt 102595-02-M-1540

-----Original Message-----
From: Jason John [mailto:jasonjohn@navajo-nsn.gov]
Sent: Friday, February 21, 2014 12:51 PM
To: Verhaaren, Bruce T.; tony@navajohistoricpreservation.org
Cc: Abplanalp, Jennifer M.; Knowles, Glen; Billerbeck, Rob P.; LaGory, Kirk E.; Balsom, Janet R.; barger, mary; Sarah_Rinkevich@fws.gov
Subject: RE: LTEMP letter Date correction

Glen, Rob and Bruce,

I was at the meeting this morning with some of the Council Delegates. I can assist in the communication.

They would like a government to government meeting with NPS and BOR in Flagstaff on either March 28 at 1pm or March 4 (after 10am) or March 6 (after 10am). Their preference is in that order. The President of Navajo Nation should be signing that letter today requesting the meeting. When signed it will be emailed. I hope one of those dates work.

Jason

Jason John
Water Management Branch

THE NAVAJO NATION

BEN SHELLY PRESIDENT
REX LEE JIM VICE PRESIDENT

February 21, 2014

Glen Knowles
Chief, Adaptive Management Group
Environmental Resources Division
Upper Colorado Region
Bureau of Reclamation
125 South State Street
Salt Lake City, UT 84138

Rob Billerback
Colorado River Coordinator
Resource Stewardship and Science
Intermountain Region
National Park Service
12795 Alameda Parkway
Denver, CO 80225

The Nation is in receipt of your letter dated February 6, 2014, requesting that the Nation choose whether or not to be a cooperating agency in the development of the Environmental Impact Statement for Adoption of a Long Term Experimental and Management Plan (LTEMP) for the Operation of Glen Canyon Dam.

As you are aware, in order to be a cooperating agency, the Nation requires approval by the Naabik'iyati Committee of the Navajo Nation Council of the proposed Memorandum of Understanding with the Bureau of Reclamation and the National Park Service. When the Naabik'iyati Committee considered approving the legislation for the MOU, the legislation was tabled by Delegate Walter Phelps in order to better understand the purpose of the LTEMP for the Operation of Glen Canyon Dam and its impact to interests of the Navajo Nation.

Accordingly, we are requesting a government to government consultation meeting with the Bureau of Reclamation and the National Park Service to discuss the purpose of the LTEMP for Operation of Glen Canyon Dam and whether or not the Nation could serve in a joint lead agency role.

The Nation therefore requests a government-to-government consultation. The following are suggested dates in order of preference: February 28 at 1:00 pm, March 4, or March 6, 2014 in Flagstaff at the National Park Service agency office or other available facility.

Sincerely,

Ben Shelly, President
THE NAVAJO NATION

From: Billerbeck, Rob [mailto:rob_p_billerbeck@nps.gov]
Sent: Friday, February 28, 2014 2:45 PM
To: Knowles, Glen
Cc: Rinkevich, Sarah; Russell, Kendra L.; LaGory, Kirk E.; barger, mary; Verhaaren, Bruce T.
Subject: Re: Request for Government to Government LTEMP Consultation

I talked to Jason John on the phone today. Mostly it sounds like a misunderstanding between levels. Jason just tried to convey the need to sign the MOU to be a cooperating agency. He mentioned that we would do govt to govt down the road, but it sounds like some others were unclear on the scope of the projects and the roles. They are not requesting that Larry W and Dave U or others come to this meeting, they are just looking to have Glen and I come out and explain the process again and Jason believes that if roles and scope are explained that they will likely want to sign the cooperating agency MOU and will likely want to wait until the summer for the formal govt to govt.

I told Jason that meeting next week looked pretty difficult and he recommended an email back with dates further out. I think before we send an email back I'll try to connect with Tony Joe on the phone as well.
If we do need a meeting, we could see if that same week of the 17 works I guess.

From: Billerbeck, Rob [mailto:rob_p_billerbeck@nps.gov]

Sent: Monday, March 17, 2014 3:40 PM

To: Jason John

Cc: Verhaaren, Bruce T.; Knowles, Glen; Abplanalp, Jennifer M.; LaGory, Kirk E.; Balsom, Janet R.; barger, mary; Sarah_Rinkevich@fws.gov; Walter Phelps; Ray Benally; Assistant Attorney General Bidtah Becker; tony@navajohistoricpreservation.org; Michele Morris

Subject: Re: Request for Government to Government LTEMP Consultation

This email is in reply to the email sent on Feb 21, 2014 and attached letter from the Navajo Nation requesting to meet with the project managers of the Glen Canyon Dam Long Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). We are sorry we could not meet the dates proposed for a meeting due to prior scheduling conflict, and we are happy to come out in the next few weeks to meet with representatives of the Navajo Nation and council. Based upon travel schedules and availability, we offer the following potential dates for a meeting in Window Rock:

April 2,3,10, or 14

We would have the project managers from the two lead agencies, NPS and BOR, come to discuss the LTEMP scope, issue, stakeholder roles and timelines, and answer questions regarding the LTEMP or participation from the Navajo Nation. Please let us know if any of these dates are convenient and if we are correctly understanding what you would like us to cover in the meeting. We are also available for a phone call in advance if that would help answer any specific questions.

Based on discussions with staff, here is some additional information about the LTEMP project in advance of a meeting that might be helpful:

LTEMP Scope and Issues

Federal laws and regulations require the federal government to evaluate the effects of its actions on the environment and to consider alternative courses of action. National Environmental Policy Act (NEPA) regulations require, among other things, federal agencies to include discussion of proposed actions and a range of reasonable alternatives in an EIS.

Generally, the scope of the LTEMP EIS project involves consideration of actions that could change flows from Glen Canyon Dam as well as a set of non-flow actions to address resource concerns. All alternatives will still comply with the 2007 Interim Guidelines for the annual delivery volumes. All of the action alternatives include High Flow Experiments with maximum flows of 45,000 cfs, but with some variation among how frequent or when these high flows would be employed. There is variation among the alternatives with approaches to fish management as some alternatives will have mechanical removal, some will have trout management flows and mechanical removal and one alternative utilizes neither fish management tool.

With this general scope in mind , we have heard the following might be of interest to the Navajo Nation:

- Potential impacts (positive or negative) to cultural sites
- Potential impacts (positive or negative) to natural resources such as sandbars/beaches, vegetation, wildlife habitat, fish and other aquatic resources
- Potential impacts (positive or negative) to hydropower production/effect on ratepayers
- Potential impacts (positive or negative) to the Glen Canyon fishery
- Potential impacts (positive or negative) to river recreation

There are also several issues that we have heard that are interest to the Navajo Nation that are outside the scope of this project:

- Boundary demarcation
- Water rights
- Operational concerns at Antelope Point

LTEMP Roles

- Lead Agencies - the two lead agencies for this project are the Bureau of Reclamation and the National Park Service. The responsibility for this project was delegated to these two agencies because Reclamation is responsible for the operation of Glen Canyon Dam and NPS has land management responsibility at Glen Canyon National Recreation Area and Grand Canyon National Park.. Joint lead responsibilities generally include consulting with the affected Tribes, identifying the purpose and need for the project, defining the scope of analysis, and managing the contracts for preparation of the EIS and responding to comments from cooperating agencies and the public, etc.

- Cooperating Agencies - Generally, cooperating agencies participate in the EIS by attending cooperating agency meetings, commenting on EIS materials and internal cooperating agency drafts, and assisting with the development of parts of the EIS if needed. This is a role with more interaction and opportunity to comment than a member of the public or a non-governmental entity.

- The following are the entities are cooperating agencies because they are state, local or tribal governments with appropriate expertise or jurisdiction for this project and that have signed an MOU confirming their role as a cooperating agency:

  - Arizona Game and Fish Department
  - Bureau of Indian Affairs
  - Colorado River Commission of Nevada
  - The Havasupai Tribe
  - The Hopi Tribe
  - The Hualapai Tribe
  - Kaibab Band of Paiute Indians
  - The Pueblo of Zuni
  - Salt River Project
  - U.S. Fish and Wildlife Service
  - Upper Colorado River Commission
  - Utah Associated Municipal Power Systems
  - Western Area Power Administration

- Thus far we have understood that the Navajo Nation wanted to be considered a cooperating agency so we have been inviting the Navajo Nation to meetings of cooperating agencies and providing information that is distributed to cooperating agencies.

Project Timeline

Past activities:

- July 2011 -Project started with a notice of intent in the Federal Register
- November 2012 - Public scoping meetings
- April 2012 - Public meeting presented preliminary draft alternative concepts
- June 2012 - Tribes provided comments on Tribal Consultation Plan and Tribes/cooperating agencies provided comments on preliminary alternatives

- August 2012 - in person meeting with Tribes/cooperating agencies to discuss and solicit comments on draft alternatives and goals and objectives
- February 2013 - development of models and metrics with experts, and meetings with Tribes and stakeholders regarding involvement in the process and modeling metrics
- March 2013 - meeting with Tribes regarding written contribution process to the EIS and modeling metrics.
- April-July 2013 - additional meetings with Tribes regarding modeling metrics
- August 2013 - Held meetings with Tribes and AMWG stakeholders, presented preliminary modeling and solicited structured decision making input
- November 2013 - Meeting with Tribal representatives to further develop modeling metrics useful for Tribes and discussed text that some Tribes wanted to contribute to the EIS.
- February 2014 - Revised alternatives and modeling metrics presented to Tribes and stakeholders at the AMWG meeting

---

Planned activities:

- March 2014 - Meetings with stakeholders and Tribes. On March 18 there will be a web session to explain structure decision input methods and a meeting March 31-April 1 in Phoenix to present modeling results
- April 2014 - We are seeking structured decision information back from stakeholders and Tribes
- May-June 2014 - We will prepare preliminary EIS draft
- June 2014 - We plan to distribute preliminary draft EIS to cooperating agencies for comment
- July-Sept 2014- planning Government to Government meetings with most Tribes because at that point we can discuss a draft and a potentially preferred alternative
- Sept/Oct 2014 - We plan to publish a draft EIS for public comment
- 2015 - We plan to publish a final EIS

We hope this information helps with understanding the LTEMP EIS project, where we are in the process and helps the Navajo Nation understand potential participation in this project.

On Jun 2, 2014, at 2:26 PM, "Billerbeck, Rob"
<rob_p_billerbeck@nps.gov<mailto:rob_p_billerbeck@nps.gov>> wrote:

Council Delegate Phelps,
We wanted to send you a follow-up note to our meeting in Flagstaff in April regarding the Long Term Experimental and Management Plan (LTEMP) EIS for the Glen Canyon Dam. We thank you again for meeting with us and hope our information on the project was helpful. We wanted to see if there was any follow-up that you foresee in terms of the cooperating agency status of the Navajo Nation on this project. We can make ourselves available if you would like us to come out and meet with the council.

In terms of schedule, we plan to distribute a first preliminary draft EIS to cooperating agencies in July, a second cooperating agency draft in late Aug-Sept, and a public draft EIS in October.

Thank you,

Rob Billerbeck, NPS and Glen Knowles, Reclamation

--

Rob Billerbeck
Colorado River Coordinator
Resource Stewardship and Science
Intermountain Region
National Park Service
Alameda Office: 303-987-6789
Email: Rob_P_Billerbeck@nps.gov<mailto:Rob_P_Billerbeck@nps.gov>

On Tue, Jun 3, 2014 at 3:44 PM, Walter Phelps <walterphelps@navajo-nsn.gov<mailto:walterphelps@navajo-nsn.gov>> wrote:
Dear Mr Billerbeck, thank you for your follow up. The Council's Nabikiyati committee approved the resolution last month. I will send you a copy of the signed resolution upon receipt. Thank you for keeping in contact with Mrs. Becker and i on further developments.

Walter Phelps

Sent from my iPhone

(h) Paiute Indian Tribe of Utah

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

Please return this form by January 6, 2012, to indicate your interest in participating as a cooperating agency in the development of a Long-Term Experimental and Management Plan and Environmental Impact Statement for the Glen Canyon Dam.

A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

____ Yes, we are interested in participating as a cooperating agency.

D.M. No, we are not interested in participating as a cooperating agency. We would like to be kept updated on the project. D.M.

Agency: Paiute Indian Tribe of Utah
Contact: Doreen Martineau
Title: Cultural Resource
Office: PITU
Address: 440 North Paiute Drive
Cedar City, Utah
84721
Direct Phone: 435-586-1112
Office Phone: " 247, 107
Mobile Phone: _____
Fax: 435 586 7388
Email: doreen.martineau@ibs.gov

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

(i) Pueblo of Zuni

ORIGINAL

Arlen Quetawki, SR.
Governor

Steve K. Boone
Lt. Governor

Vacant
Head Councilman

Vacant
Councilman

PUEBLO OF ZUNI
P. O. Box 339
Zuni, New Mexico 87327
1203-B NM State Hwy 53
Phone: (505) 782-7022
Fax: (505) 782-7202
www.ashiwi.org

505-782-7000 MAIN

Loren L. Leekela, SR
Councilman

Gerald Hooee, SR.
Councilman

Mark Martinez
Councilman

Birdena Sanchez
Councilwoman

13 December 2011

DEC 2 2 2011

CERTIFIED
Class ENV-6.00
Prj GC
003969101
To
700

Mr. Larry Walkoviak, Regional Director
Upper Colorado Region
Bureau of Reclamation
125 South State Street
Salt Lake City, UT 84138

Mr. John Wessels, Regional Director
Intermoutain Region Office
National Park Service
12795 Alameda Parkway
Denver, CO 80225

RE: Cooperating Agency Status for Pueblo of Zuni for the Development of an Environmental Impact Statement for a Long-Term Experimental and Management Plan (LTEMP) for Glen Canyon Dam operations. OR100

Dear Mr. Walkoviak and Mr. Wessels,

The Pueblo of Zuni has received your letter, dated 08 December 2011, inviting the Pueblo of Zuni to be a cooperating agency in the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement process. As you are aware the Grand Canyon, Colorado River, Little Colorado River, and all the physical, biological, and cultural resources located there are of extreme historical, cultural, and religious significance to the Zuni people. The appropriate care and management of this very sacred place and all the resources that comprise this important Zuni traditional cultural property is an on-going issue for the Zuni people; therefore, the Pueblo of Zuni accepts your invitation to become a cooperating agency in the development of this Environmental Impact Statement (EIS) for the LTEMP.

As Governor of Zuni, I designate Kurt Dongoske, RPA, Tribal Historic Preservation Officer of the Zuni Heritage and Historic Preservation Office as the primary Zuni representative as a cooperating agency in this process. Mr. Dongoske's contact information is provided in the attached form. Should you have any questions or require additional information please contact my office at 505.782.7000 or the Zuni Heritage and Historic Preservation Office at 505.782.2393. Thank you for consulting with the Pueblo of Zuni.

Sincerely,

Steve K. Boone
for Governor Arlen Quetawki, Sr.
Pueblo of Zuni

NOTICE IF YOU DETACH
ENCLOSURES PLEASE INSERT
CODE NO._____

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

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__X__ Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: Pueblo of Zuni

Contact: KURT DONGOSKE

Title: TRIBAL Historic Preservation officer

Office: Zuni Heritage and Historic Preservation Office

Address: P.O. Box 1149

Zuni, New Mexico 87327

Direct Phone:

Office Phone: 505.782.4814

Mobile Phone: 928.587.1901

Fax: 505.782.2393

Email: Kdongoske@cableone.net

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

(j) White Mountain Apache Tribe

From: Cheryl Pailzote [cpailzote@wmat.us]
Sent: Tuesday, May 15, 2012 2:42 PM
To: Barger, Mary E
Cc: markaltaha@wmat.us; rlupe@wmat.us
Subject: RE: Call today about the EIS for Glen Canyon Dam flows/ tribal consultation

Hello Mary,

I had talked to our advisors about the EIS for the Glen Canyon Dam flows. From a water resources/water rights position, we do not feel that the Glen Canyon EIS alternatives will have any impact on White Mountain Apache Tribe. Mark Altaha had stated that there are impact on cultural resources. Thus, I have will recommend to Chairman Lupe that we do not need to be cooperators on this EIS. Would you need a letter from the Chairman stating such?

Thank you,

Cheryl Pailzote
Water Resources Director
WMAT

(k) Yavapai-Apache Nation

YAVAPAI-APACHE NATION
CAMP VERDE, ARIZONA

4

Glen Canyon Dam
Long Term Experimental and Management Plan (LTEMP)
Cooperating Agency Interest

Please return this form by January 6, 2012, to indicate your interest in participating as a cooperating agency in the development of a Long-Term Experimental and Management Plan and Environmental Impact Statement for the Glen Canyon Dam.

A cooperating agency agreement will be developed to identify the specific roles and responsibilities of each agency. In general, cooperating agencies provide information in their areas of special expertise, which will assist the Bureau of Reclamation and the National Park Service in making a more informed decision.

XXXXX Yes, we are interested in participating as a cooperating agency.

_____ No, we are not interested in participating as a cooperating agency.

Agency: Yavapai-Apache Nation

Contact: Christopher Coder

Title: Tribal Archaeologist YAN

Office: Cultural Preservation

Address: 2400 West Datsi
Camp Verde, AZ 86322

Direct Phone: (928) 567-7026

Office Phone: 525-3035

Mobile Phone: NA

Fax: (928) 567-3994

Email: ccoder@yan-tribe.org

Please return the form by January 6, 2012 to:

Glen Canyon Dam LTEMP EIS Cooperators
Argonne National Laboratory
9700 S. Cass Ave. – EVS/240
Argonne IL 60439

From: Verhaaren, Bruce T.
Sent: Wednesday, October 10, 2012 11:03 AM
To: ccoder@yan-tribe.org
Cc: Carr, Adrianne E.
Subject: LTEMP Cooperator?

Hello Chris,

I hope your trip went well.

Have you been able to confirm that the Yavapai-Apache Nation no longer is interested in being a cooperating agency for the LTEMP EIS?

Best Regards

Bruce

From: Chris Coder [mailto:ccoder@yan-tribe.org]
Sent: Wednesday, October 10, 2012 12:36 PM
To: Verhaaren, Bruce T.
Cc: Carr, Adrianne E.; Anthony Canty
Subject: RE: LTEMP Cooperator?

Hi Bruce/Adrianne,

Thanks for the prompt. Our internal water team meets next Monday and as I cannot make this decision unilaterally, I will get a consensus from the team and get back to you by the middle of next week with an informed opinion from the group.

Thanks Chris

(928) 567-7026

From: Verhaaren, Bruce T. [mailto:brucev@anl.gov]
Sent: Wednesday, October 10, 2012 9:03 AM
To: Chris Coder
Cc: Carr, Adrianne E.
Subject: LTEMP Cooperator?

Hello Chris,

I hope your trip went well.

Have you been able to confirm that the Yavapai-Apache Nation no longer is interested in being a cooperating agency for the LTEMP EIS?

Best Regards

Bruce

++++++++++++++++++++++++++

Bruce Verhaaren, Ph.D.
Environmental Science Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439

Office: 630 252-3240
Fax: 630 252-4624
bverhaaren@anl.gov

From: Verhaaren, Bruce T.

Sent: Tuesday, October 23, 2012 1:55 PM

To: ccoder@yan-tribe.org

Cc: Balsom, Janet R.; barger, mary; Carr, Adrianne E.

Subject: Cooperating status

Hello Chris,

Have you had time to verify whether Yavapai-Apache Nation no longer wish to act as a cooperating agency for the LTEMP EIS for Glen Canyon Dam? It is my understanding that they do not. Please confirm.

Thanks for checking on this.

Bruce

++++++++++++++++++++++++++++

Bruce Verhaaren, Ph.D.

Environmental Science Division

Argonne National Laboratory

9700 S. Cass Avenue

Argonne, IL 60439

Office: 630 252-3240

Fax: 630 252-4624

bverhaaren@anl.gov

From: Chris Coder [mailto:ccoder@yan-tribe.org]
Sent: Wednesday, October 24, 2012 3:22 PM
To: Verhaaren, Bruce T.
Subject: RE: Cooperating status

Hi Bruce,

I have run this by our legal counsel and they have advised we do not need to be a cooperating agency, but would like to remain in the loop to the extent we can get (electronically) the draft NEPA document.

Thanks for your patience,

Chris Coder

ATTACHMENT N.3

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

IN REPLY REFER TO:
UC-725
ENV-3.00

JUN 12 2014

Mr. James Garrison
Arizona State Historic Preservation Office
Arizona State Parks
1300 West Washington Street
Phoenix, AZ 85007

Subject: Initiation of the National Historic Preservation Act of 1966 (NHPA) Section 106 Compliance for Operation of Glen Canyon Dam (GCD)

Dear Mr. Garrison:

The Bureau of Reclamation, Upper Colorado Region, and National Park Service (NPS), Intermountain Region are proposing to complete an Environmental Impact Statement (EIS) for GCD operations. This EIS will address a change in dam operation for approximately the next 20 years and is called the Long Term Experimental and Management Plan (LTEMP).

We recently completed developing six alternatives for this EIS, and as a result, have a better understanding of any potential to affect historic properties. Of the six alternatives, the highest flow proposed is 45,000 cubic feet per second, the same as was identified in the Memorandum of Agreement for the GCD High Flow Experimental Protocol.

Since the LTEMP effort has started, we have briefed stakeholders and the signatories for the Operation of GCD 1994 Programmatic Agreement (PA) on our intent to complete a new PA. We also had a meeting on January 9, 2013, with both our Federal Preservation Officers (FPOs), the Advisory Council on Historic Preservation (ACHP), and Reclamation and the NPS management to discuss a potential Section 106 process. We sent a joint letter from the NPS and Reclamation to the ACHP on February 27, 2013, that discussed the results of that meeting and your office was copied, along with the PA signatories.

Currently, we have a draft Area of Potential Effects (APE) identified for the LTEMP undertaking as follows:

> Longitudinally, the Area of Potential Effect (APE) for the LTEMP undertaking associated with GCD operations includes the active channel of the Colorado River in Glen, Marble, and Grand Canyons from Glen Canyon Dam to the western boundary of Grand Canyon National Park near Pearce Ferry. Laterally, the APE extends from the Colorado River both horizontally and vertically to varying extent based on the specific

operational, topographic, and natural processes at each location. The variable upslope extent of the APE is primarily dependent on the distribution of sandbars and the potential for fine sediment redistribution by canyon winds under the prevailing flow regimes of the Colorado River as described in the LTEMP EIS. The APE includes areas affected by the flow of the Colorado River and active aeolian processes.

Pursuant to Section 106 of the NHPA, as the Federal lead agency for this undertaking, Reclamation would like to consult with you on developing the PA for this new undertaking. Please note that we are currently in the process of identifying our consulting parties per 36 CFR 800.3, and coordinating with the NPS on the first draft PA for review by consulting parties. We will be convening a meeting of these consulting parties, including your office, in the near future.

If you have any questions, please contact Mary Barger at 602-615-0809.

Sincerely,

for Larry Walkoviak
Regional Director

cc: Ms. Jan Balsom
Grand Canyon National Park
P.O. Box 129
Grand Canyon, AZ 86023

Mr. Todd Brindle
Superintendent
Glen Canyon National Recreation Area
Rainbow Bridge National Monument
P.O. Box 1507
Page, AZ 86040

Mr. Charley Bulletts
Director
Southern Paiute Consortium
Tribal Affairs Building
HC65 Box 2
Fredonia, AZ 86022

Honorable Sherry J. Counts
Chairwoman
Hualapai Tribe
P.O. Box 179
941 Hualapai Way
Peach Springs, AZ 86434

Mr. Kurt Dongoske
Tribal Historic Preservation Office
Zuni Cultural Resource Enterprise
Pueblo of Zuni
P.O. Box 339
Zuni, NM 87327

Honorable Herman G. Honanie
Chairman
The Hopi Tribe
P.O. Box 123
Kykotsmovi, AZ 86039

Initiation of the NHPA Section 106 Compliance for Operation of GCD

Honorable Gerald Hooey
Councilman
Pueblo of Zuni
P.O. Box 339
Zuni, NM 87327

Ms. Ann Howard, Deputy
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Arizona State Parks
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Ms. Leslie James, Executive Director
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10429 S 51st Street, Suite 230
Phoenix, AZ 85044

Ms. Lyn Jeka, Manager
Colorado River Storage Project
Western Area Power Administration
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Salt Lake City, UT 84111

Mr. Leigh J. Kuwanwisiwma
Director
Hopi Cultural Preservation Office
The Hopi Tribe
P.O. Box 123
Kykotsmovi, AZ 86030

Mr. Charles Louis
Bureau of Indian Affairs
Phoenix Area Office
2600 North Central, Fourth Floor
Phoenix, AZ 85004-3050

Mr. Tom McCullough
Advisory Council on Historic Preservation
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Washington, DC 20001-2637

Ms. Lisa Meyer, Archaeologist
Western Area Power Administration
P.O. Box 281213
Lakewood, CO 80228-8213

Acting Tribal Historic Preservation Officer
Navajo Nation
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Window Rock, AZ 86515

Mr. Reid Nelson
Advisory Council on Historic Preservation
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Mr. Theodore Quasula
Acting Field Manager
Bureau of Indian Affairs
Phoenix Area Office
2600 North Central, Fourth Floor
Phoenix, AZ 85004-3050

Honorable Arlen Quetawki, Senior
Governor
Pueblo of Zuni
P.O. Box 339
Zuni, NM 87327

Mr. Manual Savala
Kaibab Band of Paiute Indians
Tribal Administration Building
#1 Pipe Spring Road
Fredonia, AZ 86022

Initiation of the NHPA Section 106 Compliance for Operation of GCD

Honorable Ben Shelly
President
Navajo Nation
P.O. Box 7440
Window Rock, AZ 86515

Ms. Rosemary Sucec
Glen Canyon National Recreation Area
P.O. Box 1507
Page, AZ 86040

Dr. Benjamin N. Tuggle
Southwest Regional Director
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, NM 87103-1306

Mr. Dave Uberuaga
Superintendent
Grand Canyon National Park
P.O. Box 129
Grand Canyon, AZ 86023

Mr. Mike Yeatts
Hopi Cultural Preservation Office
The Hopi Tribe
P.O. Box 123
Kykotsmovi, AZ 86030

Mr. Kirk Young
U.S. Fish and Wildlife Service
323 North Leroux
Flagstaff, AZ 86001

2014-0628(120202)

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

IN REPLY REFER TO:
UC-725
ENV-3.00

JUN 12 2014

RECEIVED
JUN 16 2014
JC
ARIZONA STATE HISTORIC PRESERVATION OFFICE

Mr. James Garrison
Arizona State Historic Preservation Office
Arizona State Parks
1300 West Washington Street
Phoenix, AZ 85007

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If you have any questions, please contact Mary Barger at 602-615-0809.

7/18/14
Thank you for this information
We look forward to working with you
on the PA.
Mary-Ellen Walsh
Archaeological Compliance Specialist

Sincerely,

for Larry Walkoviak
Regional Director

cc: Ms. Jan Balsom
Grand Canyon National Park
P.O. Box 129
Grand Canyon, AZ 86023

Mr. Todd Brindle
Superintendent
Glen Canyon National Recreation Area
Rainbow Bridge National Monument
P.O. Box 1507
Page, AZ 86040

Mr. Charley Bulletts
Director
Southern Paiute Consortium
Tribal Affairs Building
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Honorable Sherry J. Counts
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Hualapai Tribe
P.O. Box 179
941 Hualapai Way
Peach Springs, AZ 86434

Mr. Kurt Dongoske
Tribal Historic Preservation Office
Zuni Cultural Resource Enterprise
Pueblo of Zuni
P.O. Box 339
Zuni, NM 87327

Honorable Herman G. Honanie
Chairman
The Hopi Tribe
P.O. Box 123
Kykotsmovi, AZ 86039

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Glen Canyon Dam

Long-Term Experimental and Management Plan Environmental Impact Statement

FINAL

Volume 3—Appendices O–Q

U.S. Department of the Interior
Bureau of Reclamation,
Upper Colorado Region
National Park Service,
Intermountain Region

October 2016













Cover photo credits:

Title bar: Grand Canyon National Park
Grand Canyon: Grand Canyon National Park
Glen Canyon Dam: T.R. Reeve
High-flow experimental release: T.R. Reeve
Fisherman: T. Gunn
Humpback chub: Arizona Game and Fish Department
Rafters: Grand Canyon National Park

GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN FINAL ENVIRONMENTAL IMPACT STATEMENT

Joint-Lead Agencies
Bureau of Reclamation
National Park Service

Cooperating Agencies
Department of the Interior
Bureau of Indian Affairs
U.S. Fish and Wildlife Service
U.S. Department of Energy
Western Area Power Administration
Arizona Game and Fish Department
Colorado River Board of California
Colorado River Commission of Nevada
Upper Colorado River Commission
Havasupai Tribe
Hopi Tribe
Hualapai Tribe
Kaibab Band of Paiute Indians
Navajo Nation
Pueblo of Zuni
Salt River Project
Utah Associated Municipal Power Systems

ABSTRACT

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation and National Park Service (NPS), proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, including those of importance to American Indian Tribes.

The Final Environmental Impact Statement (FEIS) was developed in accordance with the National Environmental Policy Act of 1969, as amended (NEPA), and followed the implementing regulations developed by the President's Council on Environmental Quality in Title 40 *Code of Federal Regulations* (CFR) Parts 1500 to 1508 and DOI regulations implementing NEPA in 43 CFR Part 46. The FEIS analysis draws on the scientific information that has been collected under the Glen Canyon Dam Adaptive Management Program over the last 20 years to identify the potential environmental effects associated with taking no action, as well as a reasonable range of alternatives to no action for implementing the proposed federal action. Seven alternatives were considered and analyzed for the LTEMP EIS—a no action alternative (Alternative A), a hydropower-focused alternative (Alternative B), three condition-dependent alternatives (Alternatives C, D, and E), and two steady flow alternatives (Alternatives F and G). These alternatives incorporated a broad range of operations and experimental actions that together allowed for a full evaluation of possible impacts of the

proposed action. Based on the impact analyses conducted, DOI has chosen Alternative D as both the preferred and the environmentally preferred alternative. Alternative D is expected to result in an improvement in conditions for humpback chub, trout, and the aquatic food base; have the least impact on vegetation, wetlands, and terrestrial wildlife; improve sandbar building potential and conserve sediment; sustain or improve conditions for reservoir and river recreation; improve preservation of cultural resources; respect and enhance Tribal resources and values; and have limited impacts on hydropower resources.

For additional information, visit http://ltempeis.anl.gov or contact:

Rob Billerbeck
Colorado River Coordinator
National Park Service
Intermountain Region
12795 West Alameda Parkway
Lakewood, CO 80228
Phone: 303-987-6789
Email: rob_p_billerbeck@nps.gov

Katrina Grantz
Chief, Adaptive Management Group
Bureau of Reclamation
Upper Colorado Region
125 South State Street
Salt Lake City, UT 84138-1147
Phone: 801-524-3635
Email: kgrantz@usbr.gov

CONTENTS

ABSTRACT iii

ACRONYMS AND ABBREVIATIONS lxiii

1 INTRODUCTION 1-1

1.1 Description of the Proposed Action 1-4
1.2 Purpose of and Need for Action 1-5
1.3 Lead and Cooperating Agencies and Consulting Tribes 1-9
1.3.1 Lead Agencies 1-9
1.3.2 Cooperating Agencies and Consulting Tribes 1-9
1.4 Objectives and Resource Goals of the LTEMP 1-10
1.5 Scope of the EIS 1-13
1.5.1 Affected Region and Resources 1-13
1.5.2 Impact Topics Selected for Detailed Analysis 1-14
1.5.3 Impact Topics Dismissed from Detailed Analysis 1-15
1.6 Role of Adaptive Management 1-16
1.6.1 History of the Existing Adaptive Management Program 1-16
1.6.2 Relationship of Adaptive Management to NEPA and Changes to Operations 1-17
1.7 Role of Decision Analysis in the EIS Process 1-17
1.8 History, Location, and Setting 1-18
1.8.1 History and Purpose of Glen Canyon Dam 1-18
1.8.2 Location of Glen Canyon Dam and LTEMP Affected Area 1-19
1.8.3 Operation of the Glen Canyon Dam 1-20
1.8.4 History, Purpose, and Significance of the National Park System Units 1-22
1.8.4.1 Grand Canyon National Park 1-22
1.8.4.2 Glen Canyon National Recreation Area 1-24
1.8.4.3 Lake Mead National Recreation Area 1-24
1.8.5 Tribal Lands 1-25
1.8.5.1 Fort Mojave Tribe 1-26
1.8.5.2 Havasupai Tribe 1-26
1.8.5.3 Hopi Tribe 1-27
1.8.5.4 Hualapai Tribe 1-27
1.8.5.5 Navajo Nation 1-27
1.8.5.6 Pueblo of Zuni 1-28
1.8.5.7 Southern Paiute Tribes 1-28
1.9 Laws and Regulations Related to Operations of Glen Canyon Dam and Park Management 1-29
1.9.1 Environmental Laws and Executive Orders 1-29
1.9.2 Cultural/Historical Laws and Executive Orders 1-30

CONTENTS (Cont.)

1.9.3 American Indian and Tribal Consultation Laws and Executive Orders ... 1-31
1.9.4 Laws Establishing Criteria Related to Power Marketing ... 1-31
1.9.5 Law of the River ... 1-31
1.10 Related Actions ... 1-31
1.10.1 Biological Opinions ... 1-33
1.10.2 Environmental Impact Statements and Related Documents ... 1-33
1.10.3 Environmental Assessments and Related Documents ... 1-35
1.10.4 Other Actions, Programs, Plans, and Projects ... 1-36

2 DESCRIPTION OF ALTERNATIVES ... 2-1

2.1 Development of Alternatives ... 2-2
2.2 Descriptions of Alternatives Considered in Detail ... 2-4
2.2.1 Alternative A (No Action Alternative) ... 2-8
2.2.2 Alternative B ... 2-20
2.2.3 Alternative C ... 2-23
2.2.3.1 Base Operations under Alternative C ... 2-25
2.2.3.2 Implementation Process for Experiments under Alternative C ... 2-27
2.2.3.3 Sediment-Related Experiments To Be Evaluated under Alternative C ... 2-37
2.2.3.4 Aquatic Resource-Related Experiments To Be Evaluated under Alternative C ... 2-38
2.2.4 Alternative D (Preferred Alternative) ... 2-41
2.2.4.1 Base Operations under Alternative D ... 2-44
2.2.4.2 Operational Flexibility under Alternative D ... 2-46
2.2.4.3 Implementation Process for Experiments under Alternative D ... 2-48
2.2.4.4 Communication and Consultation Process for Alternative D ... 2-57
2.2.4.5 Sediment-Related Experiments To Be Evaluated under Alternative D ... 2-58
2.2.4.6 Aquatic Resource-Related Experiments To Be Evaluated under Alternative D ... 2-62
2.2.4.7 Conservation Measures under Alternative D ... 2-72
2.2.5 Alternative E ... 2-72
2.2.5.1 Base Operations under Alternative E ... 2-72
2.2.5.2 Experimental Framework for Alternative E ... 2-75
2.2.6 Alternative F ... 2-80
2.2.7 Alternative G ... 2-81
2.3 Alternatives Considered and Eliminated from Detailed Study ... 2-84
2.3.1 Modified Low Fluctuating Flows with Extended Protocols ... 2-84

CONTENTS (Cont.)

2.3.2 Naturally Patterned Flow Alternative 2-85
2.3.3 Seasonal Fluctuations with Low Summer Flow Alternative 2-85
2.3.4 Grand Canyon First! Alternative 2-86
2.3.5 Species Community and Habitat-Based Alternative 2-86
2.3.6 Stewardship Alternative 2-86
2.3.7 Twelve-Year Experiment of Two Steady-Flow Alternatives 2-87
2.3.8 Decommission Glen Canyon Dam Alternative 2-87
2.3.9 Fill Lake Mead First Alternative 2-88
2.3.10 Full-Powerplant Capacity Operations Alternative 2-88
2.3.11 Run-of-the-River Alternative 2-88
2.4 Alternative Elements Eliminated from Detailed Study 2-89
2.4.1 New Infrastructure 2-89
2.4.2 Flow and Non-Flow Actions 2-90
2.5 Summary Comparison of Alternatives 2-91

3 AFFECTED ENVIRONMENT 3-1

3.1 Project Area 3-1
3.1.1 Colorado River Setting 3-1
3.1.2 Geologic Setting 3-3
3.1.2.1 Tribal Perspectives on Geologic Setting 3-3
3.1.3 Climatic Setting 3-4
3.1.4 Glen Canyon Dam Releases and Flow 3-5
3.1.5 Colorado River Ecosystem Resource Linkages 3-6
3.2 Water Resources 3-6
3.2.1 Hydrology 3-7
3.2.1.1 Lake Powell Hydrology 3-8
3.2.1.2 Hydrology of the Colorado River Downstream of Glen Canyon Dam 3-11
3.2.1.3 Lake Mead Hydrology 3-13
3.2.1.4 Seeps and Springs 3-14
3.2.2 Water Quality 3-16
3.2.2.1 Lake Powell Water Quality 3-16
3.2.2.2 Colorado River Water Quality 3-19
3.2.2.3 Lake Mead Water Quality 3-27
3.2.3 Tribal Perspectives on Water Resources 3-29
3.2.4 Hydrology and Climate Change 3-32
3.2.4.1 Basis for Runoff Estimates 3-32
3.2.4.2 Water Variability and Availability 3-33
3.2.4.3 Seasonal Timing Shifts 3-34
3.2.4.4 Water Quality 3-35
3.3 Sediment Resources 3-35
3.3.1 Background: Geomorphology of the Colorado River 3-35

CONTENTS (Cont.)

3.3.1.1 Geomorphic Features of the Colorado River 3-37
3.3.1.2 Glen Canyon Geomorphology 3-40
3.3.1.3 Marble and Grand Canyon Geomorphology 3-41
3.3.2 Sediment Characteristics and Transport Mechanisms 3-43
3.3.2.1 Particle Size and Sediment Supply 3-45
3.3.2.2 Sediment Transport Capacity 3-46
3.3.2.3 River Stage 3-46
3.3.3 Sediment Sources 3-46
3.3.3.1 Gaged Tributaries 3-48
3.3.3.2 Ungaged Tributaries 3-48
3.3.4 Sediment Transport and Storage 3-50
3.3.4.1 Sediment Transport 3-50
3.3.4.2 Sediment Storage 3-51
3.3.4.3 High-Flow Experiments 3-51
3.3.4.4 Sediment Supply Limitation 3-53
3.3.4.5 Sandbar Deposition and Retention 3-53
3.3.5 Lake Deltas 3-56
3.4 Natural Processes 3-57
3.5 Aquatic Ecology 3-59
3.5.1 Aquatic Food Base 3-59
3.5.1.1 Periphyton and Rooted Aquatic Plants 3-61
3.5.1.2 Plankton 3-63
3.5.1.3 Macroinvertebrates 3-63
3.5.1.4 Nonnative Invasive Species 3-66
3.5.1.5 Food Web Dynamics 3-69
3.5.2 Native Fish 3-70
3.5.2.1 Special Status Fish Species 3-72
3.5.2.2 Other Native Species 3-86
3.5.3 Nonnative Fish 3-90
3.5.3.1 Coldwater Nonnative Species 3-94
3.5.3.2 Warmwater Nonnative Species 3-100
3.5.3.3 Interactions with Native Species 3-101
3.5.3.4 Nonnative Fish Control Activities and Effects of Flow Conditions 3-104
3.6 Vegetation 3-109
3.6.1 Historic and Remnant Riparian Plant Communities 3-110
3.6.2 Existing Riparian Vegetation Downstream from Glen Canyon Dam 3-111
3.6.2.1 Tribal Perspectives on Vegetation 3-119
3.6.3 Special Status Plant Species 3-121
3.7 Wildlife 3-124
3.7.1 Invertebrates 3-125
3.7.2 Amphibians and Reptiles 3-126
3.7.3 Birds 3-127

CONTENTS (Cont.)

3.7.4 Mammals ... 3-129
3.7.5 Special Status Wildlife Species ... 3-131
3.7.5.1 Invertebrates ... 3-132
3.7.5.2 Amphibians and Reptiles ... 3-136
3.7.5.3 Birds ... 3-136
3.7.5.4 Mammals ... 3-142
3.7.6 Tribal Perspectives on Wildlife ... 3-142
3.8 Cultural Resources ... 3-144
3.8.1 Area of Potential Effect ... 3-146
3.8.2 Description of Cultural Resources and Site Types ... 3-149
3.8.2.1 Archaeological Resources ... 3-149
3.8.2.2 Historic Resources ... 3-153
3.8.2.3 Cultural Landscapes ... 3-155
3.8.2.4 Traditional Cultural Properties and Ethnographic Resources ... 3-156
3.9 Tribal Resources ... 3-156
3.9.1 Fort Mojave Indian Tribe ... 3-157
3.9.2 Havasupai ... 3-158
3.9.3 Hopi ... 3-158
3.9.4 Hualapai ... 3-159
3.9.5 Navajo Nation ... 3-162
3.9.6 Pueblo of Zuni ... 3-164
3.9.7 Southern Paiute Tribes ... 3-167
3.9.8 Indian Trust Assets and Trust Responsibility ... 3-168
3.10 Recreation, Visitor Use, and Experience ... 3-168
3.10.1 Glen Canyon Reach of the Colorado River in Glen Canyon National Recreation Area ... 3-169
3.10.1.1 Lees Ferry Recreational Fishery ... 3-169
3.10.1.2 Day-Rafting, Boating, and Camping in the Glen Canyon Reach ... 3-174
3.10.2 The Colorado River in Grand Canyon National Park ... 3-178
3.10.2.1 Campsites in Grand Canyon National Park ... 3-179
3.10.2.2 River Flow and Fluctuation ... 3-183
3.10.2.3 Hualapai Tribe Recreation Program ... 3-186
3.10.3 Recreation Use on Lake Mead and Lake Powell ... 3-187
3.10.3.1 Lake Mead National Recreation Area ... 3-187
3.10.3.2 Lake Powell, Glen Canyon National Recreation Area ... 3-187
3.10.4 Park Operations and Management ... 3-187
3.11 Wilderness ... 3-188
3.11.1 Law and Policy ... 3-189
3.11.2 Defining Wilderness Character ... 3-190
3.12 Visual Resources ... 3-192
3.12.1 Glen Canyon National Recreation Area ... 3-193

CONTENTS (Cont.)

3.12.2 Grand Canyon and the Colorado River 3-195
3.12.3 Lake Mead National Recreation Area 3-198
3.13 Hydropower 3-198
3.13.1 Power Operations 3-199
3.13.1.1 Hydropower Generation 3-199
3.13.1.2 Basin Fund 3-200
3.13.1.3 Operational Flexibility 3-201
3.13.1.4 Scheduling 3-202
3.13.1.5 Load/Generation Following and Regulation 3-203
3.13.1.6 Capacity Reserves 3-205
3.13.1.7 Disturbances and Emergencies and Outage Assistance 3-205
3.13.1.8 Transmission System 3-206
3.13.2 Power Marketing 3-206
3.13.2.1 Wholesale Rates 3-209
3.13.2.2 Retail Rates 3-209
3.14 Socioeconomics and Environmental Justice 3-209
3.14.1 The Six-County Region of Influence 3-210
3.14.1.1 Population 3-210
3.14.1.2 Income 3-211
3.14.1.3 Employment 3-211
3.14.1.4 Unemployment 3-213
3.14.1.5 Environmental Justice 3-213
3.14.2 The Seven-State Region of Influence 3-221
3.14.2.1 Population 3-221
3.14.2.2 Income 3-222
3.14.2.3 Employment 3-224
3.14.2.4 Unemployment 3-226
3.14.2.5 Environmental Justice 3-226
3.14.3 Non-Use Value 3-228
3.15 Air Quality 3-229
3.15.1 Local Air Quality 3-229
3.15.2 Regional Air Quality 3-231
3.15.3 Regional Air Emissions 3-234
3.16 Climate Change 3-236

4 ENVIRONMENTAL CONSEQUENCES 4-1

4.1 Overall Analysis and Assessment Approach 4-1
4.2 Water Resources 4-9
4.2.1 Analysis Methods 4-10
4.2.1.1 Hydrology 4-10
4.2.1.2 Water Quality 4-13
4.2.2 Summary of Impacts 4-14

CONTENTS (Cont.)

4.2.2.1 Hydrology 4-14
4.2.2.2 Water Quality 4-37
4.2.3 Alternative-Specific Impacts 4-47
4.2.3.1 Alternative A (No Action Alternative) 4-48
4.2.3.2 Alternative B 4-49
4.2.3.3 Alternative C 4-53
4.2.3.4 Alternative D (Preferred Alternative) 4-55
4.2.3.5 Alternative E 4-58
4.2.3.6 Alternative F 4-60
4.2.3.7 Alternative G 4-62
4.3 Sediment Resources 4-65
4.3.1 Analysis Methods 4-66
4.3.2 Summary of Impacts 4-70
4.3.3 Alternative-Specific Impacts 4-72
4.3.3.1 Alternative A (No Action Alternative) 4-75
4.3.3.2 Alternative B 4-77
4.3.3.3 Alternative C 4-80
4.3.3.4 Alternative D (Preferred Alternative) 4-81
4.3.3.5 Alternative E 4-84
4.3.3.6 Alternative F 4-85
4.3.3.7 Alternative G 4-86
4.4 Natural Processes 4-87
4.4.1 Analysis Methods 4-88
4.4.2 Summary of Impacts 4-88
4.4.3 Alternative-Specific Impacts 4-97
4.4.3.1 Alternative A (No Action Alternative) 4-97
4.4.3.2 Alternative B 4-97
4.4.3.3 Alternative C 4-98
4.4.3.4 Alternative D (Preferred Alternative) 4-99
4.4.3.5 Alternative E 4-99
4.4.3.6 Alternative F 4-100
4.4.3.7 Alternative G 4-101
4.5 Aquatic Ecology 4-102
4.5.1 Analysis Methods 4-102
4.5.1.1 Aquatic Food Base 4-102
4.5.1.2 Nonnative Fish 4-103
4.5.1.3 Native Fish 4-106
4.5.1.4 Aquatic Parasites 4-107
4.5.2 Summary of Impacts 4-107
4.5.2.1 Aquatic Food Base 4-107
4.5.2.2 Nonnative Fish 4-119
4.5.2.3 Native Fish 4-127
4.5.2.4 Aquatic Parasites 4-135

CONTENTS (Cont.)

4.5.3 Alternative-Specific Impacts on Aquatic Resources 4-137
4.5.3.1 Alternative A (No Action Alternative)..... 4-137
4.5.3.2 Alternative B 4-140
4.5.3.3 Alternative C 4-143
4.5.3.4 Alternative D (Preferred Alternative)..... 4-148
4.5.3.5 Alternative E..... 4-154
4.5.3.6 Alternative F..... 4-157
4.5.3.7 Alternative G..... 4-160
4.6 Vegetation 4-163
4.6.1 Analysis Methods..... 4-164
4.6.2 Summary of Impacts..... 4-168
4.6.2.1 Impacts on Old High Water Zone Vegetation..... 4-177
4.6.2.2 Impacts on New High Water Zone..... 4-179
4.6.2.3 Wetlands..... 4-185
4.6.2.4 Special Status Plant Species..... 4-187
4.6.3 Alternative-Specific Impacts 4-190
4.6.3.1 Alternative A (No Action Alternative)..... 4-191
4.6.3.2 Alternative B 4-192
4.6.3.3 Alternative C 4-194
4.6.3.4 Alternative D (Preferred Alternative)..... 4-196
4.6.3.5 Alternative E..... 4-197
4.6.3.6 Alternative F..... 4-199
4.6.3.7 Alternative G..... 4-201
4.7 Wildlife..... 4-203
4.7.1 Analysis Methods..... 4-203
4.7.2 Summary of Impacts..... 4-204
4.7.2.1 Terrestrial Invertebrates 4-204
4.7.2.2 Amphibians and Reptiles..... 4-210
4.7.2.3 Birds 4-212
4.7.2.4 Mammals..... 4-214
4.7.2.5 Special Status Species 4-216
4.7.3 Alternative-Specific Impacts on Wildlife 4-227
4.7.3.1 Alternative A (No Action Alternative)..... 4-227
4.7.3.2 Alternative B 4-229
4.7.3.3 Alternative C 4-230
4.7.3.4 Alternative D (Preferred Alternative)..... 4-231
4.7.3.5 Alternative E..... 4-232
4.7.3.6 Alternative F..... 4-233
4.7.3.7 Alternative G..... 4-234
4.8 Cultural Resources 4-235
4.8.1 Compliance with Federal Regulations..... 4-235
4.8.2 Analysis Methods..... 4-235
4.8.3 Summary of Impacts..... 4-238

CONTENTS (Cont.)

4.8.4 Alternative-Specific Impacts 4-246
4.8.4.1 Alternative A (No Action Alternative)..... 4-246
4.8.4.2 Alternative B 4-246
4.8.4.3 Alternative C 4-247
4.8.4.4 Alternative D (Preferred Alternative)..... 4-248
4.8.4.5 Alternative E..... 4-248
4.8.4.6 Alternative F..... 4-249
4.8.4.7 Alternative G..... 4-250
4.9 Tribal Resources..... 4-251
4.9.1 Tribal Resource Goals..... 4-251
4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons 4-252
4.9.1.2 Protect and Preserve Sites of Cultural Importance..... 4-254
4.9.1.3 Preserve and Enhance Respect for Canyon Life 4-256
4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons..... 4-258
4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons..... 4-259
4.9.1.6 Economic Opportunity 4-259
4.9.1.7 Maintain Tribal Water Rights and Supply 4-260
4.9.1.8 LTEMP Process..... 4-261
4.9.2 Analysis Methods..... 4-261
4.9.3 Summary of Impacts..... 4-262
4.9.4 Alternative-Specific Impacts 4-268
4.9.4.1 Alternative A (No Action Alternative)..... 4-268
4.9.4.2 Alternative B 4-270
4.9.4.3 Alternative C 4-271
4.9.4.4 Alternative D (Preferred Alternative)..... 4-273
4.9.4.5 Alternative E..... 4-274
4.9.4.6 Alternative F..... 4-276
4.9.4.7 Alternative G..... 4-277
4.10 Recreation, Visitor Use, and Experience..... 4-279
4.10.1 Analysis Methods..... 4-279
4.10.2 Summary of Impacts..... 4-281
4.10.2.1 Glen Canyon Fishing..... 4-281
4.10.2.2 Glen Canyon Day Rafting 4-290
4.10.2.3 Glen Canyon Recreational Facilities..... 4-291
4.10.2.4 Whitewater Boating..... 4-291
4.10.2.5 Reservoir Activities and Facilities 4-292
4.10.2.6 Tribal Recreation Operations 4-293
4.10.2.7 Pearce Ferry..... 4-296
4.10.2.8 Park Operations and Management 4-296

CONTENTS (Cont.)

4.10.3 Alternative-Specific Impacts 4-297
4.10.3.1 Alternative A (No Action Alternative) 4-297
4.10.3.2 Alternative B 4-298
4.10.3.3 Alternative C 4-300
4.10.3.4 Alternative D (Preferred Alternative) 4-301
4.10.3.5 Alternative E 4-303
4.10.3.6 Alternative F 4-304
4.10.3.7 Alternative G 4-306
4.11 Wilderness 4-307
4.11.1 Analysis Methods 4-307
4.11.2 Summary of Impacts 4-308
4.11.3 Alternative-Specific Impacts 4-313
4.11.3.1 Alternative A (No Action Alternative) 4-314
4.11.3.2 Alternative B 4-314
4.11.3.3 Alternative C 4-315
4.11.3.4 Alternative D (Preferred Alternative) 4-316
4.11.3.5 Alternative E 4-317
4.11.3.6 Alternative F 4-317
4.11.3.7 Alternative G 4-318
4.12 Visual Resources 4-319
4.13 Hydropower 4-322
4.13.1 Analysis Methods 4-322
4.13.1.1 Hydropower Resource and Capacity Expansion Impacts 4-323
4.13.1.2 Wholesale Rate Impacts 4-330
4.13.1.3 Retail Rate Impacts 4-332
4.13.1.4 Hoover Dam Impacts 4-333
4.13.2 Summary of Hydropower Impacts 4-334
4.13.2.1 Monthly Water Release Impacts 4-334
4.13.2.2 Hydropower Power Generation and Capacity Impacts 4-340
4.13.2.3 Economic Impacts 4-343
4.13.2.4 Change in FES Wholesale Rates 4-349
4.13.2.5 Retail Rate and Bills Impacts 4-350
4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics 4-351
4.13.3 Alternative-Specific Impacts 4-353
4.13.3.1 Alternative A (No Action Alternative) 4-353
4.13.3.2 Alternative B 4-353
4.13.3.3 Alternative C 4-354
4.13.3.4 Alternative D (Preferred Alternative) 4-355
4.13.3.5 Alternative E 4-358
4.13.3.6 Alternative F 4-359
4.13.3.7 Alternative G 4-360

CONTENTS (Cont.)

4.14 Socioeconomics and Environmental Justice 4-362
4.14.1 Analysis Methods 4-362
4.14.1.1 Recreational Use and Environmental Non-Use Values 4-362
4.14.1.2 Recreational Economic Impacts 4-364
4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts 4-364
4.14.1.4 Environmental Justice 4-365
4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice 4-365
4.14.2.1 Recreational Use Values 4-365
4.14.2.2 Environmental Non-Use Values 4-378
4.14.2.3 Recreational Economic Impacts 4-379
4.14.2.4 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts 4-382
4.14.2.5 Environmental Justice Impacts 4-384
4.14.3 Alternative-Specific Impacts 4-390
4.14.3.1 Alternative A (No Action Alternative) 4-390
4.14.3.2 Alternative B 4-391
4.14.3.3 Alternative C 4-393
4.14.3.4 Alternative D (Preferred Alternative) 4-395
4.14.3.5 Alternative E 4-396
4.14.3.6 Alternative F 4-398
4.14.3.7 Alternative G 4-400
4.15 Air Quality 4-402
4.15.1 Analysis Methods 4-402
4.15.2 Summary of Impacts 4-403
4.15.3 Alternative-Specific Impacts 4-409
4.15.3.1 Alternative A (No Action Alternative) 4-409
4.15.3.2 Alternative B 4-409
4.15.3.3 Alternative C 4-410
4.15.3.4 Alternative D (Preferred Alternative) 4-410
4.15.3.5 Alternative E 4-410
4.15.3.6 Alternative F 4-411
4.15.3.7 Alternative G 4-411
4.16 Climate Change 4-411
4.16.1 Analysis Methods 4-412
4.16.1.1 Effects of LTEMP Alternatives on Climate Change 4-412
4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources 4-413
4.16.2 Summary of Impacts 4-414
4.16.2.1 Effects of LTEMP Alternatives on Climate Change 4-414
4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources 4-419

CONTENTS (Cont.)

4.16.3 Alternative-Specific Impacts 4-421
4.16.3.1 Alternative A (No Action Alternative)..... 4-421
4.16.3.2 Alternative B 4-424
4.16.3.3 Alternative C 4-424
4.16.3.4 Alternative D (Preferred Alternative)..... 4-424
4.16.3.5 Alternative E..... 4-425
4.16.3.6 Alternative F..... 4-425
4.16.3.7 Alternative G..... 4-426
4.17 Cumulative Impacts..... 4-426
4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts..... 4-426
4.17.1.1 Past and Present (Ongoing) Actions..... 4-427
4.17.1.2 Reasonably Foreseeable Future Actions 4-442
4.17.2 Climate-Related Changes..... 4-445
4.17.3 Cumulative Impacts Summary by Resource..... 4-446
4.17.3.1 Water Resources..... 4-446
4.17.3.2 Sediment Resources 4-457
4.17.3.3 Natural Processes 4-458
4.17.3.4 Aquatic Ecology..... 4-458
4.17.3.5 Vegetation 4-461
4.17.3.6 Wildlife..... 4-463
4.17.3.7 Cultural Resources 4-466
4.17.3.8 Tribal Resources..... 4-467
4.17.3.9 Recreation, Visitor Use, and Experience..... 4-468
4.17.3.10 Wilderness..... 4-469
4.17.3.11 Visual Resources..... 4-470
4.17.3.12 Hydropower..... 4-471
4.17.3.13 Socioeconomics and Environmental Justice 4-472
4.17.3.14 Air Quality and Climate Change..... 4-472
4.18 Unavoidable Adverse Impacts..... 4-474
4.19 Relationship between Short-Term Use and Long-Term Productivity..... 4-475
4.20 Irreversible and Irretrievable Commitments of Resources..... 4-475

5 CONSULTATION AND COORDINATION 5-1

5.1 Consultation and Coordination with Other Agencies and Programs 5-1
5.1.1 U.S. Department of the Interior 5-1
5.1.2 Cooperating Agencies..... 5-1
5.1.3 American Indian Tribes 5-2
5.1.4 Other Consultations 5-6
5.1.4.1 National Historic Preservation Act..... 5-6
5.1.4.2 State and Local Water and Power Agency Coordination..... 5-7
5.1.4.3 U.S. Fish and Wildlife Service..... 5-7

CONTENTS (Cont.)

5.2 Public Involvement 5-8
5.2.1 Public Scoping Process and Comments Received 5-8
5.2.2 Public Meetings on Alternatives 5-10
5.2.3 Glen Canyon Dam Adaptive Management Working Group 5-11
5.2.4 Public Involvement on the LTEMP DEIS 5-11

6 REFERENCES 6-1

7 LIST OF PREPARERS 7-1

8 GLOSSARY 8-1

APPENDIX A: Adaptive Management Working Group Desired Future Conditions A-1

A.1 Desired Future Conditions: Colorado River Ecosystem A-5
A.1.1 DFC Description A-5
A.1.2 DFC Background and Legislation A-6
A.1.3 Why the Colorado River Ecosystem DFCs Are Important A-6
A.1.4 Colorado River Ecosystem DFCs A-6
A.1.4.1 Sediment-Related Resources DFCs A-6
A.1.4.2 Water Quality DFCs A-7
A.1.4.3 Colorado River Ecosystem Aquatic Resource DFCs A-7
A.1.4.4 Colorado River Ecosystem Riparian Resource DFCs A-9
A.1.5 Colorado River Ecosystem DFCs Additional Information A-9
A.1.5.1 Colorado River Ecosystem Linkages A-9
A.1.5.2 Colorado River Ecosystem Metrics A-10
A.2 Power Desired Future Conditions A-10
A.2.1 Power DFC Description A-10
A.2.2 Power DFC Background and Legislation A-10
A.2.3 Why the Power DFC Is Important A-11
A.2.4 Power DFCs A-11
A.2.5 Power DFC Additional Information A-12
A.2.5.1 Power Linkages A-12
A.2.5.2 Power Metrics A-12
A.3 Cultural Resources Desired Future Conditions A-13
A.3.1 Cultural Resources DFC Description A-13
A.3.2 DFC Background and Legislation A-13
A.3.3 Why the Cultural Resources DFCs Are Important A-13
A.3.4 NRHP Eligible Historic Properties DFCs A-14
A.3.4.1 Prehistoric Archaeological Sites and Historic Sites A-14
A.3.4.2 Traditional Cultural Properties A-14
A.3.5 NRHP Eligible Historic Properties DFC Additional Information A-15
A.3.5.1 NRHP Eligible Historic Properties Linkages A-15

CONTENTS (Cont.)

A.3.5.2 NRHP Eligible Historic Properties Metrics A-16
A.3.6 Resources of Traditional Cultural Significance but Not NRHP Eligible A-16
A.3.7 Resources of Traditional Cultural Significance DFCs A-16
A.3.8 Resources of Traditional Cultural Significance Linkages A-17
A.3.9 Resources of Traditional Cultural Significance Metrics A-17
A.4 Recreation Desired Future Conditions A-17
A.4.1 Recreation DFC Description A-17
A.4.2 DFC Background and Legislation A-17
A.4.3 Why the Recreation DFC Is Important A-18
A.4.3.1 Grand Canyon National Park A-18
A.4.3.2 Glen Canyon National Recreation Area A-18
A.4.4 Recreation DFCs A-18
A.4.4.1 River Recreation in Grand Canyon National Park A-18
A.4.4.2 River Recreation in Glen Canyon National Recreation Area A-19
A.4.4.3 Blue Ribbon Trout Fishery in Glen Canyon National Recreation Area A-19
A.4.4.4 River Corridor Stewardship A-19
A.4.5 Recreation DFC Additional Information A-20
A.4.6 Recreation Linkages A-20
A.4.7 Recreation Metrics A-20
A.5 Reference A-21

APPENDIX B: Performance Metrics Used to Evaluate Alternatives B-1

B.1 Aquatic Ecology B-3
B.1.1 Humpback Chub B-3
B.1.2 Other Native Fish B-5
B.1.3 Trout Fishery B-5
B.1.4 Nonnative Aquatic Species B-6
B.2 Archaeological and Cultural Resources B-7
B.3 Hydropower and Energy B-9
B.4 Natural Processes B-10
B.5 Recreational Experience B-11
B.5.1 Grand Canyon Metrics B-11
B.5.2 Glen Canyon Metrics B-15
B.6 Riparian Vegetation B-16
B.7 Sediment B-18
B.8 Tribal Resources B-18
B.9 Water Delivery B-24
B.10 References B-25

CONTENTS (Cont.)

APPENDIX C: Decision Analysis to Support Development of the Glen Canyon Dam Long-Term Experimental and Management Plan C-1

APPENDIX D: Hydrology Technical Information and Analysis D-1

D.1 Analysis Methods D-3
D.1.1 Background D-3
D.1.2 Initial Conditions D-4
D.1.3 Reservoir Operations D-4
D.1.3.1 Upper Basin Reservoirs above Lake Powell D-4
D.1.3.2 Lake Powell and Lake Mead D-5
D.1.3.3 Lake Mohave and Lake Havasu D-9
D.1.4 Representation of the Different Alternatives in CRSS D-9
D.1.4.1 Experimental Components Modeled in CRSS D-22
D.1.5 Input Hydrology D-23
D.1.6 Input Demands D-26
D.1.7 Other Key Assumptions D-26
D.2 Supplemental Information on Impact Modeling D-27
D.2.1 Low Summer Flows D-27
D.2.2 Modeled Annual Releases Extending beyond the End of the Water Year D-28
D.2.3 Lake Elevation D-29
D.3 References D-36

APPENDIX E: Sediment Resources Technical Information and Analysis E-1

E.1 Introduction E-3
E.1.1 Analysis Period E-3
E.1.2 General Scope E-3
E.2 Methods E-4
E.2.1 Sand Budget Model E-4
E.2.1.1 Model Description E-4
E.2.1.2 Sand Budget Model Modifications E-5
E.2.1.3 Modified Sand Budget Model Inputs E-6
E.2.2 Sediment Metrics E-8
E.2.2.1 Sand Load Index E-9
E.2.2.2 Standard Deviation of High Flows E-9
E.2.2.3 Sand Mass Balance Index E-10
E.3 Results E-10
E.3.1 HFEs Determined by Alternative E-10
E.3.2 Metrics E-11
E.3.2.1 Sand Load Index E-12
E.3.2.2 Standard Deviation of High Flows E-12

CONTENTS (Cont.)

E.3.3 Sand Mass Balance Index E-12
E.3.4 Alternative Performance under Climate Change Scenarios E-13
E.3.5 Relative Impacts of Dam Operations and Hydrology on Performance E-13
E.4 Lake Deltas E-15
E.5 Limitations and Known Issues E-17
E.5.1 Geographic Scope E-17
E.5.2 Modeling Improvements E-17
E.6 References E-18

APPENDIX F: Aquatic Resources Technical Information and Analysis F-1

F.1 Introduction F-3
F.2 Aquatic Food Base Assessment F-4
F.2.1 Description of the Aquatic Food Base Downstream from Glen Canyon Dam F-4
F.2.1.1 The Aquatic Food Base Prior to Construction of Glen Canyon Dam F-5
F.2.1.2 The Aquatic Food Base of the Colorado River Downstream from Glen Canyon Dam F-5
F.2.1.3 Influence of New Zealand Mudsnail on the Aquatic Food Base F-13
F.2.2 Impacts of LTEMP Alternatives on the Aquatic Food Base F-14
F.2.2.1 Flow Effects on the Aquatic Food Base F-15
F.2.2.2 Temperature Effects on the Aquatic Food Base F-23
F.2.3 Conclusion F-26
F.3 Modeling Effects of LTEMP Alternatives on Rainbow Trout and Humpback Chub F-28
F.3.1 Model Overview F-28
F.3.1.1 Glen Canyon Trout Submodel F-29
F.3.1.2 Trout Movement Submodel F-36
F.3.1.3 Humpback Chub Population Submodel F-40
F.3.2 Results for LTEMP Alternatives F-52
F.3.2.1 Rainbow Trout Performance Measures F-52
F.3.2.2 Humpback Chub Performance Measures F-60
F.4 Modeling the Effects of LTEMP Alternatives on Temperature Suitability F-62
F.4.1 Model Overview F-64
F.4.2 Humpback Chub Aggregations F-67
F.4.2.1 Historic Temperature Suitability for Humpback Chub F-69
F.4.2.2 Results for LTEMP Alternatives F-70
F.4.3 Other Native Fish F-71
F.4.3.1 Historic Temperature Suitability for Native Fish F-73
F.4.3.2 Results for LTEMP Alternatives F-73

CONTENTS (Cont.)

F.4.4 Nonnative Fish F-78
F.4.4.1 Historic Temperature Suitability for Nonnative Fish F-79
F.4.4.2 Results for LTEMP Alternatives F-79
F.4.5 Aquatic Parasites F-81
F.4.5.1 Historic Temperature Suitability for Aquatic Parasites F-84
F.4.5.2 Results for LTEMP Alternatives F-86
F.5 References F-90

APPENDIX G: Vegetation Technical Information and Analysis G-1

G.1 Analysis Methods G-3
G.1.1 Old High-Water Zone Analysis G-4
G.1.2 New High-Water Zone G-5
G.1.2.1 Native Cover Metric G-6
G.1.2.2 Native Diversity Metric G-7
G.1.2.3 Native/Nonnative Ratio Metric G-7
G.1.2.4 Arrowweed Metric G-8
G.1.2.5 Overall Score G-8
G.1.3 Wetlands G-9
G.2 Alternative-Specific Impacts G-10
G.2.1 Alternative A (No Action Alternative) G-10
G.2.2 Alternative B G-10
G.2.3 Alternative C G-10
G.2.4 Alternative D (Preferred Alternative) G-11
G.2.5 Alternative E G-11
G.2.6 Alternative F G-12
G.2.7 Alternative G G-12
G.3 Summary G-12
G.4 References G-13

APPENDIX H: Cultural Resources Technical Information and Analysis H-1

H.1 Wind Transport of Sediment H-3
H.1.1 Wind Transport of Sediment—Methods H-4
H.1.2 Wind Transport of Sediment—Results H-5
H.2 Flow Effects on Cultural Resources in Glen Canyon H-8
H.2.1 Flow Effects on Cultural Resources in Glen Canyon—Methods H-9
H.2.2 Flow Effects on Cultural Resources in Glen Canyon—Results H-10
H.3 Time Off River H-13
H.3.1 Time Off River—Methods H-13
H.3.2 Time Off River—Results H-14
H.4 References H-16

CONTENTS (Cont.)

APPENDIX I: Tribal Resources Technical Information and Analysis I-1

I.1 Quantifiable Measures Used to Assess Impacts on Tribal Resources..... I-4
I.1.1 Riparian Diversity..... I-4
I.1.2 Wetland Abundance..... I-8
I.1.3 Trout Management Flows..... I-10
I.1.4 Mechanical Removal of Trout..... I-12
I.1.5 Water Levels at Lake Powell..... I-14
I.1.6 Access to Resources..... I-17
I.2 References..... I-18

APPENDIX J: Recreation, Visitor Use, and Experience Technical Information and Analysis..... J-1

J.1 Recreational Experience Metrics..... J-3
J.1.1 Grand Canyon Metrics..... J-4
J.1.2 Glen Canyon Metrics..... J-4
J.2 Metric Definitions, Analysis Methods, and Results..... J-5
J.2.1 Camping Area Index..... J-5
J.2.1.1 Camping Area Index—Methods..... J-6
J.2.1.2 Camping Area Index—Results..... J-7
J.2.2 Navigational Risk Index..... J-8
J.2.2.1 Navigational Risk Index—Methods..... J-9
J.2.2.2 Navigational Risk Index—Results..... J-10
J.2.3 Fluctuation Index..... J-11
J.2.3.1 Fluctuation Index—Methods..... J-12
J.2.3.2 Fluctuation Index—Results..... J-13
J.2.4 Time Off River..... J-14
J.2.4.1 Time Off River Index—Methods..... J-14
J.2.4.2 Time Off River Index—Results..... J-15
J.2.5 Glen Canyon Rafting Use..... J-15
J.2.5.1 Glen Canyon Rafting Use Metric—Methods..... J-17
J.2.5.2 Glen Canyon Rafting Use Metric—Results..... J-18
J.2.6 Glen Canyon Inundation Metric..... J-18
J.2.6.1 Glen Canyon Inundation Metric—Methods..... J-19
J.2.6.2 Glen Canyon Inundation Metric—Results..... J-21
J.3 Lake Powell and Lake Mead Dock Access..... J-21
J.4 Summary..... J-26
J.5 References..... J-26

CONTENTS (Cont.)

APPENDIX K: Hydropower Systems Technical Information and Analysis K-1

K.1 Economic Value of Glen Canyon Dam Powerplant Capacity and Energy Production K-3
K.1.1 Power Systems Background K-3
K.1.2 Glen Canyon Dam, Reservoir, and Powerplant Background K-5
K.1.3 Power Systems Geographic Scope K-8
K.1.3.1 Top Tier: General Western Interconnection Perspective Modeling K-9
K.1.3.2 Middle Tier: LTF Customer Utility Systems K-11
K.1.3.3 Bottom Tier: WAPA SLCA/IP Hydropower Resources K-15
K.1.4 Overview of Power Systems Methods K-16
K.1.5 Description of Individual Power System Models K-20
K.1.5.1 Colorado River Simulation System Model K-20
K.1.5.2 Representative Trace Tool K-21
K.1.5.3 Hydropower Outage Model K-21
K.1.5.4 Generation and Transmission Maximization-Lite K-21
K.1.5.5 Sand Budget Model K-29
K.1.5.6 Large SLCA/IP Powerplant Spreadsheets K-29
K.1.5.7 Small SLCA/IP Powerplant Spreadsheet K-30
K.1.5.8 Loads Shaping Algorithm K-30
K.1.5.9 AURORA K-31
K.1.5.10 LMP Calibration Spreadsheet K-34
K.1.5.11 Firm Capacity Spreadsheet K-35
K.1.6 SLCA/IP Market System, Data Sources, and Model K-38
K.1.6.1 Historical Data Sources K-38
K.1.6.2 AURORA Model Dispatch Results for 2013 ..... K-42
K.1.6.3 SLCA/IP Market System Projections K-43
K.1.7 Glen Canyon Dam Powerplant Capacity Cost and Benefit Methodology K-59
K.1.7.1 Treatment of Glen Canyon Dam Capital and Fixed O&M Costs K-61
K.1.7.2 WAPA's SLCA/IP LTF Obligations and Glen Canyon Dam Replacement Capacity K-61
K.1.7.3 WAPA SLCA/IP Firm Hydropower Capacity K-62
K.1.7.4 Firm Capacity Curves for LTEMP Power Systems Analyses for the Peak Month of August K-79
K.1.7.5 AURORA Capacity Expansion Reserve Margin Targets and Capacity Additions K-82
K.1.7.6 Dispatch Performed by AURORA Model Capacity Expansion Runs K-86
K.1.7.7 Rationale for the Selection of Hydrology Conditions Used for Capacity Expansion Runs K-90

CONTENTS (Cont.)

K.1.8 Glen Canyon Dam Energy Economic Benefits Methodology K-90
K.1.9 Net Present Value Calculations and Study Period Adjustments K-94
K.1.10 Power Systems Results K-96
K.1.10.1 Main Drivers of Differences among Alternatives K-97
K.1.10.2 Capacity Expansion Modeling K-101
K.1.10.3 Economic Impacts K-108
K.1.10.4 Sensitivity of Results to Exceedance Level K-116
K.1.10.5 Sensitivity of Results to Discount Rate K-121
K.1.10.6 Sensitivity of Results to the Base Capacity Expansion Path K-121
K.1.10.7 Sensitivity of Results to the Assumed Future Hydrological Conditions K-123
K.1.10.8 Sensitivity of Results to Changes in Ancillary Services K-125
K.1.10.9 Sensitivity of Results to Customer Capacity Expansion Assumptions K-129
K.1.10.10 Summary of Economic Ranking K-131
K.2 WAPA's SLCA/IP Firm Electric Service Rate Impacts K-131
K.2.1 Relationship between the Economic Impacts of LTEMP Alternatives and Impacts on SLCA/IP FES Rates K-133
K.2.2 Temporal Scope of the Analysis and Input Data K-133
K.2.3 SLCA/IP Rate Setting K-134
K.2.4 Calculation of Net Electrical Energy Expense K-135
K.2.4.1 SLCA/IP Electrical Production K-135
K.2.4.2 Sustainable Hydropower and Available Hydropower Capacity and Energy K-135
K.2.5 Calculation of Capacity Expenses and Total Net Costs K-139
K.2.6 WAPA Replacement Resources K-143
K.2.7 Post-2024 Marketing Period K-144
K.2.8 Power Repayment Studies to Determine Rate Impacts K-146
K.2.8.1 PRS Expenses K-146
K.2.8.2 PRS Revenue Distribution K-149
K.2.8.3 The SLCA/IP PRS K-149
K.2.8.4 Standard PRS Rate-Setting Method Versus the Method Used in This Analysis K-150
K.2.9 Results K-150
K.2.9.1 Pinch-Point Year K-152
K.2.10 Definitions Used in Section K.2 ..... K-153
K.3 Impacts on Retail Electricity Rates K-154
K.3.1 Analysis Approach K-154
K.3.1.1 Database of Sales, Rates, and SLCA/IP Allocation for Retail Utility Systems K-156
K.3.1.2 Incorporation of Power Systems Analysis and Capital Recovery Factors K-158

CONTENTS (Cont.)

K.3.1.3 Inflation Rates, Sales Growth, and Interest Rates from EIA K-161
K.3.1.4 Calculation Process for Computing Rate and Bill Impacts K-162
K.3.2 Results K-167
K.3.2.1 Grid Cost Changes Relative to WAPA Wholesale Revenues K-168
K.3.2.2 Retail Rate Changes for Individual Systems and SLCA/IP Power Relative to Total Resources K-169
K.3.2.3 Using Regression Equations to Approximate Retail Rate Changes for Systems Not Included in the Database K-171
K.3.3 Summary of Impacts K-172
K.3.3.1 Average Rate Impacts under LTEMP Alternatives over the 20-Year LTEMP Period K-172
K.3.3.2 Average Year-by-Year Rate Impacts K-174
K.3.3.3 Individual System Impacts and Summary Descriptions of LTEMP Alternatives K-179
K.3.4 Impacts on Small Systems K-185
K.3.5 Alternative-Specific Impacts K-187
K.3.5.1 Alternative A K-187
K.3.5.2 Alternative B K-187
K.3.5.3 Alternative C K-188
K.3.5.4 Alternative D K-189
K.3.5.5 Alternative E K-189
K.3.5.6 Alternative F K-190
K.3.5.7 Alternative G K-190
K.4 Financial Impacts of LTEMP Alternatives on American Indian Tribes K-190
K.4.1 Contractual Requirements for Calculating and Delivering Benefits to Tribes K-192
K.4.2 Calculation of Tribal Benefit Baseline under Alternative A (No Action Alternative) K-193
K.4.3 Calculation of Change in Tribal Benefit as a Result of LTEMP EIS Alternatives K-193
K.4.4 Impacts on Tribes through a Change in the Retail Rate of the Electrical Supplier to Tribal Lands K-194
K.4.5 Calculation of Tribal Impacts for Tribes That Are Direct SLCA/IP Recipients K-195
K.4.6 Total Impact of LTEMP EIS Alternatives: Benefit Change and Rate Effect K-196
K.4.7 Total Impact on Tribes and Tribal Members Versus Retail Rate Changes to Households K-202
K.4.8 Conclusions K-202
K.5 Impacts of LTEMP Alternatives on Lake Mead and the Hoover Dam Powerplant K-206

CONTENTS (Cont.)

K.5.1 Hoover Analysis Methods, Model, and Supporting Data K-209
K.5.2 Hoover Monthly Energy Production and Water-to-Power Conversion K-210
K.5.3 Hoover Maximum Operational Capacity and Firm Capacity K-213
K.5.4 Economic Value of Hoover Powerplant Energy K-213
K.5.5 Sensitivity of Model Results K-214
K.6 References K-215
Attachment K.1: Geographic Scope of the Analysis K-219
Attachment K.2: AURORA Western Interconnection Spot Market Energy Prices Adjustments K-223
Attachment K.3: Selection of Representative Trace K-226
Attachment K.4: Discounting Procedures K-244
Attachment K.5: Forced Outage Scenario Generation for Hydroelectric Power Facilities K-247
Attachment K.6: Forecast of Monthly Peak Loads and Energy by SLCA/IP Long-Term Firm Customer K-250
Attachment K.7: Analysis of the Timing of the Peak Load K-252
Attachment K.8: Analysis of Capacity Determinations — Comparing Results Using a Range of Exceedence Levels and Two Summer Peak Months K-258
Attachment K.9: Results of a Survey of Electric Utility Integrated Resource Plans K-260
Attachment K.10: Indices Used for Converting Dollars from One Year to Another K-270
Attachment K.11: Summary IRP of Capacity Additions in the Joint System and Surrounding Utility Systems through the End of CY2034 ..... K-275
Attachment K.12: Annual SLCA/IP Allocations to American Indian Tribes and Benefit Information K-277

APPENDIX L: Socioeconomic Technical Information and Analysis L-1

L.1 Recreation Economic Analyses L-3
L.1.1 Recreation Use Values L-3
L.1.1.1 Lake_Full Utility Model L-4
L.1.1.2 GCRec_Full Utility Model L-5
L.1.2 Recreation Non-Use Values L-6
L.1.3 Regional Recreation Economic Impacts L-10
L.1.4 Estimates of Recreational Economic Impacts L-12
L.2 Regional Electricity Analyses L-13
L.2.1 Regional Electricity Price Impacts L-13
L.2.2 Regional Electricity Generating Capacity Expansion Impacts L-15
L.3 Additional Socioeconomic Data L-15
L.3.1 Urban Population in the Six-County Region L-15
L.3.2 Urban Income in the Six-County Region L-20
L.4 References L-21

CONTENTS (Cont.)

APPENDIX M: Air Quality and Climate Change Technical Information and Analysis M-1

M.1 Analysis Methods M-4
M.1.1 System Power Generation M-4
M.1.2 Spot Market M-5
M.1.3 Generation Type M-6
M.2 Results M-6
M.2.1 SO_2 and NO_X M-6
M.2.2 GHG Emissions M-8
M.3 References M-9

APPENDIX N: Government-to-Government and National Historic Preservation Act Consultation N-1

N.1 Government-to-Government Consultation N-3
N.2 Consultation with the State Historic Preservation Office N-31
N.3 Reference N-31
Attachment N.1 ..... N-33
Attachment N.2 ..... N-75
Attachment N.3 ..... N-137

APPENDIX O: Biological Assessment for the Glen Canyon Dam Long-Term Experimental and Management Plan O-1

APPENDIX P: High-Flow Experiment Protocol for the Preferred Alternative P-1

P.1 Decision-Making Process P-3
P.1.1 Planning P-4
P.1.2 Modeling P-5
P.1.3 Decision and Implementation P-8
P.2 Operation of Glen Canyon Dam under the HFE Protocol P-9
P.2.1 Potential Operation of Glen Canyon Dam during the Fall HFE Implementation Window P-10
P.2.2 Potential Operation of Glen Canyon Dam during the Spring HFE Implementation Window P-10
P.3 High Flow Experiments to be Evaluated under the Preferred Alternative P-11
P.3.1 Sediment-Triggered Spring HFEs P-11
P.3.2 Proactive Spring HFEs P-12
P.3.3 Sediment-Triggered Fall HFEs P-13
P.3.4 Extended-Duration Fall HFEs P-13
REFERENCES P-14

APPENDIX Q: Responses to Public Comments on the Glen Canyon Dam Long-Term Experimental and Management Plan Draft Environmental Impact Statement Q-1

FIGURES

1-1 Generalized Locations of Glen Canyon Dam, Lake Powell, the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands 1-5

1-2 Glen Canyon Dam..... 1-6

1-3 Map of the Colorado River between Lake Powell and Lake Mead 1-20

1-4 Indian Reservations within or Adjacent to the LTEMP EIS Project Area..... 1-25

2-1 Mean, Minimum, and Maximum Daily Flows under Alternative A in an 8.23-maf Year Based on Values Presented in Table 2-3 2-18

2-2 Simulated Hourly Flows under Alternative A in an 8.23-maf Year 2-18

2-3 Simulated Hourly Flows under Alternative A for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-19

2-4 Mean, Minimum, and Maximum Daily Flows under Alternative B in an 8.23-maf Year Based on Values Presented in Table 2-4 2-21

2-5 Simulated Hourly Flows under Alternative B in an 8.23-maf Year 2-22

2-6 Simulated Hourly Flows under Alternative B for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-22

2-7 Example Mean, Minimum, and Maximum Daily Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year 2-24

2-8 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B in an 8.23-maf Year..... 2-24

2-9 Simulated Hourly Flows for a Hydropower Improvement Experiment under Alternative B for a Week in July in an 8.23-maf Year 2-25

2-10 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-5.... 2-26

2-11 Simulated Hourly Flows under Alternative C in an 8.23-maf Year 2-28

2-12 Simulated Hourly Flows under Alternative C for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-28

2-13 Decision Tree for Sediment-Related Actions under Alternative C..... 2-29

FIGURES (Cont.)

2-14 Decision Tree for Humpback Chub-Related Actions under Alternative C 2-30

2-15 Example Implementation of a Two-Cycle TMF in June and July with Resumption of Normal Fluctuations between Cycles and Afterward 2-40

2-16 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative C in an 8.23-maf Year Based on the Values Presented in Table 2-6 2-42

2-17 Mean, Minimum, and Maximum Daily Flows under Alternative D in an 8.23-maf Year Based on Values Presented in Table 2-8 2-45

2-18 Simulated Hourly Flows under Alternative D in an 8.23-maf Year 2-47

2-19 Simulated Hourly Flows under Alternative D for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-47

2-20 Decision Tree for Implementation of Sediment-Related Experimental Treatments under Alternative D..... 2-55

2-21 Decision Tree for Implementation of Aquatic Resource-Related Experimental Treatments under Alternative D..... 2-56

2-22 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of Alternative D in an 8.23-maf Year Based on the Values Presented in Table 2-10 2-69

2-23 Mean, Minimum, and Maximum Daily Flows under Alternative E in an 8.23-maf Year Based on the Values Presented in Table 2-11 2-74

2-24 Simulated Hourly Flows under Alternative E in an 8.23-maf Year..... 2-74

2-25 Simulated Hourly Flows under Alternative E for a Week in July in an 8.23-maf Year Showing Typically Lower Weekend Flows 2-75

2-26 Decision Tree for Sediment-Related Actions under Alternative E 2-76

2-27 Decision Tree for Trout-Related Actions under Alternative E..... 2-77

2-28 Mean, Minimum, and Maximum Daily Flows under Base Operations of Alternative F in an 8.23-maf Year Based on the Values Presented in Table 2-12 2-82

FIGURES (Cont.)

2-29 Mean, Minimum, and Maximum Daily Flows under Alternative G in an 8.23-maf Year Based on Values Presented in Table 2-13 2-83

3.1-1 LTEMP Project Area and Surrounding Lands 3-2

3.2-1 Map of Lake Powell and Associated Major Tributaries 3-8

3.2-2 Pattern of Annual Historic Flows at Lees Ferry 3-12

3.2-3 Map of Lake Mead and Associated Major Tributaries 3-13

3.2-4 Profile of Lake Powell from Glen Canyon Dam to the Inflow of the Colorado River 3-16

3.2-5 Water Temperature at Lees Ferry 3-18

3.2-6 Water Temperatures at Four Stations along the Colorado River from Lees Ferry to Diamond Creek, 1995–2014 3-21

3.2-7 Mid-June Warming above Release Temperatures Measured at Diamond Creek, 1994–2004, as a Function of Mean Weekly Discharge 3-22

3.3-1 Geomorphic Features of the Colorado River 3-36

3.3-2 Schematic Diagram of the Fan-Eddy Complex on the Colorado River 3-38

3.3-3 River Cross Section Depicting Sediment Entrapment and Sandbar Building 3-38

3.3-4 Aeolian and Fluvial Sand Deposits along the Colorado River 3-40

3.3-5 Debris Fans and Variation in Water-Surface Elevation and Channel Width for Colorado River Flows below Glen Canyon Dam 3-42

3.3-6 Comparison of Sandbars Used as Campsites, based on Inventories Conducted in 1973, 1983, and 1991 3-42

3.3-7 Repeated Photography Illustrating Sediment Losses and Sandbar Changes along the Colorado River 3-44

3.3-8 Annual Sediment Contributions from the Paria and Little Colorado Rivers 3-49

3.3-9 Matched Photographs of RM 172 Illustrating Positive Depositional Response to the 2008 HFE 3-52

FIGURES (Cont.)

3.3-10 Conceptual Diagram of the Dependency between Net Sandbar Size, Duration and Frequency of HFEs, and Post-HFE Erosion Rates 3-54

3.3-11 Average Campsite Area above the References Stage: before, after, and 6 Months following the 2008 HFE 3-55

3.3-12 Longitudinal Profiles of the Mainstem Colorado Riverbed Upstream of the Hoover Dam in 1935, 1948, 1963, and 2001 3-57

3.5-1 Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fishes of the Colorado River System below Glen Canyon Dam 3-71

3.5-2 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead 3-74

3.5-3 Estimated Adult Humpback Chub Abundance from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age 3-75

3.5-4 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September, 2009 through 2012 3-76

3.5-5 Water Temperatures at Lees Ferry and the Little Colorado River Confluence, 1995 to Present 3-81

3.5-6 Mean Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2013 3-96

3.5-7 Mean Electrofishing Catch Rates of Brown Trout in the Colorado River between Lees Ferry and Lake Mead, 2000–2009 3-99

3.6-1 Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam ... 3-114

3.7-1 Riparian Zones Used by Nesting Birds 3-124

3.7-2 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor 3-135

3.8-1 Spencer Steamboat 3-148

3.8-2 A Roasting Pit Feature in a Grand Canyon Dune 3-148

FIGURES (Cont.)

3.8-3 An Archaic Period Site on the Colorado River in GCNP 3-151

3.8-4 Glen Canyon Linear Style Petroglyph in GCNRA 3-151

3.8-5 Puebloan Era Architecture along the Colorado River in GCNP 3-152

3.8-6 Lees Ferry and Lonely Dell Ranch Historic District Located in GCNRA 3-155

3.10-1 Glen Canyon Reach Rainbow Trout 3-170

3.10-2 Mean Rainbow Trout Catch Per Unit Effort of Both Boat Anglers and Shore-Line Anglers from Creel Surveys at Lees Ferry 3-171

3.10-3 Fishing User Days by Month in the Glen Canyon Reach for 2006 and 2009..... 3-172

3.10-4 Angler Days in the Glen Canyon Reach from 1965 through 2011 3-173

3.10-5 Designated Campsite Areas in the Glen Canyon Reach 3-175

3.10-6 Shoreline Environment with Steep Erosion Banks at Glen Canyon Reach Ferry Swale Campsite 3-176

3.10-7 Pontoon Raft Operated by Colorado River Discovery..... 3-176

3.10-8 Boating in Grand Canyon, Anticipated Annual Use by Month 3-179

3.10-9 Change in Camp Size over Time in the Lees Ferry to Diamond Creek Reach of GCNP..... 3-181

3.10-10 Total High-Elevation Campsite Area for Each Survey between 1998 and 2006 3-182

3.10-11 High-Elevation Campsite Area in Critical and Noncritical Reaches between 1998 and 2006..... 3-182

3.12-1 Glen Canyon Viewed from the Colorado River 3-194

3.12-2 Horseshoe Bend 3-194

3.12-3 Typical View of the Colorado River and Grand Canyon Afforded Recreationists on a River Trip 3-196

3.12-4 Colorado River and Granaries at Nankoweap..... 3-196

FIGURES (Cont.)

3.12-5 Entrance to Havasu Canyon 3-197

3.12-6 Vasey's Paradise 3-197

3.14-1 Minority Population Groups in the 11-County Area 3-219

3.14-2 Low-Income Population Groups in the 11-County Area 3-220

3.15-1 Nonattainment Areas for SO_2, 8-Hour O_3, $PM_{2.5}$, PM_{10}, and Pb in the 11-State Area 3-233

3.15-2 PSD Class I Areas in the 11-State Affected Area 3-235

3.16-1 Historical Supply and Use and Projected Future Colorado River Basin Water Supply and Demand 3-238

4-1 Integrated Multiple-Resource Modeling Framework Showing Inputs, Intermediate Calculations, and Output 4-3

4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values 4-6

4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes 4-22

4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-24

4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios 4-27

4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios..... 4-29

4.2-5 Lake Powell and Lake Mead End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives 4-32

4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces and Seven Alternatives 4-33

FIGURES (Cont.)

4.2-7 Percentage of Time in Different Operating Tier than Alternative 4-34

4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces..... 4-35

4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces..... 4-36

4.2-10 Frequency of Occurrence of Modeled Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives 4-37

4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases 4-39

4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives..... 4-40

4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives 4-42

4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry 4-46

4.3-1 Conceptual Depiction of the Sand Load Index 4-67

4.3-2 Conceptual Depiction of the Sand Mass Balance Model..... 4-68

4.3-3 Variation in Lake Powell Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-75

4.3-4 Variation in Lake Mead Pool Elevation Relative to Full for 21 Hydrology Traces and Seven Alternatives..... 4-76

4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives..... 4-77

4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-78

4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives 4-79

4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem..... 4-89

FIGURES (Cont.)

4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios 4-121

4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives 4-123

4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives 4-124

4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-125

4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-127

4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations 4-129

4.5-7 Mean Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence and at Pumpkin Spring under Each Alternative..... 4-130

4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives 4-131

4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam 4-135

4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam..... 4-136

4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam..... 4-177

FIGURES (Cont.)

4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-178

4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model 4-179

4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model 4-187

4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives 4-243

4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives 4-245

4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives 4-288

4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS 4-326

4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives 4-341

4.13-3 Total NPV of Hoover Powerplant Energy over a 20-Year Period under LTEMP Alternatives 4-352

4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period 4-407

4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change 4-415

4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces 4-416

4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives 4-420

D-1 Operating Tiers as Specified by the 2007 Interim Guidelines for the Operations of Lake Powell and Lake Mead D-7

D-2 Monthly Releases for Each Alternative in an 8.23-maf Release Year D-21

FIGURES (Cont.)

D-3 Locations of CRSS 29 Natural Flow Nodes D-24

D-4 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell Annual Inflow, Lake Powell Water-Year Release Volume, and Lake Powell Monthly Release Volume D-25

D-5 Comparison of CRSS Results Generated Using 105 Traces and 21 Traces for Lake Powell End-of-December Water Elevations at the 10th, 50th, and 90th Percentiles D-25

D-6 Occurrences of Low Summer Flows in Applicable Alternatives D-28

D-7 Frequency of Occurrence of Modeled Annual Releases Extending beyond the End of the Water Year per 20-yr Trace for Each of the Alternatives D-29

D-8 Median Volume of Modeled Annual Releases Extending beyond the End of the Water-Year Releases by Trace for Each of the Alternatives D-30

D-9 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and B D-30

D-10 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and C D-31

D-11 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and D D-31

D-12 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and E D-32

D-13 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and F D-32

D-14 Lake Powell and Lake Mead End-of-December Pool Elevation for 21 Hydrology Traces under Alternatives A and G D-33

D-15 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and B D-33

D-16 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and C D-34

FIGURES (Cont.)

D-17 Percentage of Traces below Lake Powell's Minimum Power and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and D D-34

D-18 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and E D-35

D-19 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and F D-35

D-20 Percentage of Traces below Lake Powell's Minimum Power Pool and Percentage of Traces with a Lower Basin Shortage for 21 Hydrology Traces under Alternatives A and G D-36

E-1 Comparison of Calendar, Water, and Sediment Years E-20

E-2 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output E-21

E-3 Conceptual Schematic of the Sand Budget Model E-22

E-4 Historical Paria Sediment Load per Accounting Period and the 20.5-year Load for the Trace That Begins in Each Fall Accounting Period E-22

E-5 Sediment Traces s1, s2, and s3 for the Paria River Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-6 Little Colorado River Sediment Traces for s1, s2, and s3 Used in the Modeling to Account for Uncertainty in Future Delivery E-23

E-7 Conceptual Representation of the Sand Mass Balance Index E-24

E-8 Average Sediment and Hydrology Triggered HFE Count by Type for Each Long-Term Strategy E-24

E-9 Average HFE Count for Sediment Traces s1, s2, and s3 for Each Long-Term Strategy E-25

E-10 Definition of the Statistics Represented by the Box and Whisker Plots Used in This Analysis E-25

FIGURES (Cont.)

E-11 Sand Load Index Statistics from 63 Simulations for Each Long-Term Strategy..... E-26

E-12 Standard Deviation of High Flows Statistics from 63 Simulations for Each Long-Term Strategy E-26

E-13 Correlation between SDHF and SLI E-27

E-14 Sand Mass Balance Index Statistics from 63 Simulations for Each Long-Term Strategy E-27

E-15 Correlation between SMBI and SLI E-28

E-16 Sand Load Index for Long-Term Strategies Using Climate Change Weights..... E-28

E-17 Comparison of the Sand Load Index between Climate Change and Historical Weights E-29

E-18 Standard Deviation of High Flows Using Climate Change Weights..... E-29

E-19 Comparison of the Standard Deviation of High Flows between Climate Change and Historical Weights E-30

E-20 Sand Mass Balance Index Using Climate Change Weights E-30

E-21 Comparison of the Sand Mass Balance Index between Climate Change and Historical Weights E-31

E-22 Comparison of Long-Term Strategies C1 and C2 for Hydrology Trace 1, Sediment Trace 3 ..... E-31

E-23 SMBI for Alternative E Plotted against Alternative C E-32

E-24 SLI for Alternative E Plotted against Alternative C E-32

E-25 Load-Following Curtailment Effects on SLI and SMBI..... E-33

E-26 Low Summer Flows for WY 2014, Hydrology Trace 1, Sediment Trace 1 ..... E-34

E-27 Hydrology Impacts on the Sand Load Index E-35

E-28 Hydrology Impacts on the Sand Mass Balance Index E-35

E-29 Conceptual Diagram of Water Surface Elevation Affecting Delta Location..... E-36

FIGURES (Cont.)

E-30 Historical Cumulative Sand Load Leaving Marble Canyon and Reaching the Gage above Diamond Creek E-36

E-31 Hydrology Impacts of Lake Powell Pool Elevations by Month across Alternatives E-37

E-32 Hydrology Impacts of Lake Mead Pool Elevations by Month across Alternatives E-37

F-1 Fit of Regressions Predicting the Log of Recruitment of Rainbow Trout in the Glen Canyon Reach Estimated by the Korman et al. Stock Synthesis Model as a Function of the Annual Release Volume from Glen Canyon Dam, the Range of Mean Daily Flows during May–August, and the Maximum Flow Each Year.... F-31

F-2 Relationship between Annual Estimates of the Asymptotic Length of Rainbow Trout in Lees Ferry Predicted by the Stock Synthesis Model as a Function of the Estimated Abundance for Fish >150 mm Each Year..... F-32

F-3 The Relationship between Annual Recruitment of Rainbow Trout in Lees Ferry Estimated by the Korman et al. Stock Synthesis Model and the Number of Trout That Emigrate from Lees Ferry into Marble Canyon the Following Year F-35

F-4 Fit of the Glen Canyon Rainbow Trout Simulation Model to Predictions of Recruitment, Asymptotic Length, and the Number of Out-migrants Predicted by the Korman et al. Stock Synthesis Model F-37

F-5 Predicted and Observed Annual Catch of Rainbow Trout by Year and River Reach..... F-41

F-6 Best-Fitting Distributions Describing Monthly Movement of Rainbow Trout in Marble Canyon Assuming Either a Normal or Cauchy Distribution..... F-43

F-7 Visual Summary of Humpback Chub Population Model Structure..... F-44

F-8 Modeled Effects of Trout Abundance and Temperature on Humpback Chub Survival and Growth F-48

F-9 Simulated Adult Abundances from Backcasted Model Compared to Patterns Reported in Coggins and Walters F-51

F-10 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under LTEMP Alternatives and Long-Term Strategies F-54

FIGURES (Cont.)

F-11 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-55

F-12 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and the Mean Number of Rainbow Trout Exceeding 16 in. Total Length during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-56

F-13 Modeled Mean Annual Angler Catch Rate for Rainbow Trout in the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-57

F-14 Relationship between Modeled Mean Rainbow Trout Abundance in the Glen Canyon Reach and Mean Angler Catch Rates during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies..... F-58

F-15 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-59

F-16 Modeled Frequency of Triggered Mechanical Removal for Rainbow Trout in the Little Colorado River Reach during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-61

F-17 Modeled Minimum Population Size for Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-62

F-18 Relationship between Modeled Mean Numbers of Rainbow Trout Out-migrants from the Glen Canyon Reach and the Modeled Mean Minimum Abundance of Adult Humpback Chub during the 20-year LTEMP Period under the LTEMP Alternatives and Long-Term Strategies F-63

F-19 Suitability for Spawning, Egg Incubation, and Growth of Humpback Chub as a Function of Water Temperature F-68

F-20 Months for Which Annual Temperature Suitability for Specific Life History Aspects of Humpback Chub Were Calculated..... F-68

F-21 Modeled Historic Water Temperatures in the Colorado River at Humpback Chub Aggregation Locations, Water Years 1990–2012 ..... F-70

FIGURES (Cont.)

F-22 Output from the Temperature Suitability Model for Humpback Chub Aggregation Locations Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-71

F-23 Mainstem Temperature Suitability for Humpback Chub Aggregation Locations under LTEMP Alternatives and Long-Term Strategies F-72

F-24 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Native Fish Species F-74

F-25 Months for Which Temperature Suitability for Specific Life History Aspects Were Considered for Native Fish Species F-74

F-26 Modeled Historic Water Temperatures in the Colorado River Downstream of Glen Canyon Dam, Water Years 1990–2012 ..... F-75

F-27 Annual Temperature Suitability Scores for Growth, Spawning, and Egg Incubation of Native Fish Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-76

F-28 Annual Temperature Suitability Scores for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-29 Mean Annual Overall Temperature Suitability for Native Fish by Assessment Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-77

F-30 Mean Annual Mainstem Temperature Suitability for Native Fish under LTEMP Alternatives and Long-Term Strategies at RM 61, RM 157, and RM 225, and Overall Mean for RM 61–225 ..... F-78

F-31 Suitability of Water Temperatures for Spawning, Egg Incubation, and Growth of Nonnative Fish Species F-80

F-32 Months during Which Temperature Suitability for Specific Life History Aspects Were Calculated for Nonnative Fish Species F-81

F-33 Annual Temperature Suitability Scores for Spawning, Incubation, and Growth of Nonnative Fish Species at RM 225 Based on Modeled Temperatures for Water Years 1990 to 2012 ..... F-82

F-34 Mean Annual Temperature Suitability Scores for Nonnative Fish Species and for Temperature Groups by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-83

FIGURES (Cont.)

F-35 Mean Annual Overall Temperature Suitability Scores for Coldwater and Warmwater Nonnative Fish Species Groups Based on Modeled Historic Temperatures for Water Years 1990–2012 ..... F-83

F-36 Mean Annual Mainstem Temperature Suitability for Coldwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 15, RM 61, RS 157, and RM 225 ..... F-84

F-37 Mean Annual Mainstem Temperature Suitability for Warmwater Nonnative Fish under LTEMP Alternatives and Long-Term Strategies at RM 0, RM 61, RM 157, and RM 225 ..... F-85

F-38 Suitability of Various Water Temperatures for Host Activity and Infestation Rates of Parasite Species F-86

F-39 Annual Temperature Suitability Scores for Parasite Species at RM 225 Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-40 Mean Annual Temperature Suitability Scores for Parasite Species by River Location Based on Modeled Water Temperatures for Water Years 1990–2012 ..... F-87

F-41 Overall Means of Annual Suitability Scores for Parasite Species across All River Locations during the 1990–2012 Water Years F-88

F-42 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives and Long-Term Strategies for Aquatic Fish Parasites at Four Locations Downstream of Glen Canyon Dam F-89

G-1 Native Cover Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-2 Native Cover Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-46

G-3 Native Diversity Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-4 Native Diversity Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-47

G-5 Native/Nonnative Ratio Metric for the LTEMP Alternatives and Associated Long-Term Strategies G-48

FIGURES (Cont.)

G-6 Native/Nonnative Ratio Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term G-48

G-7 Arrowweed Metric for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less G-49

G-8 Arrowweed Metric under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies; Higher Values Indicate Less Arrowweed G-49

G-9 Overall Combined Score for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-10 Overall Combined Score under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-50

G-11 Relative Change in Wetland Cover for the LTEMP Alternatives and Associated Long-Term Strategies G-51

G-12 Relative Change in Wetland Cover under Climate Change for the LTEMP Alternatives and Associated Long-Term Strategies G-51

H-1 Wind Transport of Sediment Index Values for the LTEMP Alternatives and Associated Long-Term Strategies H-6

H-2 Average Number of HFEs in the 20-Year LTEMP Period H-7

H-3 Daily Maximum Discharge in a Typical 8.23-maf Water Volume Release Year from the Glen Canyon Dam during the Windy Season of March–June H-8

H-4 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives and Long-Term Strategies H-10

H-5 Average Number of Days of an HFE Event per Year H-11

H-6 Modeled Glen Canyon Dam Discharge for the Same Year H-12

H-7 Time Off River Index Values for All LTEMP Alternatives and Associated Long-Term Strategies H-14

H-8 Daily Average Discharge for Representative Long-Term LTEMP Strategies H-15

I-1 Riparian Diversity for the LTEMP Alternatives and Associated Long-Term Strategies I-6

FIGURES (Cont.)

I-2 Riparian Diversity under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-7

I-3 Wetland Abundance for the LTEMP Alternatives and Associated Long-Term Strategies I-9

I-4 Wetland Abundance under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-10

I-5 Frequency of Trout Management Flows for the LTEMP Alternatives and Associated Long-Term Strategies I-12

I-6 Frequency of Trout Management Flows under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-13

I-7 Frequency of Mechanical Removal for the LTEMP Alternatives and Associated Long-Term Strategies I-14

I-8 Frequency of Mechanical Removal under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-15

I-9 Lake Powell Water Levels for the LTEMP Alternatives and Associated Long-Term Strategies I-16

I-10 Lake Powell Water Levels under Climate Change Assumptions for the LTEMP Alternatives and Associated Long-Term Strategies I-17

J-1 Camping Area Index for LTEMP Long-Term Strategies J-8

J-2 Sand Load Index for LTEMP Long-Term Strategies J-9

J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies J-11

J-4 Fluctuation Index for LTEMP Long-Term Strategies J-14

J-5 Time Off River Index for LTEMP Long-Term Strategies J-16

J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP Alternatives J-16

J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies J-19

FIGURES (Cont.)

J-8 Average Number of HFEs in the 20-Year LTEMP Period for LTEMP Long-Term Strategies J-20

J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies J-22

J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Summer Season J-24

J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Fall and Spring Seasons J-24

J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Summer Season J-25

J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Fall and Spring Seasons J-25

K.1-1 Network Topology Used by the AURORA Western Interconnection Model K-10

K.1-2 Percentage of Total Generation Resources Owned by Individual Customers K-12

K.1-3 Simplified Network Topology of the SLCA/IP Market System K-13

K.1-4 Percentage of SLCA/IP Federal Hydropower Nameplate Capacity by Facility K-16

K.1-5 Flow Diagram of the Power Systems Methodology Used in the LTEMP EIS K-18

K.1-6 Illustration of a Typical GTMax-Lite Result for a 24-Hour Period K-24

K.1-7 GTMax-Lite Network Topology for the Large SLCA/IP Hydropower Resources Other Than Glen Canyon Dam K-26

K.1-8 Illustration of Temporal Modeling Method Used in the GTMax-Lite Five Large SLCA/IP Plant Configuration K-28

K.1-9 Example of the Load Scaling Algorithm LDC K-31

K.1-10 Example of the Load Scaling Algorithm Chronological Hourly Loads K-32

K.1-11 Projected Annual Average Calibrated AURORA LMPs at the Palo Verde Market Hub K-36

FIGURES (Cont.)

K.1-12 Historical Palo Verde On- and Off-Peak Electricity Prices Compared to Natural Gas Prices K-36

K.1-13 2014 AEO Projected Delivered Utility Natural Gas Prices K-37

K.1-14 Comparison of Modeled and Actual Annual Aggregated Generation Levels for Natural Gas, Coal, and Nuclear Powerplants under the No Action Alternative K-43

K.1-15 Total Non-coincidental Peak Loads for the SLCA/IP Market System K-49

K.1-16 Total Monthly Loads for the SLCA/IP Market System K-49

K.1-17 Projected 2014 AEO Natural Gas Prices at the Henry Hub K-56

K.1-18 2014 AEO Electricity Market Module Regions and the Mapping of States to Regions K-57

K.1-19 Projected AEO 2014 Coal Prices by Electricity Market Module Region K-59

K.1-20 WAPA SLCA/IP Hydropower Powerplants K-63

K.1-21 SLCA/IP Federal Hydropower Capacity Uses and Variability Factors K-64

K.1-22 Reductions in Operating Range when Providing Ancillary Services K-66

K.1-23 Illustration of the Trapezoidal Method Used to Compute Capacity at Flaming Gorge Dam K-72

K.1-24 Illustration of Ramping Time Increase as a Function of Increasing Water Volumes at Flaming Gorge Dam K-73

K.1-25 Capacity Values at Flaming Gorge Dam Calculated over a Wide Range of Daily Water Releases Using the Trapezoidal Method K-74

K.1-26 Average Historical Non-coincidental Annual Peak Loads for the Eight Large Customers and Percentages Relative to the Total K-75

K.1-27 Historical Coincidental Annual and Average Peak Loads for the Eight Large Customers during the CY 2006 through CY 2009 Time Period K-76

K.1-28 Historical Coincidental Annual and Average Peak Loads for Six Large Customers during the CY 2010 through CY 2012 Time Period K-77

FIGURES (Cont.)

K.1-29 SLCA/IP Models Used for Estimating SHP Capacity K-78

K.1-30 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in July K-80

K.1-31 Historical SHP Capacity Obligation and WAPA Estimated Risk Level in August K-80

K.1-32 Comparison of Firm Marketable Capacity Determinations across Alternatives, Exceedance Levels, and Summer Peak Months..... K-81

K.1-33 Timing of Capacity Additions in AURORA K-83

K.1-34 Annual Average Hydropower Generation for the Glen Canyon Dam Powerplant and the Aggregate Generation for All Other SLCA/IP Resources K-88

K.1-35 Average Daily Glen Canyon Dam Powerplant Hydropower Generations by Month Based on the Average of All 21 CRSS/SBM Hydrology Traces K-89

K.1-36 Average Annual Glen Canyon Dam Powerplant Generation for the Representative CRSS/SBM Hydrology Trace K-92

K.1-37 Representative Trace Average Daily Glen Canyon Dam Powerplant Generations by Month..... K-93

K.1-38 Average Daily Generation by Month for Each Alternative K-97

K.1-39 Palo Verde Average Daily Electricity Market Price Statistics by Month during the 20-Year LTEMP Period K-98

K.1-40 Typical Hourly Winter/Summer Price Patterns in the Western United States K-99

K.1-41 Average Number of HFEs by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-42 Average Amount of Non-Power Water Releases by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-100

K.1-43 Average Annual Number of Hours the Lake Powell Elevation Is below the Penstock Intake by Alternative for All 21 Hydrology Traces of Sediment Trace 2 ..... K-101

K.1-44 2014 Annual Energy Outlook Projections of Capacity Additions in the Western Interconnection over the LTEMP Period..... K-104

FIGURES (Cont.)

K.1-45 Cumulative Capacity Additions for Alternative A K-106

K.1-46 Cost Difference of Alternatives Compared to Alternative A at 50% Exceedance Level and 3.375% Discount Rate K-119

K.1-47 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate K-119

K.1-48 Cost Difference of Alternatives Compared to Alternative A at 99% Exceedance Level and 3.375% Discount Rate K-120

K.1-49 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 1.4% Discount Rate K-122

K.1-50 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combustion Turbines K-123

K.1-51 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate, Assuming All Alternative A New Capacity Additions Are Advanced Combined Cycle K-124

K.1-52 Cost Difference of Alternatives Compared to Alternative A at 90% Exceedance Level and 3.375% Discount Rate Assuming Average Hydropower Conditions K-125

K.2-1 Determination of Energy Hourly Expense or Revenue K-140

K.2-2 Determination of Total Net Expense or Revenue by Year for Each Alternative..... K-142

K.3-1 Flowchart Diagram of Rate Impact Analysis Process K-156

K.3-2 Projected Carrying Charge Rates Used in Rate Impact Analysis K-161

K.3-3 Flowchart Diagram of Allocation Process K-162

K.3-4 Load Factors of SLCA/IP Power K-165

K.3-5 Scatter Plot of Preference Ratio and Annual Retail Sales K-169

K.3-6 Scatter Plots of Percent Retail Rate Change and the Preference Ratio..... K-171

K.3-7 Retail Rate Distribution under Alternative A K-173

FIGURES (Cont.)

K.3-8 Monthly Residential Bill Distribution under Alternative A K-173

K.3-9 Average Retail Rate Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-10 Average Residential Bill Impacts under LTEMP Alternatives Relative to Alternative A K-175

K.3-11 Average Retail Percent Revenue Increase Relative to Alternative A K-176

K.3-12 Average Monthly Residential Bill Changes Relative to Alternative A K-177

K.3-13 Retail Rates under Alternative A K-188

K.4-1 Calculation of Change in Tribal Benefit Resulting from LTEMP EIS Alternatives K-194

K.4-2 Financial Impacts under Alternative B Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-3 Financial Impacts under Alternative C Relative to Alternative A for Tribal and Non-Tribal Entities K-203

K.4-4 Financial Impacts under Alternative D Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-5 Financial Impacts under Alternative E Relative to Alternative A for Tribal and Non-Tribal Entities K-204

K.4-6 Financial Impacts under Alternative F Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.4-7 Financial Impacts under Alternative G Relative to Alternative A for Tribal and Non-Tribal Entities K-205

K.5-1 Change in Lake Powell Monthly Water Release Volumes under LTEMP Alternatives K-207

K.5-2 Average Lake Mead EOM Pool Elevations under LTEMP Alternatives K-207

K.5-3 Average Monthly Difference in Turbine Water Releases Relative to Alternative A K-212

FIGURES (Cont.)

K.5-4 Average Monthly Hoover Powerplant Generation for All Power Systems under Primary LTEMP EIS Alternatives K-212

K.5-5 NPV of Hoover Powerplant Benefits Relative to Alternative A Resulting from LTEMP Alternatives K-214

L-1 Elements of the Lake_Full Utility Model L-5

L-2 Elements of the GCRec_Full Utility Model L-6

L-3 Elements of the Regional Recreation Impacts Analysis L-11

L-4 Elements of the Regional Electricity Price Impacts Analysis L-16

L-5 Elements of the Regional Electricity Generating Capacity Expansion Impacts Analysis L-17

P-1 Average Monthly Sand Load from the Paria River and Little Colorado River Showing the Fall and Spring HFE Accounting Periods and Implementation Windows P-4

TABLES

1-1	Glen Canyon Dam Release Constraints under Modified Low Fluctuating Flows	1-21
1-2	Selected Documents Included in the Law of the River	1-32
2-1	Operational Characteristics of LTEMP Alternatives	2-9
2-2	Condition-Dependent and Experimental Elements of LTEMP Alternatives	2-11
2-3	Flow Parameters under Alternative A in an 8.23-maf Year	2-17
2-4	Flow Parameters under Alternative B in an 8.23-maf Year	2-21
2-5	Flow Parameters under Alternative C in an 8.23-maf Year	2-26
2-6	Implementation Criteria for Experimental Treatments of Alternative C	2-31
2-7	Flow Parameters for a Year with Low Summer Flows under Alternative C in an 8.23-maf Year	2-42
2-8	Flow Parameters under Alternative D in an 8.23-maf Year	2-45
2-9	Implementation Criteria for Experimental Treatments of Alternative D	2-50
2-10	Flow Parameters for a Year with Low Summer Flows under Alternative D in an 8.23-maf Year	2-68
2-11	Flow Parameters under Alternative E in an 8.23-maf Year	2-73
2-12	Flow Parameters under Alternative F in an 8.23-maf Year	2-82
2-13	Flow Parameters under Alternative G in an 8.23-maf Year	2-83
2-14	Summary of Impacts of LTEMP Alternatives on Resources	2-93
3.5-1	Native Fish of the Colorado River through Glen and Grand Canyons	3-72
3.5-2	Nonnative Fish Found in the Colorado River through Glen and Grand Canyons	3-91
3.5-3	Mean Water Temperature and Turbidity for Selected Sites in the Colorado River Mainstem from 2006 to 2009	3-94
3.5-4	Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed	3-102

TABLES (Cont.)

3.6-1 Plant Communities Occurring on Reattachment Bars, Separation Bars, and Channel Margins 3-113

3.6-2 Special Status Plant Species Known to Occur along the Colorado River from Glen Canyon Dam to Lake Mead 3-122

3.7-1 Habitat and Distribution of Threatened, Endangered, and Sensitive Wildlife Species along the Colorado River Corridor between Glen Canyon Dam and Lake Mead 3-133

3.10-1 Colorado River Discovery Commercial Rafting Passengers 2009–2013 3-177

3.10-2 Tolerable Daily Flow Fluctuations Reported by Commercial and Private Trip Leaders 3-184

3.13-1 Energy and Capacity Characteristics of the Eight Largest WAPA Customers, 2013 3-208

3.14-1 Population in the Six-County Region 3-210

3.14-2 Income in the Six-County Region 3-212

3.14-3 Employment in the Six-County Region 3-213

3.14-4 Employment by Sector in 2011 3-214

3.14-5 Unemployment Rates in the Six-County Region 3-215

3.14-6 Minority and Low-Income Populations in the 11-County Area 3-217

3.14-7 Population in the Seven-State Region of Influence 3-222

3.14-8 Income in the Seven-State Region of Influence 3-223

3.14-9 Employment in the Seven-State Region of Influence 3-224

3.14-10 Employment by Sector in 2011 in the Seven-State Region of Influence 3-225

3.14-11 Unemployment in the Seven-State Region of Influence 3-226

3.14-12 State Minority and Low-Income Populations, 2010 3-227

3.15-1 Clean Air Act Prevention of Significant Deterioration Designations 3-230

TABLES (Cont.)

3.15-2 Criteria Pollutant and VOC Emissions in Counties Encompassing Grand Canyon National Park and for the Navajo Generating Station, 2011 3-231

3.15-3 Criteria Pollutant and VOC Emissions for 2011, and GHG Emissions for 2010, over the 11-State Affected Area within the Western Interconnection 3-236

4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative 4-4

4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality 4-15

4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek 4-50

4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources 4-73

4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative 4-90

4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources 4-92

4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology 4-109

4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base 4-116

4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels 4-165

4.6-2 Vegetation States and Corresponding Mapped Vegetation Types 4-169

4.6-3 Summary of Impacts of LTEMP Alternatives on Vegetation 4-170

4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions 4-181

4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor 4-185

4.6-6 Summary of Impacts of LTEMP Alternatives on Special Status Plant Species 4-188

4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife 4-205

TABLES (Cont.)

4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species 4-217

4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons 4-239

4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover 4-253

4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources 4-263

4.10-1 Summary of Impacts of LTEMP Alternatives on Recreation, Visitor Use, and Experience 4-282

4.10-2 Amount of Sediment Transported Out of Marble Canyon under the LTEMP Alternatives over the 20-Year LTEMP Period 4-295

4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience 4-310

4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources 4-335

4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice 4-366

4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP Alternatives 4-376

4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012 4-380

4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives 4-380

4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives 4-381

4.14-6 Seven-State Economic Impacts under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033 4-383

4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A 4-384

4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers 4-389

TABLES (Cont.)

4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality 4-404

4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative 4-408

4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions 4-417

4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions 4-422

4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area 4-428

4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives 4-447

5.1-1 Summary of Cooperating Agency Involvement 5-3

B-1 Tolerable Flow Fluctuations for Recreational River Use B-13

D-1 Initial Reservoir Conditions D-5

D-2 Monthly Release Volumes by Water-Year Release for Alternative A D-11

D-3 Monthly Release Volumes by Water-Year Release for Alternative B D-12

D-4 Monthly Release Volumes by Water-Year Release for Alternative C D-13

D-5 Monthly Release Volumes by Water-Year Release for Alternative C with Low Summer Flows D-14

D-6 Monthly Release Volumes by Water-Year Release for Alternative D D-15

D-7 Monthly Release Volumes by Water-Year Release for Alternative D with Low Summer Flows D-16

D-8 Monthly Release Volumes by Water-Year Release for Alternative E D-17

D-9 Monthly Release Volumes by Water-Year Release for Alternative E with Low Summer Flows D-18

D-10 Monthly Release Volumes by Water-Year Release for Alternative F D-19

TABLES (Cont.)

D-11 Monthly Release Volumes by Water-Year Release for Alternative G D-20

D-12 Minimum Release Constraints Used for Each Alternative D-21

D-13 Input Demands by State D-27

E-1 Sources for Historical Tributary Sediment Load Data E-38

E-2 Historical Periods Used for Paria Sediment Traces s1, s2, and s3 ..... E-38

E-3 Historical Periods Used for Little Colorado River Sediment Traces s1, s2, and s3 ..... E-38

E-4 List of HFEs Available for Sediment-Triggered Experiments E-39

F-1 Average Mean Habitat-Weighted Invertebrate Biomass at Select Sites in the Colorado River, July 2006–June 2009 ..... F-8

F-2 Average Mean Habitat-Weighted Invertebrate Production at Select Sites in the Colorado River, July 2006–June 2009 ..... F-9

F-3 Average Mean Habitat-Weighted Invertebrate Abundance at Select Sites in the Colorado River, July 2006–June 2009 ..... F-10

F-4 Distribution, Ecological Importance, and Favorable Temperature Range for Select Primary Producers F-11

F-5 Temperature Requirements for Common Zooplankton F-24

F-6 Distribution, Importance to Higher Trophic Levels, and Temperature Range for Common Benthic Macroinvertebrates Downstream of Glen Canyon Dam F-25

F-7 Temperature Requirements for the Asian Tapeworm, Anchor Worm, and Trout Nematode F-26

F-8 Summary of Metrics Values from the Rainbow Trout-Humpback Chub Model F-53

F-9 Description of Input Parameters for the LTEMP Temperature Suitability Model F-66

F-10 Humpback Chub Aggregation Locations F-67

F-11 Locations Used for Temperature Suitability Modeling of Native Fish, Nonnative Fish, and Parasites F-73

TABLES (Cont.)

G-1 Vegetation States, Plant Associations, and Corresponding Submodels G-15

G-2 Hydrologic Events Considered in the Riparian Vegetation Model G-16

G-3 Riparian Vegetation Model Transition Rules G-17

G-4 New High-Water Zone and Old High-Water Zone Vegetation Classes Mapped from Lees Ferry to Diamond Creek G-22

G-5 Vegetation States and Corresponding Mapped Vegetation Types G-24

G-6 Example Results for the Native Cover Metric G-25

G-7 Example Results for the Arrowweed Metric G-25

G-8 Results for Alternative A G-26

G-9 Results for Alternative B, Long-Term Strategy B1 ..... G-27

G-10 Results for Alternative B, Long-Term Strategy B2 ..... G-28

G-11 Results for Alternative C, Long-Term Strategy C1 ..... G-29

G-12 Results for Alternative C, Long-Term Strategy C2 ..... G-30

G-13 Results for Alternative C, Long-Term Strategy C3 ..... G-31

G-14 Results for Alternative C, Long-Term Strategy C4 ..... G-32

G-15 Results for Alternative D, Long-Term Strategy D1 ..... G-33

G-16 Results for Alternative D, Long-Term Strategy D2 ..... G-34

G-17 Results for Alternative D, Long-Term Strategy D3 ..... G-35

G-18 Results for Alternative D, Long-Term Strategy D4 ..... G-36

G-19 Results for Alternative E, Long-Term Strategy E1 ..... G-37

G-20 Results for Alternative E, Long-Term Strategy E2 ..... G-38

G-21 Results for Alternative E, Long-Term Strategy E3 ..... G-39

TABLES (Cont.)

G-22 Results for Alternative E, Long-Term Strategy E4 ..... G-40

G-23 Results for Alternative E, Long-Term Strategy E5 ..... G-41

G-24 Results for Alternative E, Long-Term Strategy E6 ..... G-42

G-25 Results for Alternative F G-43

G-26 Results for Alternative G G-44

G-27 The Effects of LTEMP Long-Term Strategies on Wetlands G-45

I-1 Federal Regulations and Executive Orders Pertaining to Consultation with Tribes I-3

I-2 Vegetation States I-5

J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial Motor Guides, Commercial Oar Guides, and Private Trip Leaders Who Have Experienced Daily Fluctuations of at Least 15,000 cfs in the Grand Canyon J-12

J-2 Recreation Response to Daily Maximum Flow J-20

J-3 Summary of Recreation, Visitor Use, and Experience Metrics J-26

K.1-1 Cost and Performance Characteristics of Capacity Expansion Candidates K-51

K.1-2 Cumulative Annual Percentage Increase in Natural Gas Prices at the Henry Hub K-55

K.1-3 Cumulative Annual Percent Increase in Regional Coal Prices K-58

K.1-4 Cumulative Annual Percentage Increase in Regional Distillate Fuel Prices K-60

K.1-5 Assumed Ancillary Services Provided by SLCA/IP Hydropower Facilities from 2013 to 2030 ..... K-65

K.1-6 Summary of Utility IRPs for Four Large SLCA/IP Customers and Other Large Utilities in Areas Neighboring the SLCA/IP System K-87

K.1-7 SLCA/IP Marketable Capacity at the 90% Exceedance Level K-102

K.1-8 Difference in Cumulative Capacity Additions of Each Alternative Relative to Alternative A K-105

TABLES (Cont.)

K.1-9 Comparison of the Amount and Timing of New Capacity Additions for Alternatives A and F K-107

K.1-10 Total Economic Impacts by Alternative at the 90% Exceedance Level K-109

K.1-11 Estimated Cost of LTEMP Experiments K-116

K.1-12 Comparison of Marketable Capacity, Replacement Capacity, and Capacity Additions by Exceedance Level K-117

K.1-13 Firm SLCA/IP Federal Hydropower Capacity at Various Exceedance Levels at Glen Canyon Dam by Alternative and Ancillary Service Scenarios K-127

K.1-14 Comparison of Capacity and Energy Values at Glen Canyon Dam by Alternative and Ancillary Services Scenarios at the 90% Exceedance Level K-128

K.1-15 Difference Relative to Alternative A K-128

K.1-16 Alternative Cost Increase Estimates for Mixed NGCC/CT Technology Capacity Replacement Relative to CT Only Replacement as Estimated Using GTMax-Lite K-130

K.1-17 Summary of Economic Rankings for Baseline and All Sensitivity Scenarios K-132

K.2-1 SHP Contractual Obligations and Project Use Required Deliveries by Month K-136

K.2-2 SHP Hourly Load Shapes by Month and Type of Day K-137

K.2-3 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year K-141

K.2-4 Total Levelized Capital and Fixed O&M Cost for System Capacity Expansion by Alternative and Year Expressed as the Difference from Alternative A K-143

K.2-5 Total Net Purchase Power Expenses by Year and Alternative for the Continuous Current Obligations Scenario K-147

K.2-6 Total Net Purchase Power Expenses by Year and Alternative for the Reduced Obligations to Match Resource Scenario K-148

K.2-7 SLCA/IP Rate Impact by Alternative K-151

K.3-1 Energy Allocations for Systems Receiving Indirect SLCA/IP Allocations K-157

TABLES (Cont.)

K.3-2 Coverage of Retail Information from EIA Database Relative to SLCA/IP Preference Power Allocation K-159

K.3-3 Average Annual Grid Cost Relative to SLCA/IP Wholesale Revenues Relative to Alternative A K-168

K.3-4 Summary Table of Comparative Values K-178

K.3-5 Individual Systems with the Largest Percent Retail Rate Impacts Relative to Alternative A K-180

K.3-6 Individual Systems with the Smallest Percent Retail Rate Impacts Relative to Alternative A K-182

K.3-7 Individual Systems with the Largest Monthly Residential Bill Impacts Relative to Alternative A K-183

K.3-8 Individual Systems with the Smallest Monthly Residential Bill Impacts Relative to Alternative A K-184

K.3-9 Size and Preference Ratio for Utility Systems with Large Rate Impacts K-186

K.3-10 Rate Impacts for Selected Groups in Maximum Impact Year K-186

K.4-1 Monthly Change in Residential Electric Utility Bill for Tribes by Alternative K-197

K.4-2 Total Dollar Annual Impact on Tribes under LTEMP Alternatives Relative to Alternative A K-199

L-1 Total Regional Economic Impacts of Non-Local Recreation Expenditures, 2013 ..... L-13

L-2 Urban Population, Income, and Poverty in the Six-County Region L-18

M-1 Emission Factors by Plant for System Power Generation and Spot Market M-10

M-2 Power Generation Averaged over the 20-Year LTEMP Period by Alternative M-12

M-3 Summary of Potential Impacts of LTEMP Alternatives on Visibility and Regional Air Quality M-15

M-4 Annual SO_2 Emissions Averaged over the 20-Year LTEMP Period by Alternative M-16

TABLES (Cont.)

M-5 Annual NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative M-19

M-6 Summary of Impacts of LTEMP Alternatives on SO_2 and NO_x Emissions M-22

M-7 Annual Greenhouse Gas Emissions under LTEMP Alternatives M-23

M-8 Summary of Impacts of LTEMP Alternatives on CO_2e Emissions M-26

N-1 Summary of Tribal Participation Status N-5

N-2 Summary of Tribal Correspondence N-6

N-3 Summary of Major Face-to-Face Meetings, Webinars, and Conference Calls Involving Tribes N-25

N-4 Summary of Individual Tribal Consultation Meetings to Date N-27

N-5 Index of Project Tribal Government Consultation and Coordination Correspondence N-29

P-1 List of HFEs Available for Sediment-Triggered Experiments under the Preferred Alternative P-7

Q-1 Comment Issues and Location in the Report Q-6

Q-2 Commenter Distribution by State Q-10

Q-3 Commenter, Affiliation, and Location Where Responses Are Found Q-88

ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
ACHP	Advisory Council on Historic Preservation
AML	abandoned mine land
AMSL	above mean sea level
AMWG	Adaptive Management Work Group
AOP	Annual Operation Plan for Colorado River Reservoirs
APE	Area of Potential Effect
Argonne	Argonne National Laboratory
ASMR	Age-Structured Mark Recapture Model
AZGFD	Arizona Game and Fish Department
AZ-SGCN	Arizona Species of Greatest Conservation Need
BA	Balancing Authority (in Chapter 3 only) Biological Assessment (in all other sections)
BGEPA	Bald and Golden Eagle Protection Act of 1940
BIA	Bureau of Indian Affairs
BO	Biological Opinion
C	Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
CCC	Civilian Conservation Corps
CEQ	Council on Environmental Quality
CFMP	*Comprehensive Fisheries Management Plan*
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
CPUE	catch per unit effort
CRBC	Colorado River Board of California
CRCN	Colorado River Commission of Nevada
CRD	Colorado River Discovery
CREDA	Colorado River Energy Distributors Association
CRMP	Colorado River Management Plan
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
CRSS	Colorado River Simulation System
CSU	Colorado Springs Utilities

DEIS	Draft Environmental Impact Statement
Deseret	Deseret Generation and Transmission Cooperative
DFC	desired future condition
DO	dissolved oxygen
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DPS	Distinct Population Segment
EA	Environmental Assessment
eGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ELCOM	Estuary, Lake and Coastal Ocean Model
EMS	emergency medical services
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ESA	Endangered Species Act of 1973, as amended
F	Fahrenheit
FCPP	Four Corners Power Plant
FES	Firm Electric Service
FONSI	Finding of No Significant Impact
FR	*Federal Register*
ft	foot (feet)
FWS	U.S. Fish and Wildlife Service
FY	fiscal year
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCM	general circulation model
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
GHG	greenhouse gas
GMP	General Management Plan
GW	gigawatt(s)
GWh	gigawatt-hour(s)
GWP	global warming potential
H_2S	hydrogen sulfide
HBC	humpback chub
HFC	hydrofluorocarbon
HFE	high-flow experiment
hr	hour(s)

HRR	Hualapai River Runners
in.	inch(es)
IPM	Integrated Pest Management
IRP	integrated resource plan
ISM	Indexed Sequential Method
kaf	thousand acre-feet
kWh	kilowatt-hour(s)
lb	pound(s)
LCRMSCP	Lower Colorado River Multi-Species Conservation Program
LMM	Lake Mead Model
LMNRA	Lake Mead National Recreation Area
LROC	Long-Range Operating Criteria
LTEMP	Long-Term Experimental and Management Plan
LTEP	Long Term Experimental Plan
LTF	long-term firm
maf	million acre-feet
MAMB	miscellaneous algae, macrophytes, and bryophytes
MBTA	Migratory Bird Treaty Act
MCL	maximum contaminant level
mi	mile(s)
MLFF	Modified Low Fluctuating Flow
MMt	million metric tons
MOA	Memorandum of Agreement
MT	metric ton(s)
MW	megawatt(s)
MWh	megawatt-hour(s)
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NAU	Northern Arizona University
NC	no change
NEPA	National Environmental Policy Act of 1969, as amended
NERC	North American Electric Reliability Corporation
NEV	net economic use value
NGO	nongovernmental organization
NHPA	National Historic Preservation Act
NM	national monument
NO_2	nitrogen dioxide
NO_3	nitrate-nitrogen
NOI	Notice of Intent
NO_x	nitrogen oxides
NPS	National Park Service

NPV	net present value
NRHP	*National Register of Historic Places*
NTUA	Navajo Tribal Unit Authority
O&M	operation and maintenance
O_3	ozone
OPAC	Office of Planning and Compliance
OSMRE	Office of Surface Mining Reclamation and Enforcement
PA	Programmatic Agreement
Pb	lead
PEPC	Planning, Environment, and Public Comment
PFC	perfluorocarbon
P.L.	Public Law
PM	particulate matter
$PM_{2.5}$	particulate matter ≤2.5 μm in aerodynamic diameter
PM_{10}	particulate matter ≤10 μm in aerodynamic diameter
POM	particulate organic matter
PSAR	preventative search and rescue
PSD	Prevention of Significant Deterioration
RA	resource available
Reclamation	Bureau of Reclamation
RM	river mile
RMP	Resource Management Plan
ROD	Record of Decision
RSG	Reserve Sharing Group
SAAQS	State Ambient Air Quality Standards
SBM	Sand Budget Model
SCP	Salinity Control Project
SD	standard deviation
SDA	Structured Design Analysis
SE	standard error
Secretary, the	Secretary of the Interior
SF_6	sulfur hexaflouride
SHPO	State Historic Preservation Officer
SLCA/IP	Salt Lake City Area Integrated Projects
SO	Secretarial Order
SO_2	sulfur dioxide
SPC	Southern Paiute Consortium
SRP	Salt River Project
SRSG	Southwest Reserve Sharing Group
TCD	temperature control device
TCP	traditional cultural property

TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer
TL	total length
TMF	trout management flow
Tri-State	Tri-State Generation and Transmission Association
TWG	Technical Working Group
UAMPS	Utah Associated Municipal Power Systems
UBWR	Utah Board of Water Resources
UCRC	Upper Colorado River Commission
UMPA	Utah Municipal Power Agency
USC	*United States Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VOC	volatile organic compound
WACM	Western Area Colorado-Missouri Region
WALC	Western Area Lower Colorado Region
WAUW	Western Area Upper Great Plains West Region
WECC	Western Electricity Coordinating Council
Western	Western Area Power Administration
YOY	young-of-year
yr	year(s)
ZHHPO	Zuni Heritage and Historic Preservation Office

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APPENDIX O:

BIOLOGICAL ASSESSMENT FOR THE GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN

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RECLAMATION

Managing Water in the West

Biological Assessment for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP)

U.S. Department of the Interior

August 2016

CONTENTS

ACRONYMS AND ABBREVIATIONS ix

1 INTRODUCTION AND BACKGROUND 1

1.1 Synopsis of the Proposed Action 3
1.2 Description of the Federal Action 4
1.2.1 Regulatory Context 4
1.2.2 Action Area 5
1.2.3 Project Description 6
1.2.4 Conservation Measures 10
1.2.4.1 Humpback Chub 10
1.2.4.2 Razorback Sucker 12
1.2.4.3 Nonnative Species – Removal and Control Actions 13
1.2.4.4 Southwestern Willow Flycatcher and Yuma Ridgway's Rail 14
1.2.5 Base Operations 15
1.2.6 Operational Flexibility 15
1.2.7 Implementation of Experimental Elements 18
1.2.8 Overall Implementation Process for Experiments 18
1.2.9 Sediment-Related Experimental Treatments 24
1.2.9.1 Sediment-Triggered Spring HFEs 26
1.2.9.2 Proactive Spring HFEs 27
1.2.9.3 Sediment-Triggered Fall HFEs 28
1.2.9.4 Extended-Duration Fall HFEs 28
1.2.10 Aquatic Resource-Related Experimental Treatments 30
1.2.10.1 Trout Management Flows 31
1.2.10.2 Tier 1 Conservation Actions for Humpback Chub 34
1.2.10.3 Tier 2 Mechanical Removal of Nonnative Fish 35
1.2.10.4 Low Summer Flows 36
1.2.10.5 Low Steady Weekend Flows for Macroinvertebrate Production 40
1.2.11 Native and Nonnative Plant Management and Experimental Actions 41

2 ENVIRONMENTAL BASELINE 43

2.1 Description of Species Identified for Analysis 43
2.1.1 Kanab Ambersnail 43
2.1.1.1 Legal Status 43
2.1.1.2 Recovery Goals and Status 43
2.1.1.3 Historic and Current Range 44
2.1.1.4 Habitat 44
2.1.1.5 Life History 44
2.1.2 Humpback Chub 45
2.1.2.1 Legal Status 45
2.1.2.2 Recovery Goals and Status 45

CONTENTS (Cont.)

2.1.2.3 Historic and Current Range 47
2.1.2.4 Population within the Action Area 48
2.1.2.5 Habitat 52
2.1.2.6 Life History 55
2.1.2.7 Factors Affecting Distribution and Abundance in the Grand Canyon 57
2.1.3 Razorback Sucker 60
2.1.3.1 Legal Status 60
2.1.3.2 Recovery Goals and Status 61
2.1.3.3 Historic and Current Range 61
2.1.3.4 Population within the Action Area 63
2.1.3.5 Habitat 64
2.1.3.6 Life History 64
2.1.3.7 Factors Affecting Distribution and Abundance in the Grand Canyon 65
2.1.4 Southwestern Willow Flycatcher 68
2.1.4.1 Legal Status 68
2.1.4.2 Recovery Goals and Status 68
2.1.4.3 Historic and Current Range 68
2.1.4.4 Population within the Action Area 69
2.1.4.5 Lees Ferry to Diamond Creek 70
2.1.4.6 Lower Grand Canyon 70
2.1.4.7 Life History and Habitat 71
2.1.4.8 Factors Affecting Distribution and Abundance in the Grand Canyon 72
2.1.5 Yuma Ridgway's Rail 72
2.1.5.1 Legal Status 72
2.1.5.2 Recovery Goals and Status 73
2.1.5.3 Historic and Current Range 73
2.1.5.4 Population within the Action Area 73
2.1.5.5 Habitat and Life History 74
2.1.5.6 Factors Affecting Distribution and Abundance in the Grand Canyon 75
2.2 Baseline Take Resulting from Handling and GCDAMP Research 75
2.2.1 Humpback Chub 75
2.2.2 Razorback Sucker 76

3 EFFECTS ANALYSIS OF PROPOSED ACTION 77

3.1 Effects of the Proposed Action on Kanab Ambersnail 77
3.1.1 Direct and Indirect Effects 77
3.1.1.1 Effects of Sediment-Related Experiments 77
3.1.1.2 Effects of Vegetation Management 78

CONTENTS (Cont.)

3.1.1.3 Effects of Climate Change 78
3.2 Effects of the Proposed Action on Humpback Chub 78
3.2.1 Direct and Indirect Effects 79
3.2.1.1 Effects of Base Operations 79
3.2.1.2 Effects of Dam Operational Flexibility 82
3.2.1.3 Overall Implementation Process for Experiments 84
3.2.1.4 Effects of Sediment-Related Experiments 84
3.2.1.5 Effects of Trout Management Flow Experiments 88
3.2.1.6 Effects of Triggered Conservation Actions and Mechanical Removal of Nonnative Fish Experiments 90
3.2.1.7 Effects of Low Summer Flow Experiments 91
3.2.1.8 Effects of Low Steady Weekend Flows for Macroinvertebrate Production Experiments 92
3.2.1.9 Effects of Ongoing Conservation Measures 93
3.2.1.10 Effects of New Conservation Measures 98
3.2.1.11 Effects of Native and Nonnative Plant Management Experimental Actions 98
3.2.1.12 Effects of Activities to Preserve and Protect Historic Properties and Cultural Sites 98
3.2.1.13 Effects of Climate Change 98
3.3 Effects of the Proposed Action on Razorback Sucker 99
3.3.1 Direct and Indirect Effects 100
3.3.1.1 Effects of Base Operations 100
3.3.1.2 Effects of Sediment-Related Experiments and Low Summer Flows 102
3.3.1.3 Effects of Low Steady Weekend Flows for Macroinvertebrate Production Experiments 103
3.3.1.4 Effects of Trout Management Flow Experiments 103
3.3.1.5 Effects of Triggered Conservation Actions and Mechanical Removal of Nonnative Fish Experiments 104
3.3.1.6 Effects of Conservation Measures 105
3.3.1.7 Effects of Climate Change 108
3.4 Effects of the Proposed Action on Southwestern Willow Flycatcher 108
3.5 Effects of the Proposed Action on Yuma Ridgway's Rail 109
3.6 Cumulative Effects 110
3.6.1 Grand Canyon Escalade 110
3.6.2 Uranium Mining on State and Private Lands 111
3.6.3 Increased Municipal and Agricultural Water Demand 112
3.6.4 Urban and Agricultural Runoff 112
3.6.5 Nonnative Vegetation and Defoliating Nonnative Insect Expansion 112
3.6.6 Cumulative Effects Summary 113
3.6.6.1 Aquatic Species – Humpback Chub, Razorback Sucker, and Kanab Ambersnail 113

CONTENTS (Cont.)

3.6.6.2 Wildlife 113
3.6.7 Summary of Climate-Related Changes 113

4 CONCLUSIONS AND DETERMINATIONS OF EFFECT 117

4.1 Listed Species Determinations 117
4.2 Humpback Chub 119
4.3 Razorback Sucker 120
4.4 Kanab Ambersnail 121
4.5 Southwestern Willow Flycatcher 121
4.6 Yuma Ridgway's Rail 121

5 LITERATURE CITED 123

APPENDIX A: Southwestern Willow Flycatcher Detections and Nest Sites, Grand Canyon National Park, Arizona, 1982–2012 ..... A-1

APPENDIX B: Southwestern Willow Flycatcher Historic and Recent Territories and Nesting Sites, Grand Canyon National Park, Arizona B-1

APPENDIX C: Ridgway's Rail Historic Records at Grand Canyon National Park, Arizona C-1

APPENDIX D: Proposed Action Triggers for the Management of Humpback Chub Colorado River, Grand Canyon D-1

FIGURES

1 Locations of Glen Canyon Dam, Lake Powell, and the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands 5

2 Mean, Minimum, and Maximum Daily Flows under the Proposed Action in an 8.23-maf Year 16

3 Simulated Hourly Flows under the Proposed Action in an 8.23-maf Year 17

4 Decision Tree for Implementation of Sediment-Related Experimental Treatments under the Proposed Action 25

5 Example Implementation of a Two-Cycle Trout Management Flow in June and July with Resumption of Normal Fluctuations between Cycles and Afterward 31

6 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of the Proposed Action in an 8.23-maf Year Based on the Values Presented in Table 4 38

7 Closed Chapman Petersen Abundance Estimates of Humpback Chub ≥150 mm and ≥200 mm in the Little Colorado River during Spring and Fall Seasons 49

8 Estimated Adult Humpback Chub Abundance from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age 51

9 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September 2009 through 2012 51

10 Total Abundance of Humpback Chub in Havasu Creek, Based on Annual Population Estimates between 2012 and 2015 53

11 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead 53

12 Water Temperatures at the Little Colorado River Confluence, 1995 to Present 60

13 Historic and Present Range of Razorback Sucker in the Colorado River Basin 62

C.1 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor C-3

TABLES

1 Federally Listed Species Occurring within the Project Area 1

2 Flow Parameters under the Proposed Action in an 8.23-maf Year 16

3 Implementation Criteria for Experimental Treatments under the Proposed Action 20

4 Flow Parameters for a Year with Low Summer Flows under the Proposed Action in an 8.23-maf Year 37

5 Temperature Requirements for Spawning, Incubation, Growth, and Lethality of 36 Native and Nonnative Fish Species of the Colorado River and Its Tributaries in and near the Project Area 83

6 Summary of Effects Determinations for the Five Listed Species 118

C.1 Ridgway's Rail Historic Records at Grand Canyon National Park, Arizona C-3

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ACRONYMS AND ABBREVIATIONS

ac	acre(s)
ac-ft	acre-foot (feet)
AMWG	Adaptive Management Work Group
ASMR	Age-Structured Mark Recapture Model
AZGFD	Arizona Game and Fish Department
BA	biological assessment
BIA	Bureau of Indian Affairs
BO	Biological Opinion
C	Celsius
CFMP	*Comprehensive Fisheries Management Plan*
CFR	*Code of Federal Regulations*
cfs	cubic feet per second
cm	centimeter(s)
CRSP	Colorado River Storage Project
CRSPA	Colorado River Storage Project Act of 1956
DOI	U.S. Department of the Interior
EA	environmental assessment
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
ESA	Endangered Species Act of 1973, as amended
F	Fahrenheit
FR	*Federal Register*
ft	foot (feet)
ft^3	cubic foot (feet)
FWS	U.S. Fish and Wildlife Service
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GCPA	Grand Canyon Protection Act of 1992
HBC	humpback chub
HFE	high-flow experiment
Hg	mercury
hr	hour(s)

IKAMPT	Interagency Kanab Ambersnail Monitoring Team
in.	inch(es)
JCM	juvenile chub monitoring
kaf	thousand acre-feet
km	kilometer(s)
lb	pound(s)
LCRMSCP	Lower Colorado River Multi-Species Conservation Program
LMNRA	Lake Mead National Recreation Area
LTEMP	Glen Canyon Dam Long-Term Experimental and Management Plan
maf	million acre-feet
mi	mile(s)
MLFF	Modified Low Fluctuating Flow
mm	millimeter(s)
MVP	Minimum Viable Population
NEPA	National Environmental Policy Act of 1969, as amended
NHPA	National Historic Preservation Act
NPS	National Park Service
NRHP	*National Register of Historic Places*
OSMRE	Office of Surface Mining Reclamation and Enforcement
ppb	part(s) per billion
Reclamation	Bureau of Reclamation
RM	river mile
ROD	Record of Decision
Se	selenium
SNARRC	Southwestern Native Aquatic Resources and Recovery Center
TL	total length
TMF	trout management flow
TWG	Technical Working Group
UCRC	Upper Colorado River Commission
USC	*United States Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

WAPA	Western Area Power Administration
YOY	young-of-the-year

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1 INTRODUCTION AND BACKGROUND

The Bureau of Reclamation (Reclamation) has prepared this biological assessment (BA) to analyze the potential effects of the proposed Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) as described in the associated Environmental Impact Statement (EIS) on federally listed species. The BA analyzes the effects of implementation of flow and non-flow actions over a 20-year period at Glen Canyon Dam and in the Colorado River downstream of Glen Canyon Dam within Glen Canyon National Recreation Area (GCNRA) and Grand Canyon National Park (GCNP), Coconino County, Arizona, to Lake Mead National Recreation Area (LMNRA) (Figure 1). This BA was prepared by Reclamation as part of its compliance with the Endangered Species Act of 1973, as amended (ESA; 87 Stat. 884; 16 U.S.C. §1531 et seq.). A BA evaluates the potential effects of the action on listed and proposed species and designated and proposed critical habitat and determines whether any such species or habitat are likely to be adversely affected by the action (50 CFR 402.12).

A total of nine species currently listed under the ESA occur within the project area (Table 1). Five species are addressed in this BA due to potential effects from the proposed action: humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), southwestern willow flycatcher (*Empidonax traillii extimus*), Ridgway's Rail (formerly Yuma Clapper Rail) (*Rallus obsoletus*), and the Kanab ambersnail (*Oxyloma kanabensis*). Reclamation made "No effect" determinations for the Mexican spotted owl (*Strix occidentalis lucida*), the western yellow-billed cuckoo (*Coccyzus americanus*), and sentry milk-vetch (*Astragalus cremnophylax cremnophyla*). None of these species, or their habitat, occur in the area where activities would be implemented, and thus they are not considered further in this analysis. Reclamation has previously consulted on the bald eagle (*Haliaeetus leucocephalus*), American peregrine falcon (*Falco peregrinus anatum*), and California condor (*Gymnogyps californianus*). The California condor is an endangered species that would not be affected by this action, and the condors released in Arizona are designated as a non-essential, experimental population under the 10(j) rule of the ESA. The peregrine falcon and bald eagle have been removed from the list of threatened and endangered species and are not addressed in this BA.

TABLE 1 Federally Listed Species Occurring within the Project Area

Name	Species	Status
Mexican Spotted Owl	*Strix occidentalis lucida*	Threatened
Southwestern Willow Flycatcher	*Empidonax traillii extimus*	Endangered
California Condor	*Gymnogyps californianus*	Considered Threatened in National Parks; Experimental Non-Essential population in Northern Arizona
Western Yellow-billed Cuckoo	*Coccyzus americanus*	Threatened
Yuma Ridgway's (formerly Yuma Clapper) Rail	*Rallus obsoletus yumanensis*	Endangered
Kanab Ambersnail	*Oxyloma haydeni kanabensis*	Endangered
Humpback Chub	*Gila cypha*	Endangered
Razorback Sucker	*Xyrauchen texanus*	Endangered
Sentry Milk-vetch	*Astragalus cremnophylax cremnophylax*	Endangered

The BA provides the information and analysis to support Reclamation's conclusions concerning possible effects on the species and habitats listed in Table 1. Based upon the information contained in this BA, Reclamation has determined that the proposed action may affect, but is not likely to adversely affect, the southwestern willow flycatcher and Ridgway's Rail, and requests concurrence from the U.S. Fish and Wildlife Service (FWS). Reclamation has also determined that the proposed action may affect and is likely to adversely affect the humpback chub and its critical habitat, the razorback sucker and its critical habitat, and the Kanab ambersnail, and provides this information to the FWS to initiate formal consultation.

Reclamation is the lead agency within the U.S. Department of the Interior (DOI) that operates Glen Canyon Dam of the Colorado River Storage Project as a multipurpose storage facility in northern Arizona. Construction and operation of the dam were authorized by the 1956 Colorado River Storage Project Act. Operation of the dam is governed by a complex set of compacts, federal statutes and regulations, court decrees, and an international treaty collectively and commonly referred to as the Law of the River.

Development of the proposed action included the evaluation of specific alternatives that could be implemented to meet the Grand Canyon Protection Act's (GCPA's; 1992) requirements and to minimize, consistent with law, adverse impacts on the downstream natural, recreational, and cultural resources in the two park units, including resources of importance to American Indian Tribes. The need for the proposed action stems from the need to use scientific information developed since the 1996 Record of Decision (ROD) and the Operation of Glen Canyon Dam Final Environmental Impact Statement (1995 EIS) to better inform DOI decisions on dam operations and other management and experimental actions so that the Secretary of the Interior (Secretary) may continue to meet statutory responsibilities for protecting downstream resources for future generations, conserving federally listed species, avoiding or mitigating impacts on National Register-eligible properties, and protecting Native American interests, while meeting obligations for water delivery and the generation of hydroelectric power. The action will provide a framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with the GCPA and other provisions of applicable federal law. Several key issues related to natural resources downstream of Glen Canyon Dam and new scientific information related to them are summarized below.

The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and many types of ongoing dam releases further deplete sediment delivered to the main channel by causing erosion. However, high-flow releases, between approximately 30,000 and 45,000 cfs that are triggered when there is sufficient sediment from the Paria River, mobilize sand stored in the river channel and redeposit it as sandbars and beaches and associated backwater and riparian habitats (Melis et al. 2011). Because sandbars are one of the natural resources addressed by the GCPA that are to be protected, mitigated, and, where possible, improved, the LTEMP EIS uses current comprehensive scientific data and modeling to consider possible improvements related to the use of high-flow experiments (HFEs), as well as possible intervening flow operations, that may help better achieve the goal of retaining sandbars.

Since the 1995 EIS, the status of the endangered humpback chub has continued to be an issue of concern since the population in Grand Canyon, the largest in existence, declined during the late 1990s coincident with cooler water temperatures and high nonnative trout abundance and other factors. The cause of the decline was probably the result of a combination of factors, and based on Age-Structured Mark Recapture (ASMR) and multi-state models (see Figure 8), the species has since rebounded over the last decade, when water temperatures were warmer and trout abundance lower (Yackulic et al. 2014; Yard et al. 2011). Until recently, Rainbow trout have been the nonnative species of concern, but brown trout and warmwater nonnatives are becoming or are likely to become an additional concern. Uncertainty remains as to future humpback chub population response to changes in flows, nonnative species, and water temperatures that are largely driven by reservoir elevation.

There is concern among managers and scientists that nonnative fish compete with or prey upon the native or endangered fish to varying degrees (Yard et al. 2011; Whiting et al. 2014; Gloss and Coggins 2005). The effects of dam operations were examined in the 1995 EIS, and much additional information has been accumulated about the effects of dam operations on native and nonnative fish since that time. The LTEMP EIS applies the best available science and modeling methods to further consider the impacts of a variety of dam operations on native and nonnative fish and to determine what future experimentation is needed regarding these flow regimes to reduce the negative interactions of nonnative fish with native fish.

In addition to humpback chub, other important fish fauna found in the Colorado River below Glen Canyon Dam include razorback sucker (also listed as endangered), and three other native fish, flannelmouth sucker (*Catostomus latippinis*), bluehead sucker (*Catostomus discobolus*), and speckled dace (*Rhinichthys osculus*). Razorback sucker were thought to be extirpated from the Grand Canyon, but adults (Arizona Game and Fish Department [AZGFD], 2012 Data) and larval razorback sucker (Albrecht et al. 2014) have recently been found in the western Grand Canyon. Populations of bluehead and flannelmouth suckers have fluctuated in the Colorado River in the Grand Canyon since the 1995 EIS (Rogowski et al. 2015).

1.1 SYNOPSIS OF THE PROPOSED ACTION

The LTEMP EIS proposed action (Alternative D) affects monthly, daily, and hourly releases from Glen Canyon Dam but does not affect annual water release determinations. Under the proposed action (Alternative D of the EIS), the total monthly release volume of October, November, and December would be equal to that under Modified Low Fluctuating Flows (MLFF), the current operations, to avoid the possibility of the operational tier differing from that of MLFF, as established in the Interim Guidelines (Reclamation 2007a). The August volume was set to a moderate volume level (800 kaf in an 8.23-maf release year) to balance sediment conservation prior to a potential fall HFE, and power production and capacity concerns. January through July monthly volumes were set at levels that roughly track Western Area Power Administration's (WAPA's) contract rate of power delivery. This produced a redistribution of monthly release volumes under the proposed action and results in a relatively even distribution of flows. Under the proposed action, the allowable within-day fluctuation range from Glen Canyon Dam would be proportional to the volume of water scheduled to be released during the month

(10 × monthly volume in kaf in the high-demand months of June, July, and August and 9 × monthly volume in kaf in other months), with a maximum daily fluctuation of 8,000 cfs. The down-ramp rate would be increased to 2,500 cfs/hr, but the up-ramp rate would remain unchanged at 4,000 cfs/hr.

Experimentation under the proposed action includes testing the effects of the following actions:

1. Sediment-triggered spring and fall HFEs through the entire 20-year LTEMP period;

2. 24-hr proactive spring HFEs in high volume years (≥10 maf release volume);

3. Extension of the duration of up to 45,000 cfs fall HFEs for as many as 250 hr depending on sediment availability;

4. Proactive conservation actions for humpback chub if triggered by declines in humpback chub abundance and mechanical removal of nonnative fish near the Little Colorado River confluence, if proactive conservation actions fail to arrest humpback chub population decline;

5. Trout management flows;

6. A test of low summer flows in the second 10 years of the LTEMP period to allow greater warming; and

7. Sustained low flows to improve the aquatic food base.

A wide range of possible hydrologic conditions will occur over the LTEMP implementation time frame in response to intra-annual and inter-annual variability in basin-wide precipitation cycles. Within a year, monthly operations are typically adjusted (increased or decreased) based on changing annual runoff forecasts, and, since 2007, application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

1.2 DESCRIPTION OF THE FEDERAL ACTION

1.2.1 Regulatory Context

Past consultations have evaluated the impact of proposed actions on the threatened and endangered species that live in the Colorado River and its floodplain between Glen Canyon Dam and at the time, Separation Canyon, near the inflow area of Lake Mead, Coconino and Mohave Counties, northern Arizona. This BA focuses on the area of the Colorado River from Glen Canyon Dam to Lake Mead below Pierce Ferry Rapid (river mile [RM] 280, [451 km]), although

the impacts of some elements of the proposed action could extend downstream and upstream of this area, and into tributary streams. The anticipated area of effect lies within the State of Arizona and in LMNRA, GCNRA, and GCNP. The area is bordered by, or is in proximity to, the Navajo Nation, Havasupai, and Hualapai tribal lands.

1.2.2 Action Area

The action area for this proposed federal action is the Colorado River corridor from Glen Canyon Dam in Coconino County, Arizona, downstream to the Colorado River Inflow in Lake Mead. The action area includes the area potentially affected by implementation of the LTEMP (normal and experimental operations of Glen Canyon Dam and non-flow actions). This area includes Lake Powell, Glen Canyon Dam, and the river downstream to Lake Mead (see Figure 1 for the locations of Lakes Powell and Mead, Glen Canyon Dam, the Colorado River, and adjacent lands). More specifically, the scope primarily encompasses the Colorado River Ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian and terrace zones, located primarily from the forebay of Glen Canyon Dam to the western boundary of GCNP. It includes the area where dam operations impact physical,

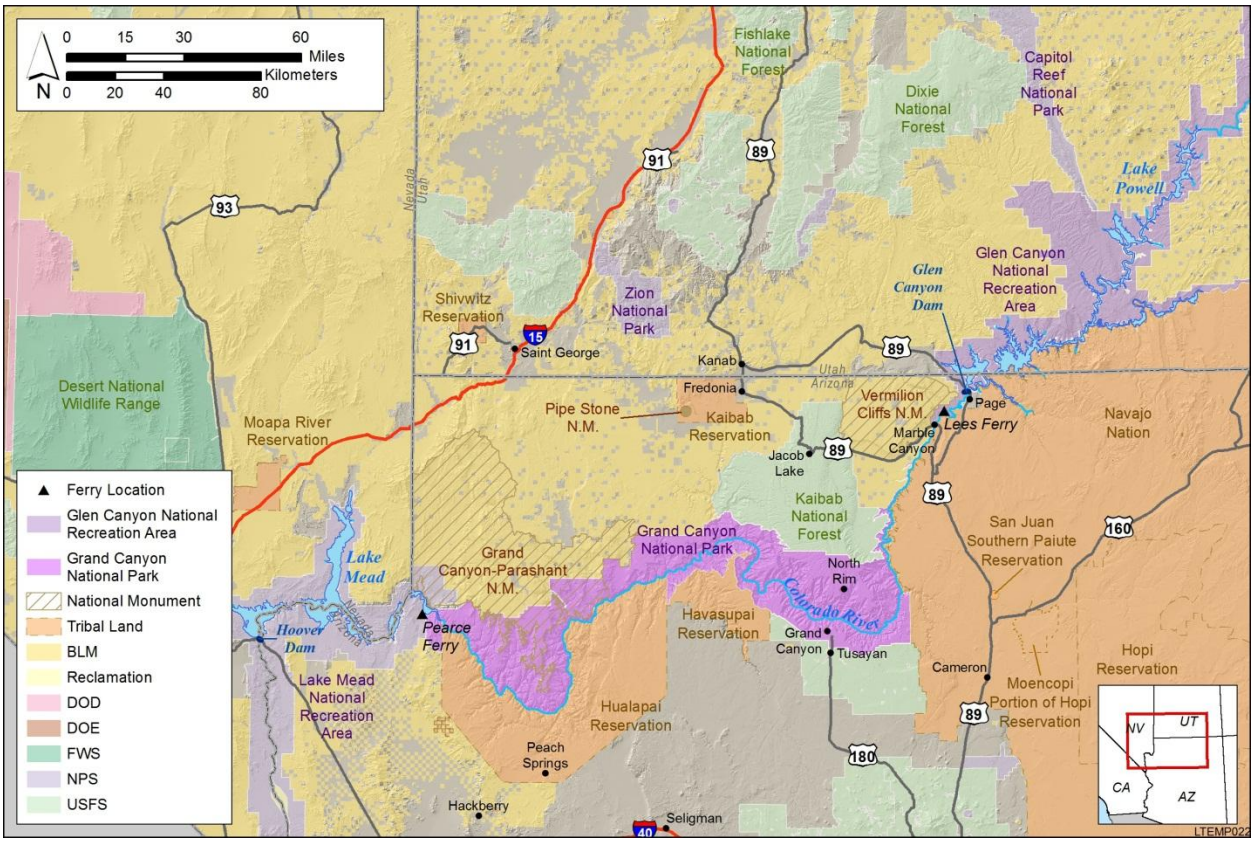


FIGURE 1 Locations of Glen Canyon Dam, Lake Powell, and the Colorado River between Lake Powell and Lake Mead, and Adjacent Lands

biological, recreational, cultural, and other resources. Portions of GCNRA, GCNP, and LMNRA are included within this area.

1.2.3 Project Description

The DOI has identified several primary objectives of operating Glen Canyon Dam under the LTEMP, as well as more specific goals to improve resources within the Colorado River ecosystem (primarily from Glen Canyon Dam downstream to the headwaters of Lake Mead) through experimental and management actions. These objectives and resource goals were considered in the formulation and development of alternatives in this EIS.

The following is a list of the objectives of the LTEMP:

- Develop an operating plan for Glen Canyon Dam in accordance with the GCPA to protect, mitigate adverse impacts on, and improve the values for which GCNP and GCNRA were established, including, but not limited to, natural and cultural resources and visitor use, and to do so in such a manner as is fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the U.S. Supreme Court in Arizona v. California, and the provisions of the Colorado River Storage Project Act (CRSPA) of 1956 and the Colorado River Basin Project Act of 1968 that govern the allocation, appropriation, development, and exportation of the waters of the Colorado River Basin and in conformance with the Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs as currently implemented by the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Ensure water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

- Consider potential future modifications to Glen Canyon Dam operations and other flow and non-flow actions to protect and improve downstream resources.

- Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

- Respect the interests and perspectives of American Indian Tribes.

- Make use of the latest relevant scientific studies, especially those conducted since 1996.

- Determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process.

- Identify the need for a Recovery Implementation Program for endangered fish species below Glen Canyon Dam.

- Ensure Glen Canyon Dam operations are consistent with the GCPA, ESA, National Historic Preservation Act (NHPA), CRSPA, and other applicable federal laws.

Reclamation and the National Park Service (NPS) developed resource goals considering public input and desired future conditions (DFCs) previously adopted by the Glen Canyon Dam Adaptive Management Work Group (AMWG). The following resource goals were identified:

1. *Archaeological and Cultural Resources.* Maintain the integrity of potentially affected *National Register of Historic Places* (NRHP)-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

2. *Natural Processes.* Restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems.

3. *Humpback Chub.* Meet humpback chub recovery goals, including maintaining a self-sustaining population, spawning habitat, and aggregations in the humpback chub's natural range in the Colorado River and its tributaries below the Glen Canyon Dam.

4. *Hydropower and Energy.* Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources.

5. *Other Native Fish.* Maintain self-sustaining native fish species populations and their habitats in their natural ranges on the Colorado River and its tributaries.

6. *Recreational Experience.* Maintain and improve the quality of recreational experiences for the users of the Colorado River ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon.

7. *Sediment.* Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.

8. *Tribal Resources.* Maintain the diverse values and resources of traditionally associated Tribes along the Colorado River corridor through Glen, Marble, and Grand Canyons.

9. *Rainbow Trout Fishery.* Achieve a healthy high-quality recreational rainbow trout fishery in GCNRA and reduce or eliminate downstream trout migration consistent with NPS fish management and ESA compliance.

10. *Nonnative Invasive Species.* Minimize or reduce the presence and expansion of aquatic nonnative invasive species.

11. *Riparian Vegetation.* Maintain native vegetation and wildlife habitat, in various stages of maturity, such that they are diverse, healthy, productive, self-sustaining, and ecologically appropriate.

The preferred alternative in the LTEMP EIS is Alternative D, which was developed by the DOI after a full analysis of the other six LTEMP alternatives had been completed. Alternative D adopted operational and experimental characteristics from other alternatives, after the effects of operations under other alternatives were modeled, and the results of that modeling suggested ways in which characteristics of each could be combined and modified to improve performance and reduce impacts, while meeting the purpose, need, and objectives of the LTEMP EIS. Alternative D features condition-dependent flow actions (operations at Glen Canyon Dam) and non-flow actions that would be triggered by resource conditions. Operations under the preferred alternative would use only existing dam infrastructure. There are a number of experimental and management actions that are a part of the preferred alternative; these are described briefly in the list below.

- Spring and fall HFEs would be implemented when triggered to rebuild sandbars. These HFEs include sediment-triggered HFEs in spring or fall, proactive spring HFEs as triggered by high annual release volume (> 10 maf), and extended duration (>96 hr) fall HFEs (Section 1.2.9).

- Nonnative fish control actions would be implemented if the Little Colorado River humpback chub population declined, and proactive conservation actions had failed to reverse declining populations. Two different tiers of population metrics would be used to trigger responses such as actions to increase growth and survival of humpback chub (Tier 1), or mechanical nonnative fish control

(Tier 2), which would only be implemented when Tier 1 actions fail to slow or reverse the decline in the humpback chub population (Section 1.2.10; Appendix D).

- Experimental trout management flows (TMFs) could be used to control annual trout production in the Glen Canyon reach for the purposes of managing the trout fishery and for limiting emigration to Marble Canyon and the Little Colorado River reach. Trout management flows will be tested early in the experimental period, preferably in the first 5 years (Section 1.2.10).

- Low summer flows may be tested in the second 10 years of the LTEMP period, for the purpose of achieving warmer river temperatures (> 14°C) to benefit humpback chub and other native species. Under low summer flows, daily fluctuations would be less than under base operations (e.g., approximately 2,000 cfs) (Section 1.2.10).

- Low steady weekend flows for macroinvertebrate production, "bug flows." The primary objective of bug flows is to test whether these flows will increase insect abundance. On an experimental basis, for example, flows would be held low and steady for 2 days per week (weekends) from May through August to attempt to improve the productivity of the aquatic food base, and increase the diversity and abundance of mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), referred to as EPT. While seeing EPT in the canyon is a worthwhile goal, it is a very long-term goal and unlikely to occur during initial experimentation (Section 1.2.11).

- Preservation of historic properties through a program of research, monitoring, and mitigation to address erosion and preservation of archeological and ethnographic sites and minimize loss of integrity at National Register historic properties.

- Continued adaptive management under the Glen Canyon Dam Adaptive Management Program (GCDAMP), including a research and monitoring component. Research projects have been developed on a 3-year funding cycle under the direction of the GCDAMP, which would continue under the proposed action. The level of fisheries monitoring will be expected to remain the same, or increase slightly, in order to address uncertainties and monitor responses to experiments and changed operations.

In addition, the joint-lead agencies have established "sideboards" that constrain the breadth and nature of the implementation of flow and non-flow actions of the proposed action.

1.2.4 Conservation Measures

Conservation measures identified in the 2011 Biological Opinion (BO) on operations of Glen Canyon Dam (FWS 2011a) included the establishment of a humpback chub refuge, evaluation of the suitability of habitat in the lower Grand Canyon for the razorback sucker, and establishment of an augmentation program for the razorback sucker, if appropriate. Other measures include humpback chub translocation; Bright Angel Creek brown trout control; Kanab ambersnail monitoring; determination of the feasibility of flow options to control trout, including increasing daily down-ramp rates to strand or displace age-0 trout, and high flow followed by low flow to strand or displace age-0 trout; assessments of the effects of actions on humpback chub populations; sediment research to determine effects of equalization flows; and Asian tapeworm (*Bothriocephalus acheilognathi*) monitoring. Most of these conservation measures are ongoing and are elements of existing management practices (e.g., brown trout control, humpback chub translocation, and sediment research to determine the effects of equalization flows), while new conservation measures or adjustments to the existing ones have been developed for the proposed action. These include experimental and management actions at specific sites such as nonnative plant removal, revegetation with native species, and mitigation at specific and appropriate cultural sites.

Five species listed under the ESA are addressed in the BA: humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), Kanab ambersnail (*Oxyloma kanabensis*), southwestern willow flycatcher (*Empidonax traillii extimus*), and Yuma Ridgway's rail (*Rallus longirostris yumanensis*). Conservation measures to minimize or reduce the effects of the proposed action or benefit or improve the status of listed species as part of the LTEMP are organized by species below.

1.2.4.1 Humpback Chub

Ongoing actions for the humpback chub include the following:

- Reclamation will continue to support the NPS, FWS, Grand Canyon Monitoring and Research Center (GCMRC), and the GCDAMP in funding and implementing translocations of humpback chub into tributaries of the Colorado River in Marble and Grand Canyons, and in monitoring the results of these translocations, consistent with agencies' plans and guidance (e.g., NPS Comprehensive Fisheries Management Plan [CFMP], FWS Humpback Chub Genetics Management Plan, and Translocation Framework, and GCMRC Triennial Work Plan). Specifically, the following will occur:
  - Humpback chub will be translocated from the lower reaches of the Little Colorado River to areas above Chute Falls in an effort to increase growth rates and survivorship.
  - Monitoring will be conducted annually, or as needed, depending on the data required, to determine survivability, population status, or genetic integrity of the Havasu humpback chub population. Intermittent translocations of additional humpback chub in Havasu Creek will be

conducted if the FWS and NPS determine it is necessary to maintain genetic integrity of the population.

- Reclamation will continue to fund a spring and fall population estimate annually, using a mark recapture based model for the Little Colorado River or the most appropriate model developed for the current collecting techniques and data.

- Reclamation will continue to fund control or removal of nonnative fish in tributaries prior to chub translocations depending on the existing fish community in each tributary. Reclamation, NPS, and FWS will lead any investigation into the possibility of using a chemical piscicide, or other tools, as appropriate. Tributaries and the appropriate control methods will be identified by the FWS, NPS, Reclamation, and GCMRC, in consultation with the AZGFD. Depending on the removal methods identified, additional planning and compliance (e.g., National Environmental Policy Act [NEPA], NHPA) may be necessary.

- Reclamation will continue to fund the FWS in maintenance of a humpback chub refuge population at a federal hatchery (Reclamation has assisted the FWS in creating a humpback chub refuge at the Southwestern Native Aquatic Resources and Recovery Center [SNARRC]) or other appropriate facility by providing funding to assist in annual maintenance (including the collection of additional humpback chub from the Little Colorado River for this purpose). In the unlikely event of a catastrophic loss of the Grand Canyon population of humpback chub, a humpback chub refuge will provide a permanent source of sufficient numbers of genetically representative stock for repatriating the species.

- Reclamation will continue to assist the FWS, NPS and the GCDAMP to ensure that a stable or upward trend of humpback chub mainstem aggregations can be achieved by:
  - Continuing to conduct annual monitoring of the Little Colorado River humpback chub aggregation (e.g., juvenile chub monitoring [JCM] parameters). Periodically, an open or multistate model should be run to estimate abundance of the entire Little Colorado River aggregation inclusive of mainstem fish.
  - Supporting annual monitoring in the mainstem Colorado River to determine status and trends of humpback chub and continuing to investigate sampling and analytical methods to estimate abundance of chub in the mainstem.
  - Conducting periodic surveys to identify additional aggregations and individual humpback chub.
  - Evaluating existing aggregations and determining drivers of these aggregations, for example, recruitment, natal origins, spawning locations,

and spawning habitat (e.g., consider new and innovative methods such as telemetry or the Judas-fish approach) (Keggeries et al. 2015).
  - Exploring means of expanding humpback chub populations outside of the Little Colorado River Inflow aggregation. Evaluate the feasibility of mainstem augmentation of humpback chub that would include larval collection, rearing, and release into the mainstem at suitable areas outside of or within existing aggregations.

An ongoing action for the humpback chub that needs enhancement is the following:

- Reclamation will, through the GCDAMP, conduct disease and parasite monitoring in humpback chub and other fishes in the mainstem Colorado. The U.S. Geological Survey (USGS) and GCMRC are currently conducting parasite monitoring in the Little Colorado River. However, in order to better understand how/if disease and parasites (primarily Asian tapeworm) are affecting chub and how temperature differences may affect parasite occurrence, this work will be expanded to include investigations of parasites in humpback chub (and surrogate fish if necessary) in the mainstem.

New actions for the humpback chub include the following:

- Reclamation will collaborate with the FWS, GCMRC, NPS, and the Havasupai Tribe to conduct preliminary surveys and a feasibility study for translocation of humpback chub into Upper Havasu Creek (above Beaver Falls). The implementation of surveys and translocations, following the feasibility study, will be dependent on interagency discussions, planning and compliance, and resulting outcomes of Tribal consultation under Section 106 of the NHPA.

- Reclamation will, in cooperation with the FWS, NPS, GCMRC, and AZGFD, explore and evaluate other tributaries for potential translocations.

1.2.4.2 Razorback Sucker

Ongoing actions for the razorback sucker include the following:

- Reclamation will continue to assist the NPS, FWS, and the GCDAMP in funding larval and small-bodied fish monitoring in order to:
  - Determine the extent of hybridization in flannelmouth and razorback sucker larvae collected in the western Grand Canyon through genetic analysis.

- Determine habitat use and distribution of different life stages of razorback sucker to assist in future management of flows that may help conserve the species. Sensitive habitats to flow fluctuations could be identified and prioritized for monitoring.
- Assess the effects of TMFs and other dam operations on razorback sucker.

1.2.4.3 Nonnative Species – Removal and Control Actions (for all native aquatic species)

Nonnative fish are important stressors contributing to the decline of native and endangered fish species in the Colorado River. While many of these species are ubiquitous and likely impossible to remove or control, actions targeted on particular species and locations can decrease nonnative effects on endangered species. Reclamation maintains, through the GCDAMP, the experimental fund that retains funding for emergency needs such as removal of nonnative fish.

Reclamation will continue, in cooperation with, the NPS, FWS, AZGFD, GCMRC, and GCDAMP, funding and implementation of the following ongoing actions:

- Reclamation, in collaboration with the NPS and FWS, and in consultation with the AZGFD, will investigate the possibility of renovating Bright Angel and Shinumo Creeks with a chemical piscicide, or other tools, as appropriate. Additional planning and compliance, and Tribal consultation under Section 106 of the NHPA, would be required. This feasibility study is outlined in the CFMP (see "Feasibility Study for Use of Chemical Fish Control Methods").

- Reclamation will continue to fund efforts of the GCMRC and NPS to remove brown trout (and other nonnative species) from Bright Angel Creek and the Bright Angel Creek Inflow reach of the Colorado River, and from other areas where new or expanded spawning populations develop, consistent with the NPS CFMP. After 5 years of removal efforts are completed (in 2017), an analysis of success will be conducted. Piscicides may be considered for removal of nonnative species if determined to be appropriate and following completion of the necessary planning and compliance actions.

Reclamation will continue, in cooperation with, the NPS, FWS, AZGFD, GCMRC, and the GCDAMP, funding and implementation of the following new actions:

- Reclamation will explore the efficacy of a temperature control device at the dam to respond to potential extremes in hydrological conditions due to climate change and could result in nonnative fish establishment. Evaluations would be ongoing for all current and evolving technological advances that could provide for warming and cooling the river in both high- and low-flow discharge scenarios, high and low reservoir levels. These studies should

include evaluating and pursuing new technologies, an analysis of the feasibility, and a risk assessment and cost analysis for any potential solutions.

- Reclamation will pursue means of preventing the passage of deleterious invasive nonnative fish through Glen Canyon Dam. Because Glen Canyon Dam release temperatures are expected to be warmer under low reservoir elevations that may occur through the LTEMP period, options to hinder expansion of warmwater nonnative fishes into Glen and Grand Canyons will be evaluated. Potential options to minimize or eliminate passage through the turbine or bypass intakes, or minimize survival of nonnative fish that pass through the dam will be assessed (flows, provide cold water, other). While feasible options may not currently exist, technology may be developed in the LTEMP period that could help achieve this goal.

- Reclamation will, in consultation with the FWS and AZGFD, fund the NPS and GCMRC on the completion of planning and compliance to alter the backwater slough at RM-12, making it unsuitable or inaccessible to warmwater nonnative species. Depending on the outcome of NPS planning and compliance, Reclamation will implement the plan in coordination with the FWS, AZGFD, NPS and GCMRC. Additional coordination will be conducted to determine and access any habitats that may support warmwater nonnatives.

- Reclamation will support the GCMRC and NPS in consultation with the FWS and AZGFD on the completion of planning and compliance of a plan for implementing rapid response control efforts for newly establishing or existing deleterious invasive nonnative species within and contiguous to the action area. Control efforts may include chemical, mechanical, or physical methods. While feasible options may not currently exist, new technology or innovative methods may be developed in the LTEMP period that could help achieve this goal. Rapid response to new warmwater fish invasions may become a more frequent need in the future with lower reservoir elevations and warmer dam releases.

- Reclamation, in cooperation with the GCDAMP, will explore the use of flow (e.g., TMFs) to inhibit brown trout spawning and recruitment in Glen Canyon, or other mainstem locations.

1.2.4.4 Southwestern Willow Flycatcher and Yuma Ridgway's Rail

Reclamation will fund the NPS to conduct southwestern willow flycatcher and Yuma Ridgway's rail presence/absence, nest surveys, and on-the-ground monitoring of habitat throughout the action area throughout the life of the LTEMP. Specifically, the following will occur:

- Reclamation will partially assist in funding NPS to conduct Yuma Ridgway's rail surveys once every 3 years for the life of the LTEMP.

- Reclamation will partially assist in funding NPS to conduct southwestern willow-flycatcher surveys once every 2 years for the life of the LTEMP.

1.2.5 Base Operations

Under the proposed action, monthly water release volumes correspond closely to the monthly hydropower demand as shown in Table 2. The total monthly release volume of October, November, and December is equal to that under current operations (MLFF) to minimize the possibility of the operational tier differing from that of current operations, as established in the Interim Guidelines (Reclamation 2007a). The distribution of monthly release volumes under the proposed action results in a more even distribution of flows over the course of a water year relative to existing, or baseline, MLFF.

Under base operations of the proposed action, the allowable daily fluctuation range from Glen Canyon Dam (i.e., the difference between the minimum and maximum flows within a day) is proportional to the volume of water scheduled to be released during the month (10 × monthly volume in thousand acre-feet (kaf) in the high-demand months of June, July, and August and 9 × monthly volume in kaf in other months; Table 2; Figure 2). For example, the daily fluctuation range in July with a scheduled release volume of 800 kaf would be 8,000 cfs, and the daily fluctuation range in December with the same scheduled release volume would be 7,200 cfs. The maximum allowable daily fluctuation range in flows in any month would be 8,000 cfs, which is the same as under current operations. However, the down-ramp rate limit under the proposed action would be increased by 1,000 cfs/hr, to 2,500 cfs/hr. The up-ramp rate would remain the same at 4,000 cfs/hr. Figure 2 shows minimum, mean, and maximum daily flows in an 8.23-milion acre-foot (maf) year, assuming all days in a month adhere to the same mean daily flow within a month. Figure 3 shows the hourly flows in a simulated 8.23-maf year within the constraints of the proposed action.

1.2.6 Operational Flexibility

Reclamation retains the authority to utilize operational flexibility at Glen Canyon Dam because hydrologic conditions of the Colorado River Basin (or the operational conditions of Colorado River reservoirs) cannot be completely known in advance. Consistent with current operations, Reclamation, in consultation with WAPA, will make specific adjustments to daily and monthly release volumes during the water year. Monthly release volumes may be rounded for practical implementation or for maintenance needs. In addition, when releases are actually implemented, minor variations may occur regularly for a number of operational reasons that cannot be projected in advance.

TABLE 2 Flow Parameters under the Proposed Action in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	763	0.0928	12,415	6,871
February	675	0.0820	12,157	6,076
March	713	0.0866	11,596	6,417
April	635	0.0772	10,672	5,715
May	632	0.0768	10,278	5,688
June	663	0.0806	11,142	6,630
July	749	0.0910	12,181	7,490
August	800	0.0972	13,011	8,000
September	600	0.0729	10,083	5,400

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

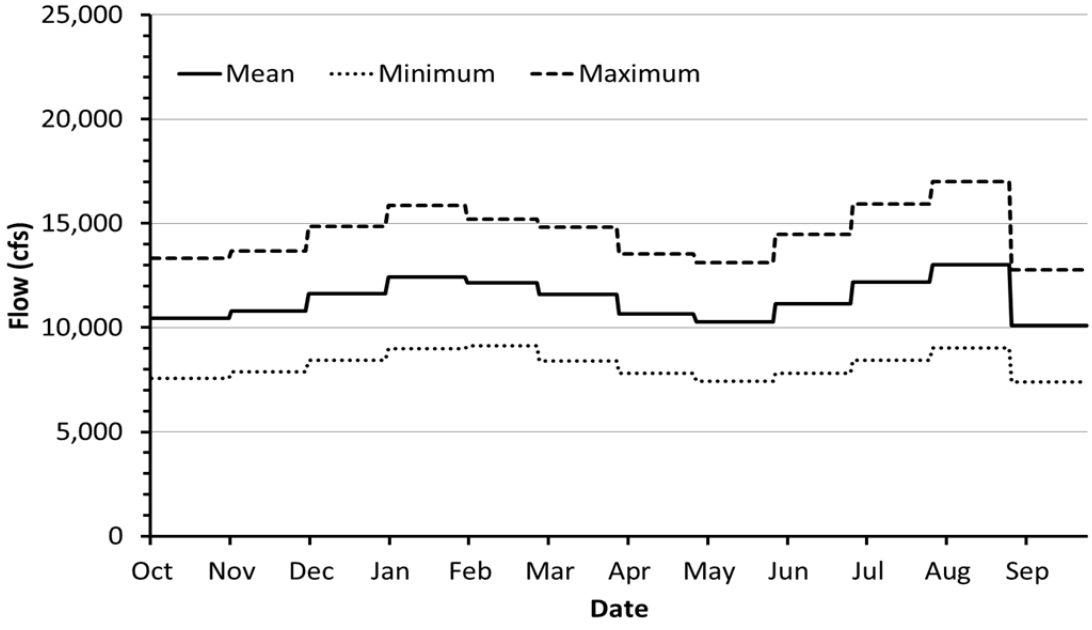


FIGURE 2 Mean, Minimum, and Maximum Daily Flows under the Proposed Action in an 8.23-maf Year

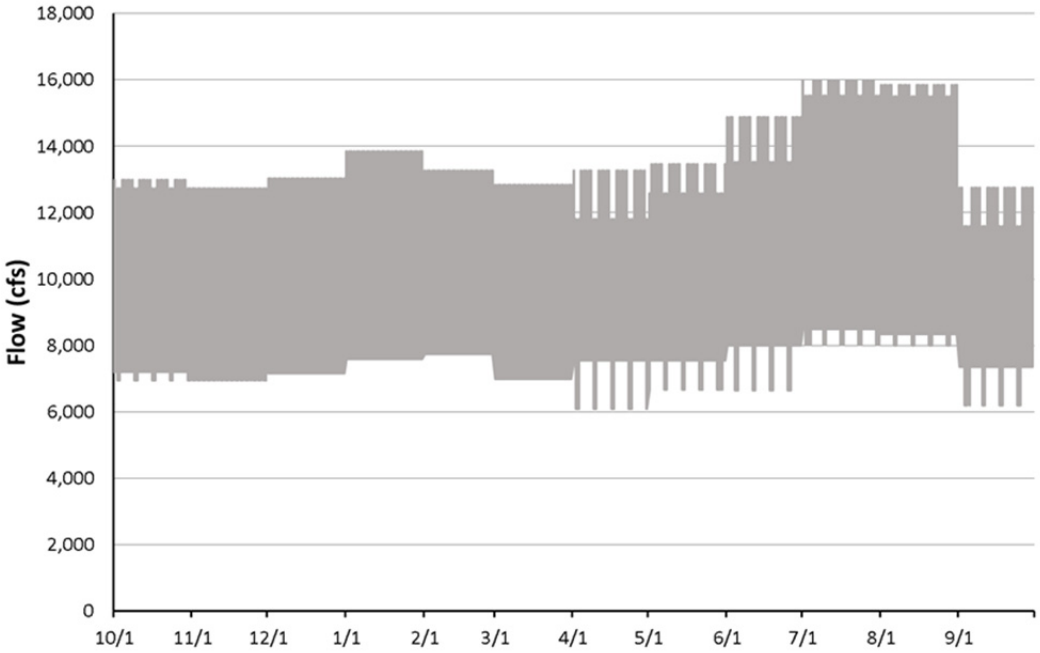


FIGURE 3 Simulated Hourly Flows under the Proposed Action in an 8.23-maf Year (Note that there are differences in the mean, maximum, and minimum flows shown here and in Figure 2. These differences reflect flexibility in operational patterns allowed within the constraints of the proposed action.)

Reclamation also will make specific adjustments to daily and monthly release volumes, in consultation with other entities as appropriate, for a number of reasons, including operational, resource-related, and hydropower-related issues. Examples of these adjustments may include, but are not limited to, the following:

- For water distribution purposes, volumes may be adjusted to allocate water between the Upper and Lower Basins, consistent with the Law of the River as a result of changing hydrology;

- For resource-related issues that may occur uniquely in a given year, release adjustments may be made to accommodate nonnative species removal, to assist with aerial photography, or to accommodate other resource considerations separate from experimental treatments under the LTEMP; and

- For hydropower-related issues, adjustments may occur to address issues such as electrical grid reliability, actual or forecasted prices for purchased power, transmission outages, and experimental releases from other Colorado River Storage Project dams.

In addition, Reclamation may make modifications under circumstances that may include operations that are prudent or necessary for the safety of dams, public health and safety, other

emergency situations, or other unanticipated or unforeseen activities arising from actual operating experience (including, in coordination with the Basin States, actions to respond to low reservoir conditions as a result of drought in the Colorado River Basin). Also, the Emergency Exception Criteria established for Glen Canyon Dam will continue under the proposed action. (See, e.g., Section 3 of the Glen Canyon Operating Criteria at 62 FR 9448, March 3, 1997.)

1.2.7 Implementation of Experimental Elements

The proposed action identifies condition-dependent flow and non-flow treatments intended to safeguard against unforeseen adverse changes in resource impacts, and to prevent irreversible changes to those resources. These condition-dependent treatments will be implemented experimentally during the LTEMP period unless they prove ineffective or result in unacceptable adverse impacts on other resources. Experimental treatments include sediment treatments, triggered humpback chub conservation actions, TMFs, mechanical removal of nonnative fish, low summer flows, macroinvertebrate production flows, and non-flow-related vegetation treatments.

1.2.8 Overall Implementation Process for Experiments

Prior to implementation of any experiment, the relative effects of the experiment on the following resource areas will be evaluated and considered: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and WAPA's assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources. Although these key resources are listed for consideration on a regular basis, the DOI intends to retain sufficient flexibility in implementation of experiments to allow for response to unforeseen circumstances or events that involve any other resources not listed here. The recent discovery of nonnative green sunfish in the Glen Canyon reach illustrates the need to be responsive to unforeseen conditions.

The proposed approach differs fundamentally from a more formal experimental design (e.g., before-after control-impact design, factorial design) that attempts to resolve uncertainties by controlling for or treating potentially influential or confounding factors. There are several reasons to avoid such a formal design and instead focus on the condition-dependent approach described here. Among these are (1) the difficulties in controlling for specific conditions in a system as complex as the Colorado River; (2) wide variability in temperature and flow conditions that are important drivers in ecological processes; (3) inherent risk of some experimentation to protected sensitive resources, in particular, endangered humpback chub; (4) conflicting multiple-use values and objectives; and (5) low expected value-of-information for the uncertainties that could be articulated, and around which a formal experimental design would be established. For these reasons, the proposed action includes a condition-dependent adaptive approach.

Table 3 provides the implementation criteria for condition-dependent experimental treatments of the proposed action, and triggers for treatments are discussed under the description below. Triggers for experimental changes in operations, implementation considerations for determining if an experimental treatment should proceed, conditions that would cause the treatment to be terminated prior to completion (i.e., off-ramps), and the number of replicates that are initially considered needed are discussed below. In many cases, two to three replicates of an experimental treatment are considered necessary. The results of these tests will be used to determine if these condition-dependent treatments should be retained as part of the suite of long-term actions implemented under LTEMP. In other cases, implementation of experimental treatments would continue throughout the LTEMP period if triggered (e.g., spring and fall HFEs), except in years when it was determined that the proposed experiment could result in unacceptable adverse impacts on resource conditions. For these experiments, effectiveness would be monitored and the experiments would be terminated or modified only if sufficient evidence suggested the treatment was ineffective or had unacceptable adverse impacts on other resources. All experimental treatments will be closely monitored for adverse side effects on important resources. At a minimum, an unacceptable adverse impact would include significant negative impacts on resources as a result of experimental treatments that have not been analyzed for the proposed action in the LTEMP EIS.

In implementing the processes described here and the associated decision process shown in Table 3, the DOI will exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. As an initial platform to discuss potential future experimental actions, the DOI will hold GCDAMP annual reporting meetings for all interested stakeholders; these meetings will present the best available scientific information and learning from previously implemented experiments and ongoing monitoring of resources. As a follow-up to this process, the DOI will meet with the Technical Working Group (TWG) to discuss the experimental actions being contemplated for the year.

The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (USGS, NPS, FWS, Bureau of Indian Affairs [BIA], and Reclamation), WAPA, AZGFD, and representatives from the Basin States and the Upper Colorado River Commission (UCRC). Each DOI bureau will provide updates on the status of resources and dam operations. In addition, WAPA will provide updates on the status of the Basin Fund, projected purchase power prices, and its financial and operational considerations. These meetings or calls are intended to provide an opportunity for participants to share and obtain the most up-to-date information on dam operational considerations and the status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One liaison from each Basin State and from the UCRC will be allowed to participate in the monthly operational coordination meetings or calls.

TABLE 3 Implementation Criteria for Experimental Treatments under the Proposed Action

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations[a]	Long-Term Off-Ramp Conditions	Action, If Successful
Sediment Treatments						
Spring HFE up to 45,000 ft^3/s (cfs) (in Mar. or Apr.)	Trigger: Sufficient Paria River sediment input in spring accounting period (Dec.–Jun.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Not conducted during first 2 years of LTEMP, otherwise, implement in each year triggered, dependent on resource condition and response	≤96 hr	Potential short-term unacceptable impacts on the resources listed in footnote (a); unacceptable cumulative effects of sequential HFEs; sediment-triggered spring HFEs will not occur in the same water year as an extended-duration (>96 hr) fall HFE	Sediment-triggered spring HFEs are not effective in building sandbars, or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered and resource conditions allow
Proactive spring HFE up to 45,000 cfs (Apr., May, or Jun.)	Trigger: High-volume year with planned equalization releases (≥10 maf) Objective: Protect sand supply from equalization releases	Not conducted during first 2 years of LTEMP, otherwise, implement in each year triggered, dependent on resource condition and response	First test 24 hr; subsequent tests could be shorter, but not longer, depending on results of first tests	Potential short-term unacceptable impacts on the resources listed in footnote (a); unacceptable cumulative effects of sequential HFEs; would not be implemented in same water year as a sediment-triggered spring HFE or extended duration fall HFE	Proactive spring HFEs are not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Fall HFEs ≤ 96 up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE Objective: Rebuild sandbars	Implement in each year triggered dependent on resource condition and response	≤96 hr	Potential unacceptable impacts on resources listed in footnote (a)	This type of HFE was not effective in building sandbars; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered and existing resource conditions allow

TABLE 3 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations[a]	Long-Term Off-Ramp Conditions	Action, If Successful
Sediment Treatments (Cont.)						
Fall HFEs longer than 96-hr duration up to 45,000 cfs in Oct. or Nov.	Trigger: Sufficient Paria River sediment input in fall accounting period (Jul.–Nov.) to achieve a positive sand mass balance in Marble Canyon with implementation of an HFE longer than a 96-hr, up to 45,000-cfs flow Objective: Rebuild sandbars	Implement in each year triggered; limited to total of four tests in LTEMP period	Up to 250 hr depending on availability of sand; duration of first test not to exceed 192 hr	Potential short-term unacceptable impacts on the resources listed in footnote (a); unacceptable cumulative effects of sequential HFEs.	Extended duration fall HFEs are not effective in building sandbars; resulting sandbars are no bigger than those created by shorter-duration HFEs; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered and existing resource conditions allow
Aquatic Resource Treatments						
Trout management flows	Trigger: Predicted high trout recruitment in the Glen Canyon reach Objective: Test efficacy of flow regime on trout numbers and survival of chub	Implement as needed when triggered; after consultation with Tribes; test may be conducted early in the 20-year period even if not triggered by high trout recruitment[b]	Implemented in as many as 4 months (May–Aug.)	Potential unacceptable impacts on resources listed in footnote (a)	Trout management flows have little or no effect on trout recruitment after at least three tests, or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment triggered by predicted high trout recruitment in Glen Canyon, taking into consideration Tribal concerns
Tier 1: Expanded translocation of humpback chub in the Little Colorado River	Trigger: Number of adult or subadult humpback chub in the Little Colorado River reach below tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective.	As needed	Potential short-term unacceptable impacts on resources listed in footnote (a)	Expanded translocation has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered

TABLE 3 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations[a]	Long-Term Off-Ramp Conditions	Action, If Successful
Aquatic Resource Treatments (Cont.)						
Tier 1: Implement headstart program for larval humpback chub	Trigger: Number of adult or subadult humpback chub in Little Colorado River reach below Tier 1 triggers Objective: Increase number of adult and subadult humpback chub	Implement in each year triggered unless determined ineffective	As needed	Potential short-term unacceptable impacts on resources listed in footnote (a)	Head-start program has little or no effect on increasing the number of adult or subadult humpback chub; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered
Tier 2: Mechanical removal of nonnative fish in Little Colorado River reach	Trigger: Tier 1 actions ineffective; humpback chub number in Little Colorado River below Tier 2 triggers Objective: Increase number of adult and sub-adult humpback chub	Implement in each year triggered unless determined ineffective, after consultation with Tribes	Monthly removal trips (Feb.–Jul.) until "predator index" or adult humpback chub reach acceptable levels (Appendix D)	Potential short-term unacceptable impacts on resources listed in footnote (a)	Mechanical removal has little or no reduction in predator index in the Little Colorado River reach; no population-level benefit on humpback chub or unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment when triggered, taking into consideration Tribal concerns
Low summer flows (minimum daily mean 5,000 to 8,000 cfs) to target ≥ 14°C at Little Colorado River confluence	Trigger: Initial experiment in the second 10 years of the LTEMP period, when target temperature of ≥14°C can only be achieved with low summer flow Objective: Increase humpback chub growth	Subsequent experimental use if (1) initial test was successful, (2) humpback chub population concerns warrant their use, (3) water temperature appears to be limiting recruitment and (4) target temperature of ≥14°C could be achieved only with low summer flow	3 months (Jul.–Sep.)	Potential unacceptable impacts on resources listed in listed in footnote (a)	Low summer flows do not increase growth and recruitment of humpback chub; increase in warmwater nonnative species or trout at the Little Colorado River; or long-term unacceptable impacts on resources listed in footnote (a) are observed, or sufficient warming does not occur as predicted	Implement as adaptive treatment when conditions allow

TABLE 3 (Cont.)

Experimental Treatment	Trigger and Primary Objective	Replicates	Duration	Annual Implementation Considerations[a]	Long-Term Off-Ramp Conditions	Action, If Successful
Aquatic Resource Treatments (Cont.)						
Low steady weekend flows for macroinvertebrate production	Trigger: None Objective: Improve food base productivity and abundance or diversity of mayflies, stoneflies, and caddisflies	Target two to three replicates	Up to 4 months (May–Aug.)	Potential short-term unacceptable impacts on resources listed in footnote (a); coordinate planning with other experiments to avoid confounding conditions or results	Steady weekend flows have little or no benefit on food base, trout fishery, or native fish; increase in warmwater nonnative species or trout in the Little Colorado River reach; or long-term unacceptable adverse impacts on the impacts on resources listed in footnote (a) are observed	Implement as adaptive treatment in target months when conditions allow
Riparian Vegetation Treatments						
Non-flow vegetation treatments	Trigger: None Objective: Improve vegetation conditions at key sites	Not applicable	20 years if successful pilot phase	Potential short-term unacceptable impacts on resources listed in footnote (a)	Control and replanting techniques are not effective or practical; or long-term unacceptable adverse impacts on the resources listed in footnote (a) are observed	Implement as adaptive treatment if invasive species can be reduced and native species increased

[a] Prior to implementation of any experiment, the relative effects of the experiment on the following resource areas will be evaluated and considered: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and WAPA's assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources.

[b] The decision to conduct TMFs in a given year would consider the resource conditions listed in footnote (a) and would also involve considerations regarding the efficacy of the test based on those resource conditions.

To determine whether conditions are suitable for implementing or discontinuing experimental treatments or management actions, the DOI will schedule implementation/planning meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA and Reclamation), WAPA, AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by the participants. The implementation/planning group will strive to develop a consensus recommendation to bring forth to the DOI regarding resource issues as detailed at the beginning of this section, as well as including WAPA's assessment of the status of the Basin Fund. The Secretary of the Interior will consider the consensus recommendations of the implementation/planning group; however, it retains sole discretion to decide how best to accomplish operations and experiments in any given year pursuant to the LTEMP ROD and other binding obligations.

The DOI will also continue separate consultation meetings with the Tribes, AZGFD, the Basin States, and UCRC upon request, or as required under existing RODs.

Sections 1.2.9 and 1.2.10 describe specific processes for development and implementation of experiments related to sediment, aquatic resources, and riparian vegetation. The overall approach attempts to strike a balance between identifying specific experiments and providing flexibility to implement those experiments when resource conditions are appropriate. As discussed above, rather than proposing a prescriptive approach to experimentation, an adaptive management-based approach that is responsive and flexible would be used to adapt to changing environmental and resource conditions and new information. The potential for confounding interactions among individual experimental treatments is discussed when relevant for each of the proposed treatments. Given the size of the project area, and the variability inherent in the system, this pragmatic approach to experimentation is warranted. Although confounding treatments are possible given the complexity of the experimental plan, they are not expected to limit learning over the life of the LTEMP.

1.2.9 Sediment-Related Experimental Treatments

Figure 4 shows the decision tree for implementation of sediment experiments during the LTEMP period. Under the proposed action, the existing HFE protocol was updated and incorporated into the LTEMP process as specified in Appendix P of the LTEMP EIS. Changes to the existing protocol were related to implementation of the new HFEs that are included under the proposed action and an extension of the protocol to the end of the LTEMP period. This new protocol would replace the existing protocol when the LTEMP ROD is issued. Spring and fall HFEs would be implemented when triggered during the 20-year LTEMP period based on the estimated sand mass balance resulting from Paria River sediment inputs during the spring and fall accounting periods, and the dam release pattern during the accounting period. HFE releases would be 1 to 250 hr long and between 31,500 and 45,000 cfs. Depending on the cumulative amount of sediment input from the Paria River during the spring (December 1 through June 30) or fall (July 1 through November 30) accounting periods, and the expected accumulation of sand, the maximum possible magnitude and duration of HFEs that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling, would be implemented.

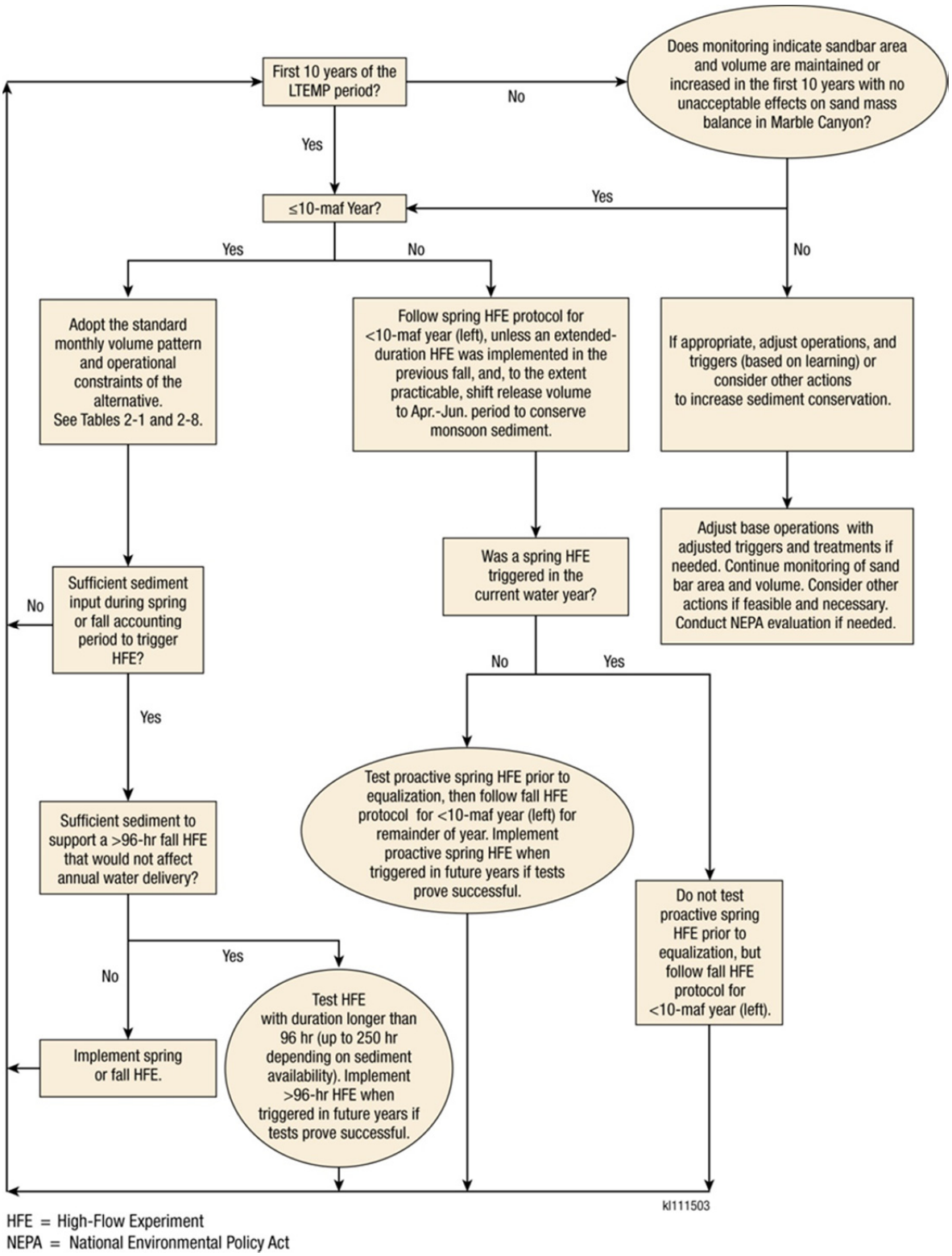


FIGURE 4 Decision Tree for Implementation of Sediment-Related Experimental Treatments under the Proposed Action

Sand mass balance modeling would be used to ensure that the duration and magnitude of an HFE are best matched with the mass of sand present in the system during a particular release window. The magnitude and duration of HFEs will not affect the total annual release from Glen Canyon Dam. Reclamation will consider the total water to be released in the water year when determining the magnitude and duration of an HFE.

Sediment-related experiments under the proposed action include (1) sediment-triggered spring and fall HFEs up to 96-hr duration; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years prior to equalization releases; and (3) implementation of up to four extended-duration (>96 hr) HFEs, up to 250 hr long, depending on sediment conditions. The pattern of transferring water volumes from other months to make up the HFE volume would be discussed in the monthly Glen Canyon Dam operational coordination meetings described in Section 1.2.8.

If sediment resources are stable or improving, the combination of base operations, HFE protocols, and other treatments will continue as prescribed. If sediment resource conditions decrease to unacceptable levels during the LTEMP period, operations may be modified to the extent allowable under the LTEMP ROD or would be evaluated and considered under a separate NEPA process, potentially including additional studies of sediment augmentation or other actions.

For all sediment experiments, testing will be modified or temporarily or permanently suspended if (1) experimental treatments are ineffective at accomplishing their objectives, or (2) there were unacceptable adverse impacts on resources (Table 3). Monitoring results will be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments are warranted.

Implementation of HFEs would consider resource condition assessments and resource concerns using the annual processes described in Section 1.2.8. HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8. In addition, there is uncertainty associated with cumulative impacts from sequential HFEs. These cumulative impacts would be considered before implementing an HFE.

1.2.9.1 Sediment-Triggered Spring HFEs

Under the proposed action, sediment-triggered spring HFEs will be implemented after an initial 2-year delay in order to enable testing of the effectiveness of TMFs, if warranted, and address concerns raised by the apparent positive response of trout to the 2008 spring HFE (Korman et al. 2011; Melis et al. 2011). Modeling the trout response to spring HFEs for the EIS was based on relationships developed from the observed response to the 2008 spring HFE. That modeling also evaluated uncertainty related to the effectiveness of TMFs to control excess trout produced by HFEs. Modeling indicated that even at a relatively low level of effectiveness (10% reduction in trout recruitment), TMFs could effectively reduce the number of trout out-migrants from Glen Canyon to the Little Colorado River reach (RM 61) where humpback chub occur.

After the first 2 years of the LTEMP period, spring HFEs will be implemented when triggered in accordance with the HFE protocol unless an extended-duration fall HFE occurred in the same water year. Modeling indicates spring HFEs will be triggered in about 26% of the years in the LTEMP period. Sediment-triggered spring HFEs would be implemented when triggered during the entire LTEMP period unless new information indicated they were not effective in building sandbars, or there were unacceptable adverse effects on resources (Section 1.2.8).

Implementation of a spring HFE may provide important replication of the 2008 spring HFE and aid in understanding the effect of spring HFEs on the trout population. It is possible that the strong 2008 response was a result of the specific conditions present in 2008 (e.g., condition of the food base, trout population size). It is unclear whether implementation under current conditions would produce the same result, and there is a good deal of learning that could result from implementation early in the LTEMP period. Implementing a spring HFE early in the LTEMP period when chub numbers are relatively high may also be a relatively low-risk option. To provide a means of controlling trout recruitment following tests of spring HFEs, TMFs will be experimentally implemented and tested for efficacy early in the LTEMP period (see discussion of TMFs below).

Implementation of sediment-triggered spring HFEs would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Spring HFEs may not be tested when there appears to be the potential for unacceptable adverse impacts on the resources listed in Section 1.2.8. In addition, there is uncertainty associated with the cumulative impacts of sequential HFEs on sediment, aquatic, and potentially other resources. These cumulative impacts would be considered before implementing a spring HFE particularly if a fall HFE had been implemented in the same water year.

1.2.9.2 Proactive Spring HFEs

GCMRC scientists identified proactive spring HFEs as a potential experimental treatment to transport and deposit in-channel sand at elevations above those of equalization flows. These HFEs will be tested only in years with high annual water volume (i.e., ≥10 maf), and modeling suggests that this would be a relatively rare treatment. A first test would be a 24-hr 45,000-cfs release conducted in April, May, or June. Duration in subsequent tests could be shortened depending on the observed response during the first tests. It would be preferable to test proactive spring HFEs at least two to three times in the 20-year LTEMP period, but being able to do so will be dependent upon annual hydrology. Modeling indicates that proactive spring HFEs would be triggered in about 10% of the years in the LTEMP period.

Proactive spring HFEs would not be tested in the first 2 years of the LTEMP period. In addition, proactive spring HFEs will not be tested in years when there had been a spring HFE or extended-duration fall HFE earlier in the same water year. Proactive spring HFEs could be performed in the same water year as a 96-hr or shorter sediment-triggered fall HFE, although prior to implementation, the potential effects of these HFEs would be carefully evaluated using the processes described in Section 1.2.8. The first test would be carefully evaluated to determine whether additional tests were warranted based on the efficacy of building and maintaining

sandbars. If initial tests show positive results without unacceptable adverse effects on the resources listed in Section 2.2.4.3, proactive spring HFEs would be implemented when triggered during the entire LTEMP period..

Implementation of proactive spring HFEs would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Proactive spring HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources identified in Section 1.2.8. The cumulative impacts of sequential HFEs would be considered before implementing a proactive spring HFE.

1.2.9.3 Sediment-Triggered Fall HFEs

The effects of sediment-triggered fall HFEs on trout recruitment are uncertain, but fall HFEs are expected to have less effect on trout production than spring HFEs. HFEs in November 2012, 2013, and 2014 resulted in little or no increase in the number of young-of-the-year (YOY) trout (VanderKooi 2015; Winters et al. 2016), and this observation may be based on the observed resilience of the food base to disturbance in the fall (Kennedy et al. 2015). However, factors affecting trout response to fall HFEs are not well understood. Modeling for the EIS considered the effect of fall HFEs on trout and modeled fall HFEs in two ways: in one, the effect of fall HFEs was half as long as that of a spring HFE (i.e., it affected trout production only in the water year in which it occurred); in the other, fall HFEs had no effect on trout production. Modeling the effect of fall HFEs in these two ways had an effect on the overall predicted number of trout produced, the number of out-migrants, and ultimately their effect on humpback chub. The number of trout produced and out-migrants were higher, and the number of humpback chub was lower if fall HFEs were assumed to have an effect on trout production.

Modeling indicates fall HFEs would be triggered in about 77% of the years in the LTEMP period. Testing fall HFEs is considered to be a relatively low-risk treatment due to the lack of observed or documented trout response from previous fall HFEs, and testing would be implemented when triggered during the entire LTEMP period unless new information indicated fall HFEs were not effective in building sandbars, or there were unacceptable adverse effects.

Implementation of sediment-triggered fall HFEs would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Fall HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8. The cumulative impacts of sequential HFEs would be considered before implementing a sediment-triggered fall HFE.

1.2.9.4 Extended-Duration Fall HFEs

Sediment-triggered fall HFEs with durations longer than 96 hr (up to 250 hr) would be tested under the proposed action. The duration of these extended-duration fall HFEs would be based on the amount of sediment delivered from the Paria River during the fall accounting period and would be no more than the maximum magnitude and duration of an HFE that would achieve

a positive sand mass balance in Marble Canyon, as determined by modeling. Based on examination of the observed historical sediment input from the Paria River, it was determined that HFEs up to 10.4 days in length (250 hr) could be supported before exhausting seasonal sediment inputs and affecting water delivery requirements. GCMRC scientists have suggested that increasing the duration of HFEs when sediment supply can support a longer duration may lead to more sand being deposited at higher elevations, resulting in bigger sandbars. Modeling indicates that this treatment will be triggered in 25% of the years in the LTEMP period. There will be no more than four extended-duration fall HFEs over the 20-year LTEMP period.

The duration of the first implementation of an extended-duration HFE will be limited to no more than 192 hr (twice as long as the current limit of 96 hr). This duration is considered long enough to produce a measurable result if the treatment represents an effective approach to building sandbars under enriched sediment conditions. The duration of all tests will be based on available sediment, current hydrology, reviews of available information, the expert opinion of GCMRC and other Grand Canyon scientists, and consideration of potential effects on the resources listed in Section 1.2.8. If feasible, monitoring will include real-time observations of sediment concentrations to determine if sediment deposition continues throughout the duration of the extended HFEs.

Implementation of extended-duration fall HFEs would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Extended-duration fall HFEs may not be tested when there appears to be potential unacceptable impacts on the resources listed in Section 1.2.8. Because the effects of extended-duration HFEs on Lake Mead water quality are a concern, DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of extended-duration HFEs. The cumulative impacts of sequential HFEs would be considered before implementing an extended-duration fall HFE.

Another important concern that results from the large volume of water bypassed is water delivery. Water delivery issues would be considered before deciding to implement an extended-duration fall HFE. An extended-duration HFE would not be implemented if annual release volume would be affected. It is possible that in lower volume years there would not be sufficient water available to support an extended-duration HFE. A 250-hr extended-duration HFE would result in a monthly total release of approximately 1.2 maf. In lower volume release years (e.g., 7.0 maf or 7.48 maf), the maximum duration may be less than 250 hr. In addition, a sediment-triggered spring HFE or proactive spring HFE would not be conducted in the same water year as an extended-duration fall HFE. If an extended-duration fall HFE was triggered but not implemented for any of the reasons described above, a fall HFE 96 hr or less in duration could be implemented instead. Implementation would necessitate reducing water volume in other months of the same water year.

In order to fully test the efficacy of these longer HFEs, several replicates would be desirable in the 20 year LTEMP period. Extended-duration HFEs would be considered successful and would be continued up to a total of four times in the 20-year LTEMP period as part of an adaptive experimental treatment if there was a widespread increase in bar size relative to ≤96-hr HFEs, and if sand mass balance was not significantly compromised relative to the

ability to maintain a long-term equilibrium. Extended-duration HFEs would not continue to be tested if they were not effective in building sandbars, if resulting total sandbar volumes were no bigger than those created by shorter-duration HFEs, or if unacceptable adverse impacts on the resources listed in Section 1.2.8 were observed.

1.2.10 Aquatic Resource-Related Experimental Treatments

Under the proposed action, most experimental flow and non-flow actions will be triggered or adjusted by considering the estimated number of humpback chub, number of rainbow trout, number of other nonnative fish, water release temperature, or a combination of these variables, depending on the action under consideration. Humpback chub triggers and trout triggers were developed in consultation with the FWS, NPS, and AZGFD. These triggers may be modified based on experimentation conducted early in the LTEMP period.

Aquatic resource experiments that will be tested include (1) TMFs, (2) Tier 1 conservation actions for humpback chub; (3) Tier 2 mechanical removal of nonnative fish, (3) low summer flows in the second 10 years of the LTEMP, and (4) macroinvertebrate production flows. Aquatic resource experiments would seek to refine our understanding of the impacts of water releases, HFEs, and TMFs on these resources. The primary uncertainty surrounding HFEs revolves around the extent to which the seasonality of HFEs or the number of adult rainbow trout determines the strength of rainbow trout recruitment.

Experimental nonnative fish control actions would be implemented if the humpback chub population declined, and proactive conservation actions had failed to reverse declining populations. Two different tiers of population metrics would be used to trigger responses including actions to increase growth and survival of humpback chub (Tier 1) and mechanical removal of nonnative fish (Tier 2); these would only be implemented when Tier 1 actions fail to slow or reverse the decline in the humpback chub population. This tiered approach and the triggers that would be used to implement it are described below.

For all aquatic resource experiments, testing will be modified or temporarily or permanently suspended if (1) experimental treatments are ineffective at accomplishing their objectives, or (2) there are potential unacceptable adverse impacts on the resources listed in Section 1.2.8. Monitoring results will be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments are warranted.

Implementation of aquatic resource experiments would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Aquatic resource experiments may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8.

1.2.10.1 Trout Management Flows

Mechanical removal of nonnative fish is a controversial issue in the Colorado River through Glen and Grand Canyons. A spring 2015 meeting of Grand Canyon biologists (NPS, FWS, AZGFD, and GCMRC) to assess current removal triggers resulted in a concept of early conservation measure intervention to maximize conservation benefit to humpback chub and minimize the likelihood of mechanical predator removal. Trout management flows are a potential tool that could be used to control annual trout production in the Glen Canyon reach for the purposes of managing the trout fishery and for limiting emigration from the Glen Canyon reach to Marble Canyon and the Little Colorado River reach.

Trout management flows are a special type of fluctuating flow designed to reduce the recruitment of trout by disadvantaging YOY trout (Figure 5). Trout management flows have been proposed and developed on the basis of research described in Korman et al. (2005). The underlying premise of TMFs is based on observations that YOY trout tend to occupy nearshore shallow-water habitats to avoid predation by larger fish. A potential scenario for TMFs features repeated fluctuation cycles that consist of relatively high flows (e.g., 20,000 cfs) sustained for a period of time (potentially ranging from 2 days to 1 week) followed by a rapid drop to a low flow (e.g., 5,000 to 8,000 cfs). This low flow will be maintained for a period of less than a day (e.g., 12 hr) to prevent adverse effects on the food base. Low flows would be timed to start in the morning, after sunrise, to expose stranded fish to direct sunlight and heat. Up-ramp rates to the

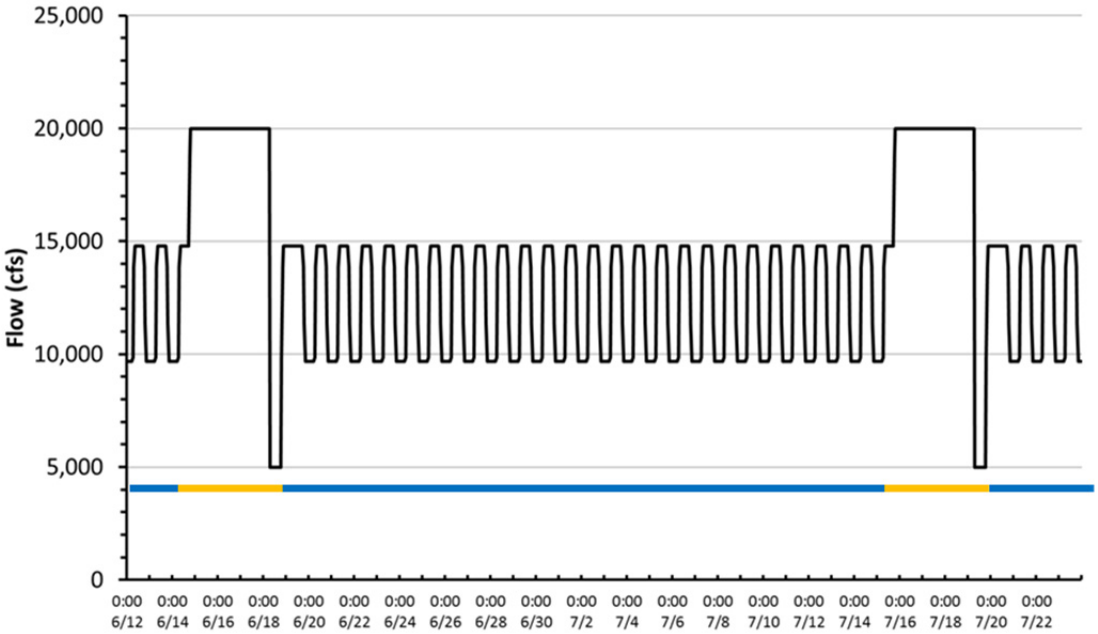


FIGURE 5 Example Implementation of a Two-Cycle Trout Management Flow in June and July with Resumption of Normal Fluctuations between Cycles and Afterward (Monitoring for effectiveness would occur before and after each cycle. The horizontal line below the graph shows periods of normal fluctuation [blue] and TMFs [orange].)

peak TMF will be the same as the limit for the proposed action overall (i.e., 4,000 cfs/hr). The down-ramp from peak to base would be over a single hour (e.g., 15,000 cfs/hr for a drop from 20,000 cfs to 5,000 cfs). These flow levels and rates are not fixed in order to allow flexibility in their design. In a TMF cycle, YOY trout are expected to occupy nearshore habitat when flows are highest, and would be subsequently stranded by the sudden drop to low flow. Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs. Trout management flows will be used to control trout recruitment in the Glen Canyon reach to manage the rainbow trout fishery, and to limit emigration of juvenile trout to downstream reaches, particularly to habitat occupied by humpback chub near the confluence with the Little Colorado River. Triggers for implementation of TMFs will be determined in consultation with the AZGFD, GCMRC, NPS, and Reclamation.

If resource conditions are appropriate, TMFs may be tested early in the experimental period, preferably in the first 5 years. These first tests could be triggered by modeled trout recruitment levels or otherwise implemented to test the effectiveness of TMFs. The intent of early tests is to determine the effectiveness of TMFs and a best approach to trout management. If TMFs are determined to be effective for controlling trout numbers while minimizing impacts on other resources, they may be deployed as an adaptive experimental treatment triggered by estimated trout recruitment.

It should be noted that several Tribes have expressed concerns about TMFs as a taking of life within the canyon without a beneficial use. The Pueblo of Zuni has expressed concern that the taking of life by trout stranding has an adverse effect on the Zuni value system. The joint-lead agencies will continue to work with the Tribes regarding options for trout management and to determine the most appropriate means of mitigating impacts on Tribal values when TMFs are implemented.

As many as three TMF cycles per month in a period of up to 4 months during May through August could be tested, depending on the results of early tests. Aspects of TMF design that would be investigated include:

- Duration of high flows needed to lure YOY rainbow trout into nearshore habitats,
- Magnitude of the high flow that would be more effective in luring YOY trout to nearshore habitats,
- Whether or not moving to high flows first is needed to reduce YOY trout numbers (as opposed to simply dropping rapidly from normal flows to minimum flows),
- Timing of TMF cycles during the May–August period of trout emergence, and
- Number of cycles necessary to effectively limit trout recruitment.

If TMFs prove to be effective in controlling trout production and emigration to the Little Colorado River reach and they become an integral part of the LTEMP, regular implementation of TMFs may need to include variable timing to prevent adaptation of the population to specific timing (e.g., increase in recruitment by fall-spawning rainbow trout).

Certain aspects of TMF effectiveness can be addressed through observational studies (e.g., the number of YOY rainbow trout observed in the nearshore environment in daily increments after the high flow is initiated)[1]; others may be addressed through consideration of the physical environment in Glen Canyon (i.e., what areas are inundated or exposed at different flows). Ultimately, however, effectiveness will be judged based on comparison of fall trout recruitment estimates to expectations based on prior years. It may take several years to make this determination, depending on the strength of the response and the type of TMFs tested. Ultimately, however, effectiveness will be based on the ability of TMFs to reduce recruitment in and emigration from the Glen Canyon reach. The driving forces behind emigration are not fully understood, but they are expected to be related to population size and food base in the Glen Canyon reach.

For the EIS modeling, a trigger of 200,000 YOY trout was used to determine when TMFs would be implemented. A regression equation based on annual volume, the variability in flows from May through August, and the occurrence of a spring HFE was used to predict the number of YOY. The actual trigger used could be higher or lower depending on the results of experiments that will be conducted on the effectiveness of TMFs. In addition, the predictive regression equation could be modified based on new information. The trigger and predictive equation used would be modified as needed in an adaptive management context utilizing the process described in Section 1.2.8. Triggers for implementation of TMFs would also be developed in consultation with the AZGFD and other entities as appropriate.

Monitoring of other resources, particularly the food base and the physiologic condition of adult rainbow trout, will also be considered. In addition, the number of YOY trout at the end of the summer would be estimated to determine if it equals or exceeds the estimated number of recruits needed to sustain the desired number of adult trout. If the estimated number of recruits is less than the recruitment target, TMFs will be re-evaluated for modification before implementation in subsequent years. It is anticipated that the trout population could rebound from a 1-year drop below this target level.

As discussed in relation to sediment experiments above, there is concern among scientists and stakeholders with regard to the risk associated with the implementation of spring HFEs as related to trout response and subsequent effects on the humpback chub population. For this reason, TMFs will be implemented and tested for effectiveness early in the LTEMP period if possible; preferably before the first spring HFEs are triggered, even if not triggered by high trout recruitment. Trout management flows could be implemented in years that featured a spring HFE and in the water year that follows an equalization flow because of the expected positive effects of

[1] Because older age classes of trout tend to occupy deeper habitats toward the middle of the river channel, they are less susceptible to stranding and are less likely to be directly affected by TMFs.

equalization on rainbow trout recruitment. Modeling indicates TMFs will be triggered by trout recruitment numbers in 32% of the years in the LTEMP period.

There is potential for confounding effects when coupling TMFs with HFEs. If trout recruitment is still high after implementation of TMFs that follow HFEs, this would suggest that TMFs were not as effective as designed for that trial. If recruitment is lower than expected after TMF implementation, however, uncertainty will remain about whether an HFE failed to stimulate trout recruitment or whether TMFs were effective in suppressing otherwise strong recruitment. It may not be necessary to determine the underlying effect on trout numbers unless TMFs have undesirable side effects on other resources or the trout population.

If TMFs are found to be highly effective in controlling trout recruitment and emigration of trout, and emigration only occurs or primarily occurs immediately following high recruitment years, it may be possible to limit TMF implementation and achieve multiple resource goals, particularly if unintended impacts of TMFs on other resources such as native fish become evident. If adverse impacts of TMFs become evident, this may also suggest revisiting whether or not TMFs are necessary in response to spring HFEs. Lastly, if there is an observed increase in trout recruitment due to fall HFEs, then application of TMFs in the spring following a fall HFE would be considered.

Implementation of TMFs would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. TMFs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8.

1.2.10.2 Tier 1 Conservation Actions for Humpback Chub

Tier 1 conservation actions designed to improve rearing and recruitment of juvenile humpback chub would be implemented if the combined point estimate for adult (≥200 mm) humpback chub in the Colorado River mainstem Little Colorado River aggregation (RM 57–RM 65.9) and in the Little Colorado River falls below 9,000 (2,000 in the mainstem and 7,000 in the Little Colorado River) as estimated by the currently accepted humpback chub population model, or if recruitment of subadult (150–199 mm) humpback chub does not meet or exceed estimated adult mortality. Tier 1 actions would include expanded translocations of YOY humpback chub within the Little Colorado River to areas within the river that have relatively few predators (i.e., above Chute Falls, Big Canyon), or larval fish would be taken to a rearing facility and released in the Little Colorado River inflow area once they reach 150 to 200 mm. In addition to these translocation activities, 300 to 750 larval or YOY humpback chub would be collected from the Little Colorado River and reared in a fish hatchery to less vulnerable sizes before releasing them. Once these fish reach 150 to 200 mm, they would be translocated to the Little Colorado River in the following year.

1.2.10.3 Tier 2 Mechanical Removal of Nonnative Fish

Experimental implementation of mechanical removal of nonnative fish will incorporate aspects of the protocol outlined in Reclamation's Non-Native Fish Control Environmental Assessment (NNFC EA) (Reclamation 2011b). However, modifications to the trigger criteria (Appendix D) were made to address Tribal concerns related to "taking of life" in the canyon, which prioritize proactive humpback chub conservation actions over mechanical removal of nonnative fish at the Little Colorado River when humpback chub abundance begins to decline. These modifications attempt to minimize the likelihood of mechanical removal, and mechanical removal of nonnative fish at the Little Colorado River would only occur if proactive conservation actions failed to reverse declines in adult humpback chub, and the adult abundance falls below 7,000. Modeling conducted for the EIS indicated that mechanical removal at this level was effective unless immigration rates into the Little Colorado River reach were high.

Two tiers of sequential actions were identified; the first would emphasize conservation actions that would take place early during an adult or subadult humpback chub population decline (Section 1.2.10.2). The second tier would serve as a backstop prescribing predator removal (Threat Reduction) if conservation measures did not mitigate a decline in humpback chub abundance.

Many factors affect humpback chub population dynamics such as water temperature and turbidity in the Colorado River, and potentially the hydrology of the Little Colorado River. These factors may constrain the effectiveness of available conservation actions that can be implemented in the event of a declining population of humpback chub. Juveniles and YOY can be translocated to other areas within and outside the Little Colorado River system; YOY or juvenile humpback chub can be head-started (temporarily held until sufficient growth is achieved) at a hatchery, and predator control can be implemented. Under current constraints, these are the only conservation tools available for humpback chub within the Colorado River reach and associated tributaries between Glen Canyon Dam and Lake Mead.

While healthy wildlife populations are rarely static, trigger objectives include prescribing actions to reverse/ameliorate impacts in order to maintain the Little Colorado River humpback chub population within an acceptable range, and, secondarily to reduce reliance on mechanical removal of nonnative fish. For the purposes of these triggers, it is assumed that the primary drivers of humpback chub population dynamics are interspecific interactions with nonnative species, especially rainbow trout (or brown trout), and low water temperature in the mainstem of the Colorado River (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; FWS 2002a; Coggins et al. 2011; Yard et al. 2011). It is suspected that coldwater temperatures suppress growth and thus subject young humpback chub to predation for extended periods of time. The triggers focus on management of predator impacts only, if management actions are found to be ineffective or other factors are found to negatively control the humpback chub population, adaptation of triggers and conservation responses will be necessary.

The DOI recognizes that lethal mechanical removal is a concern for Tribes, particularly the Hopi Tribe and Pueblo of Zuni, who view it as a taking of life in the canyon without a beneficial use. Reclamation had committed in agreements with Tribes in 2012 to consider live removal when feasible (Reclamation 2012a); however, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. Reclamation and NPS have worked with the Tribes to determine a beneficial use of the removed fish on other projects and understand that what is considered beneficial use may not be the same for all Tribes. Reclamation and NPS are committed to consult further with the Tribes to determine acceptable mitigation for nonnative fish control.

1.2.10.4 Low Summer Flows

Low summer flows could be considered a potential tool for improving the growth and recruitment of young humpback chub if temperature had been limiting these processes for a period of years. Low summer flows may lead to warmer water temperatures in the Little Colorado River reach and farther downstream, as well as contributing to enhanced growth rates of young humpback chub. There are also potential negative effects from low summer flows to several resources such as hydropower, sediment, water quality, vegetation, and recreation. Low summer flows may also negatively affect humpback chub due to an increase in warmwater nonnative fish or a decrease in the aquatic food base. One test of low steady summer flows was conducted below Glen Canyon Dam in 2000; the results, however, relative to humpback chub were not conclusive (Ralston et al 2012).

Because of the uncertainty related to the effects of low summer flows on humpback chub, other native fish, warmwater nonnative fish, water quality, and potentially other resources, DOI will ensure that the appropriate baseline data are collected throughout the implementation of LTEMP. In addition, DOI will convene a scientific panel that includes independent experts prior to the first potential use of low summer flows to synthesize the best available scientific information related to low summer flows. The panel may meet periodically to update the information, as needed. This information will be shared as part of the AMWG annual reporting process.

It is thought that the potential benefit of an increase in temperature will be greatest if a water temperature of at least 14°C could be achieved at the Little Colorado River, because these warmer temperatures could favor higher growth rates of humpback chub (nearly 60% higher). For comparison, the July through September growth increments of YOY humpback chub are estimated to be 4, 7, 11, 14, and 17 mm at temperatures of 12, 13, 14, 15, and 16°C, respectively, based on a growth-temperature regression in Robinson and Childs (2001). Note that reduction in summer flows would necessitate increasing flows in other months relative to base operations (Table 4; Figure 6).

TABLE 4 Flow Parameters for a Year with Low Summer Flows under the Proposed Action in an 8.23-maf Year[a]

Month	Monthly Release Volume (kaf)	Proportion of Total Annual Volume	Mean Daily Flow (cfs)	Daily Fluctuation Range (cfs)
October	643	0.0781	10,451	5,783
November	642	0.0780	10,781	5,774
December	716	0.0870	11,643	6,443
January	764	0.0928	12,423	6,874
February	675	0.0820	12,153	6,074
March	691	0.0840	11,245	6,223
April	859	0.1044	14,433	7,730
May	851	0.1034	13,841	7,659
June	930	0.1130	15,631	8,000
July	492	0.0598	8,000	2,000
August	492	0.0598	8,000	2,000
September	476	0.0578	8,000	2,000

[a] Within a year, monthly operations may be increased or decreased based on changing annual runoff forecasts and other factors, such as application of the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

If tested, low summer flows would occur for 3 months (July, August, and September), and only in the second 10 years of the LTEMP period. The duration of low summer flows could be shortened to less than 3 months in successive experiments if supported by the scientific panel described above or based on the scientific data and observed effects. The probability of triggering a low summer flow experiment is considered low (about 7% of years) because the water temperature conditions that would allow such a test occur infrequently.

Low summer flows would only be implemented in years when the projected annual release was less than 10 maf, and if the temperature at the Little Colorado River confluence would be below 14°C without low summer flows, and release temperature was sufficiently high that 14°C could be achieved at the Little Colorado River with the use of low summer flows.

The ability to achieve target temperatures at the Little Colorado River confluence by providing lower flows is dependent on release temperatures, which are in turn dependent on reservoir elevation. For example, using the temperature model of Wright et al. (2008), in a 8.23-maf year, release temperatures of 10.8°C, 11.0°C, and 11.7°C would be needed in July, August, and September, respectively, to achieve a target temperature of 14°C at the Little Colorado River confluence at flows of 8,000 cfs.

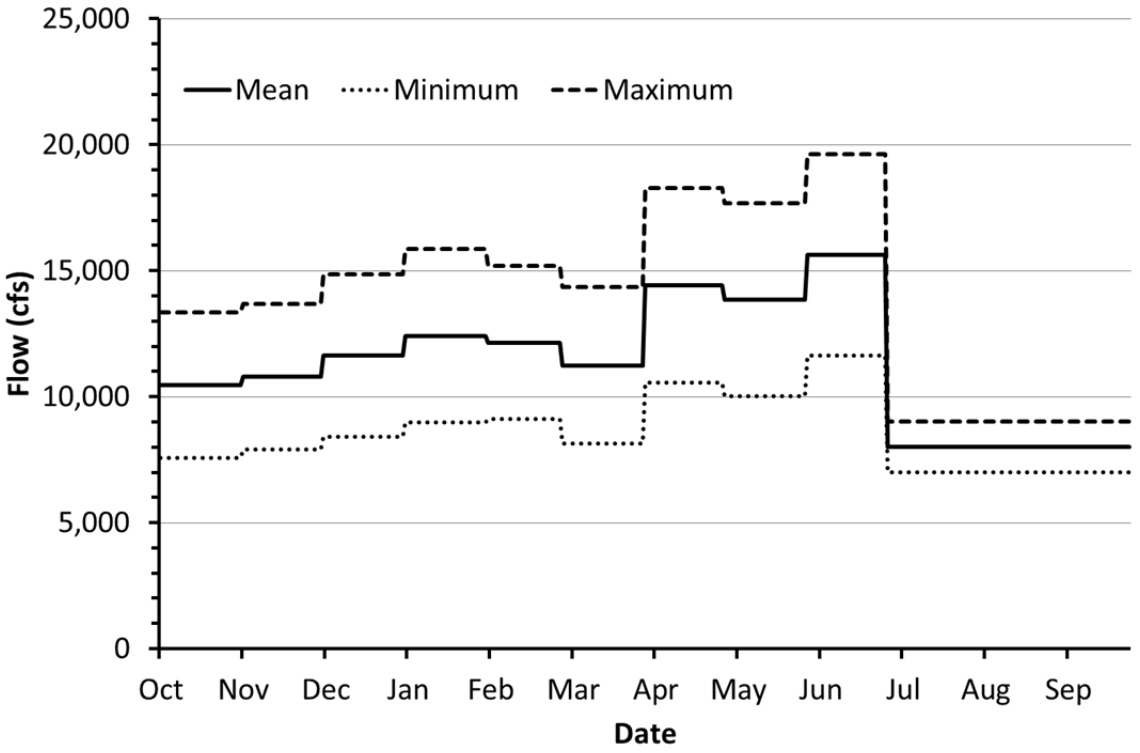


FIGURE 6 Mean, Minimum, and Maximum Daily Flows under Triggered Low Summer Flows of the Proposed Action in an 8.23-maf Year Based on the Values Presented in Table 4

Release temperatures fall into three categories for any temperature target: (1) too low to achieve the target temperature at the Little Colorado River even at low flow, (2) high enough to achieve the target temperature at the Little Colorado River only if low flows (5,000 to 8,000 cfs) are provided, and (3) high enough to achieve target temperature at the Little Colorado River regardless of the flow level. Low summer flows would only be triggered in years that fell into the second category.

Implementation of a low-flow experiment is complicated by two factors: the earliest date at which it could be determined that a target temperature of at least 14°C could be achieved in all 3 months, and the ability to release the remaining annual volume once that determination is made. The earliest time a determination could be made would be in early April of each year, and it would be based on the April 1 forecast of reservoir elevation. Because low summer flows could be implemented in the 3 months at the end of the water year, it is possible that by the time a determination was made to conduct a low summer flow experiment, it may not be possible to release enough water in the remainder of the spring to compensate for the low-flow period. A low-flow experiment would only be tested in years when performing the experiment would not result in a deviation from the annual Glen Canyon Dam release volumes made pursuant to the Long-Range Operating Criteria for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

It is possible that a low summer flow could negatively impact humpback chub through impacts on the food base. In moderate or higher water years, the April–June monthly volumes would have to be quite high and would likely be at or near 25,000 cfs. Following these high flows, there would be an abrupt drop to 8,000 cfs or lower (e.g., 5,000 cfs), which would likely leave much or all of the food base in Glen Canyon and downriver up above the new lower water line (Kennedy and Ralston 2011). These values represent declines in midges and gammarus in the portions of the channel that have been dewatered, and only a small portion of the channel is actually dewatered. Low summer flows will also provide ideal egg laying conditions for aquatic insects, which should facilitate a rapid recovery of the invertebrate prey base to the reduced habitat area associated with this type of experiment. Nonetheless, the potential for low summer flow experiments to negatively impact the food base exist, and measures that seek to minimize any negative impacts will be considered if a low summer flow is implemented.

Finch et al. (2015) found that humpback chub grew more slowly during steady flows than they did during fluctuating flows in the same year, but that turbidity was potentially confounding in this analysis. Recent evidence suggests that not only is the system food limited in most years (Cross et. al. 2013), but that in 2014 and 2015, a system-wide reduction in fish numbers and condition resulting from food limitation was observed. This was a strong enough response that spring Little Colorado River adult estimates were extremely low, and the leading hypothesis was that the adults were skipping spawning and remaining in the mainstem due to lack of sufficient conditions to spawn, yet temperatures were quite warm in 2014 and 2015 (reaching 16°C and 15°C, respectively). Thus, it would seem that under the right conditions, low summer flow could benefit chub, but under conditions that already show high numbers of fish and relatively low food availability, the impacts could be adverse, the rate of skip spawning could increase, and the net impact on chub could be low reproduction and recruitment for that year. However, in 3 years of monitoring the Little Colorado River in June and July, YOY numbers were highest despite the lowest number of spawners (Van Haverbeke 2015). Also key to this experiment being successful is the number of YOY humpback chub being produced in the Little Colorado River, which was pointed out as a confounding factor in the 2000 low summer flow experiment. Production in the Little Colorado River was low (poor habitat conditions), and thus few fish were in the mainstem to be exposed to the treatment. If similar conditions occur, low summer flow would be expected to not have a beneficial impact on the population.

A first test of a low summer flow would feature low flow of 8,000 cfs and relatively little fluctuation (±1,000 cfs per day). Depending on the results of the first test with regard to warming and humpback chub response, the magnitude of the low flow could be adjusted up or down (as low as 5,000 cfs), and the level of fluctuation also modified up to the full range allowed under the proposed action (i.e., 10 × monthly volume [in kaf] in July and August, and 9 × monthly volume [in kaf] in September).

The first test of low summer flows will be determined to be successful or unsuccessful for humpback chub based on input from an independent scientific panel review. If the first test was determined to be unsuccessful (and it was determined to have been implemented properly without major confounding factors), then additional tests would not be performed. Low summer flows would be considered successful if it can be determined that they produced sufficient growth of YOY humpback chub and that growth resulted in an increase in recruitment, but

avoided unacceptable increases in warmwater nonnative fishes, trout, or aquatic parasites, or resulted in unacceptable adverse impacts on other aquatic resources. If it was determined to be successful, then additional low summer flows would occur only when humpback chub population concerns warranted them and water temperature has been colder for a period of years and the desired warming could be achieved only with low summer flows. The temperature target could be adjusted 1°C higher based on the results of the first test or the limitations between predicted and measured temperatures.

Implementation of low summer flows would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. Low summer flows may not be conducted in years when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8.

The effects of low summer flows on Lake Mead water quality are an identified concern. DOI will coordinate with relevant water quality monitoring programs or affected agencies prior to implementing any test of low summer flows. There are concerns related to the risk of warmwater nonnative fish expansion or invasion (e.g., the elevation of Lake Mead was high or the number of warmwater nonnative fish was high). These issues are potential off-ramps as described in Section 1.2.8.

1.2.10.5 Low Steady Weekend Flows for Macroinvertebrate Production

A more diverse and productive aquatic food base could benefit a variety of priority resources including native fish (including the endangered humpback chub), the rainbow trout fishery, and other riparian species that occur in Glen, Marble, and Grand Canyons. Mayflies (Ephemeroptera), stoneflies (Plecoptera), and caddisflies (Trichoptera), collectively referred to as EPT, are notably absent from the Glen and Marble Canyon reaches and very low in abundance and diversity in the Colorado River in the Grand Canyon. Furthermore, it has been demonstrated that EPT taxa are recruitment limited, because daily flow fluctuations to meet hydropower demand cause high egg mortality and which is the limiting factor. The rationale behind this hypothesis is that fluctuations from Glen Canyon Dam create a varial (intermittently wetted) zone along shorelines that is large enough to dewater eggs. The varial zone is primarily determined by the shape of the canyon, and in narrow stretches of the canyon the varial zone can be high, while in wider stretches of the river the varial zone is much smaller. Because the Colorado River in Glen, Marble, and Grand Canyons is canyon-bound and the tributaries that join the river all have comparatively low flow, the size of the varial zone does not appreciably decrease with distance downstream. Thus, although water temperature regimes become more naturalized with distance downstream, the effect that daily flow fluctuations to meet hydropower demand have on the stability of shoreline habitat does not attenuate with distance from the dam.

This hypothesis attributes the absence of EPT and the poor health of the invertebrate assemblage to the width of the varial zone, similar to earlier investigations (Blinn et al. 1995), but focuses on the effects unstable shorelines have on the eggs of these species. This hypothesis assumes that egg-laying by EPT occurs principally along shorelines. According to the hypothesis, EPT taxa downstream of Glen Canyon Dam are recruitment limited, because daily

flow fluctuations to meet hydropower demand negatively affect habitat quality along the shorelines where egg-laying is assumed to occur. This could have been tested during the 2000 Low Steady Summer Flow experiment or in the fall steady-flow experiment from 2008 to 2012, but food base field research was not adequate at the time to detect any changes in EPT related to the steady flows. However, even though substantial steady flow periods were implemented, especially in 2000, increases in EPT species and production were not observed (Kennedy and Ralston 2011).

To test this hypothesis, steady flows would be provided every weekend from May through August (34 days total).[2] The flow on weekends would be held to the minimum flow for that month, which would ensure that the insect eggs laid during weekends would remain submerged throughout larval development. If the hypothesis is true, there would be an increase in insect production, and possibly diversity, due to the reproductive success of insects that laid eggs during weekends. No changes in monthly volumes, ramping rates, or the maximum daily range in flow during weekdays would be required for this experiment. To offset the smaller water releases that would occur during weekends within a given month, larger releases would need to occur during the weekdays within a given month.

Implementation of macroinvertebrate production flows would consider resource condition assessments and resource concerns using the processes described in Section 1.2.8. These flows may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section 1.2.8.

Effects of the tests would be evaluated using observations to determine the locations where insect eggs are deposited and the emergence rates of species. Depending on the outcome of the tests, the experiment could be discontinued if there were unacceptable effects on other resources. There is also the possibility that implementation would result in confounding interactions with TMF experiments, and this would be discussed during the process described in Section 1.2.8.

1.2.11 Native and Nonnative Plant Management and Experimental Actions

Experimental riparian vegetation treatment activities would be implemented by NPS under the proposed action and would modify the cover and distribution of riparian plant communities along the Colorado River. All activities would be consistent with NPS Management Policies (NPS 2006) and would occur only within the Colorado River Ecosystem in areas that are influenced by dam operations. NPS will work with Tribal partners and GCMRC to experimentally implement and evaluate a number of vegetation control and native replanting activities on the riparian vegetation within the Colorado River Ecosystem in GCNP and GCNRA. These activities would include ongoing monitoring and removal of selected nonnative plants, species in the corridor, systematic removal of nonnative vegetation at targeted sites, and native replanting at targeted sites and subreaches, which may include complete removal of

[2] The duration and other characteristics of experimental macroinvertebrate production flows could be adjusted within the range of the analysis based on the results of initial experiments.

tamarisk (both live and dead) and revegetation with native vegetation. Treatments would fall into two broad categories, including the control of nonnative plant species and revegetation with native plant species. Principal elements of this experimental riparian vegetation proposal include:

- Control nonnative plant species affected by dam operations, including tamarisk and other highly invasive species;
- Develop native plant materials for replanting through partnerships and use of regional greenhouses;
- Replant native plant species to priority sites along the river corridor, including native species of interest to Tribes;
- Remove vegetation encroaching on campsites; and
- Manage vegetation to assist with cultural site protection.

2 ENVIRONMENTAL BASELINE

2.1 DESCRIPTION OF SPECIES IDENTIFIED FOR ANALYSIS

2.1.1 Kanab Ambersnail

2.1.1.1 Legal Status

The Kanab ambersnail, *Oxyloma haydeniensis*, was listed as endangered in 1992 (FWS 1995). The Kanab ambersnail is the only threatened, endangered, or sensitive invertebrate species that may occur along the Colorado River in the Grand Canyon. However, recent evidence from anatomical and molecular genetics studies indicates that this is a geographically widespread taxon whose listing under the ESA may have been incorrect (Littlefield 2007). In a study of *Oxyloma* specimens collected from 12 locations throughout the western United States, including Kanab ambersnail from the Grand Canyon, morphometric and genetic results indicated that the Kanab ambersnail can be regarded as a member of the same species as the other *Oxyloma* populations analyzed (Culver et al. 2013). However, until this taxonomic change occurs, the Kanab ambersnail remains a listed species (FWS 2011b). No critical habitat is designated for this species.

2.1.1.2 Recovery Goals and Status

The recovery plan for Kanab ambersnail was completed in 1995 (FWS 1995). The Kanab ambersnail may be considered for downlisting to threatened when the following criteria have been attained:

1. The location and/or establishment of additional populations. Maintain 10 separate populations which have been demonstrated to have population numbers large enough to allow for the long-term viability of the population. This criterion is provisional. It is probable that this criterion will be modified as additional information is acquired concerning the species distribution, abundance, and stability of its separate populations.

2. The establishment of formal land management designations and/or implementation of land management plans which provide long-term, undisturbed habitat for the Kanab ambersnail for the above 10 populations.

The 5-year status review for the Kanab ambersnail was completed in 2011 (FWS 2011d). The FWS found that no change in the status of the species was warranted due to the ongoing, existing threats due to private land development, controlled flooding in the Colorado River, climate change, and inadequate existing regulatory mechanisms. However, Arizona and Utah ambersnail populations identified as “Kanab ambersnail” and “Niobrara ambersnail” are based

primarily on morphological distinctions. Recent genetic analysis and morphological evaluation by Culver et al. (2013) on ambersnail specimens suggests that the Arizona and Utah populations, including Vaseys Paradise, are genetically and morphologically similar to other *Oxyloma* populations in the study, and their taxonomic identity may be revised in the future. The consensus appears to be that this snail is part of a much larger population that has higher numbers and distribution. The FWS did recognize that genetic, anatomical, and morphological information resulted in conflicting views on the taxonomy of the species.

2.1.1.3 Historic and Current Range

Globally, the Kanab ambersnail is only found in three locations. Two of these are within the Grand Canyon: the riparian vegetation at Vasey's Paradise and Elves Chasm. Vasey's Paradise is at RM 31.5, and Upper Elves Chasm is at RM 116.6. The latter population was created from snails translocated from Vasey's Paradise (FWS 2008). The third location for the Kanab ambersnail is Three Lakes, Utah (Reclamation 2007b).

2.1.1.4 Habitat

The Kanab ambersnail lives in association with watercress (*Nasturtium officinale*), cardinal monkeyflower (*Mimulus cardinalis*), cattails (*Typha*), sedges (*Carex*), and rushes (*Juncus*). Populations within the Grand Canyon occur in areas with water sources originating from limestone or sandstone geologic strata (Meretsky and Wegner 2000; Sorensen 2009). The increase in cover, reduction in beach-scouring flows, and introduction of the nonnative watercress led to a >40% increase in suitable Kanab ambersnail habitat area at Vasey's Paradise compared to pre-dam conditions (Stevens et al. 1997a).

Climate change has the potential to affect the Kanab ambersnail habitat. The water source at Vasey's Paradise consists of waterfalls emanating from groundwater and emerging from the cliff face. In 2014 and 2015, the flow was noticeably reduced, likely as a result of basinwide drought. Consequently, the usually dense vegetation at Vasey's Paradise is notably diminished.

2.1.1.5 Life History

Kanab ambersnails live 12 to 15 months and are capable of self-fertilization. Mating and reproduction occur from May to August. Subadults dominate the overwinter population. Snails enter dormancy in October–November and become active in March–April. Overwinter mortality ranges between 25 and 80% (Stevens et al. 1997a; IKAMT 1998). During mild winters, they can continue their life cycle without dormancy or may go in and out of dormancy several times throughout the winter (Sorensen and Nelson 2002).

Based on annual survey data, live counts of Kanab ambersnails at Vasey's Paradise declined in 2011 from previous years, although the ambersnail habitat at Vasey's Paradise was in overall good condition in 2011. At Elves Chasm, live counts of Kanab ambersnails remained

higher in 2011 than previous years, and habitat at this location was in good condition in 2011 (Sorensen 2012). The population at Vasey's Paradise generally occurs at elevations above 33,000-cfs flows. However, as much as 7.3% of the Vasey's Paradise population occurs below the elevation of 33,000-cfs flow, and as much as 16.4% of the population occurs below the elevation of 45,000-cfs flow. The Elves Chasm population is located above the elevation of 45,000-cfs flow (Reclamation 2011b).

2.1.2 Humpback Chub

2.1.2.1 Legal Status

The humpback chub (*Gila cypha*) is currently listed as "endangered" under the ESA. It was first included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967 (32 FR 4001) and was considered endangered under provisions of the Endangered Species Conservation Act of 1969 (16 U.S.C. 668aa). The humpback chub was included in the United States List of Endangered Native Fish and Wildlife issued on June 4, 1973 (38 FR 33085), and received protection as endangered under Section 4(c)(3) of the original ESA of 1973. Critical habitat includes 280 km of the Colorado River through Marble and Grand Canyons from Nautiloid Canyon (RM 34) to Granite Park (RM 208), and the lower 13 km of the Little Colorado River. Primary threats to the species include streamflow regulation and habitat modification (including coldwater dam releases and habitat loss), competition with and predation by nonnative fish species, parasitism, hybridization with other native Gila, and pesticides and pollutants (FWS 1990, 2002a).

2.1.2.2 Recovery Goals and Status

Recovery for the humpback chub was defined by the FWS Humpback Chub Recovery Goals (Recovery Goals) (67 FR 55270) (FWS 2002a). In 2006, a U.S. District Court ruling set aside the Recovery Goals, because they lacked time and cost estimates for recovery. Nevertheless, the recovery programs and the GCDAMP continue to utilize the underlying science in the Recovery Goals. The FWS's 2011 Humpback Chub 5-Year Review relies on the information provided in the recovery goals and provides supplemental information on the species' distribution and status.

The court did not fault the Recovery Goals as deficient in any other respect, thus the FWS, the GCDAMP, and the Upper Colorado River Endangered Fish Recovery Program (UCRRP), the program that addresses conservation of all of the upper Colorado River basin populations of humpback chub, continue to utilize the underlying science in the Recovery Goals. In the 2009 Supplemental Opinion, the FWS referenced the draft 2009 revisions to the Recovery Goals document because that document provided updates on species biology and distribution and represented the best available scientific information at that time. The draft 2009 revisions to the Recovery Goals included the same demographic criteria found in the 2002 Recovery Goals. Thus, we are using the demographic criteria found in both the 2002 Recovery Goals and

2009 draft Recovery Goals. The FWS's 2011 Humpback Chub 5-Year Review relies on the information provided in the Recovery Goals and provides supplemental information on the species' distribution and status.

That supplemental information, as well as the demographic criteria found in the Recovery Goals, has been considered in this BA and is summarized here.

The Recovery Goals consist of actions to improve habitat and minimize threats.

The Recovery Goal demographic criteria for downlisting (endangered to threatened) are as follows:

Upper Basin Recovery Unit

1. Each of the five self-sustaining populations is maintained over a 5-year period, starting with the first point estimate acceptable to the FWS, such that:

    a. The trend in adult (age 4+; ≥ 200 mm [7.9 in.] total length [TL]) point estimates does not decline significantly, and

    b. Mean estimated recruitment of age-3 (150–199 mm [5.9–7.8 in.] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. One of the five populations (e.g., Black Rocks/Westwater Canyon or Desolation/Grey Canyons) is maintained as a core population such that each point estimate exceeds 2,100 adults (Note: 2,100 is the estimated Minimum Viable Population (MVP) number; see Section 3.3.2 of the Recovery Goals).

Lower Basin Recovery Unit

1. The Grand Canyon population is maintained as a core over a 5-year period, starting with the first point estimate acceptable to the FWS, such that:

    a. The trend in adult (age 4+; ≥ 200 mm [7.9 in.] TL) point estimates does not decline significantly,

    b. Mean estimated recruitment of age-3 (150–199 mm [5.9–7.8 in.] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

    c. Each core population point estimate exceeds 2,100 adults (MVP).

The Recovery Goal demographic criteria for delisting are as follows:

Upper Basin Recovery Unit

1. Each of the five self-sustaining populations is maintained over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the FWS, such that:

    a. The trend in adult (age 4+; ≥ 200 mm [7.9 in.] TL) point estimates does not decline significantly, and

    b. Mean estimated recruitment of age-3 (150–199 mm [5.9–7.8 in.] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. Two of the five populations (e.g., Black Rocks/Westwater Canyon and Desolation/Grey Canyons) are maintained as core populations such that each point estimate exceeds 2,100 adults (MVP).

Lower Basin Recovery Unit

a. The Grand Canyon population is maintained as a core over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the FWS, such that:

b. The trend in adult (age 4+; ≥ 200 mm [7.9 in.] TL) point estimates does not decline significantly,

c. Mean estimated recruitment of age-3 (150–199 mm [5.9–7.8 in.] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

d. Each core population point estimate exceeds 2,100 adults (MVP).

The 5-year status review for the humpback chub was completed in 2011 (FWS 2011c). A change in the status of the humpback chub was not recommended because 5 of 6 demographic recovery criteria and 4 of 22 downlisting criteria had not been met. Factors continuing to threaten the Grand Canyon humpback chub population are described below.

2.1.2.3 Historic and Current Range

The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family may attain a length of 20 in., weigh 2 lb or more, and live as long as 40 years (Andersen 2009). Historically, this species occurred throughout much of the Colorado River and its larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming (FWS 2002b and refs. therein). Although historic abundance levels are

unknown, the humpback chub is currently thought to occupy 24% of its historic range, restricted to six population centers, five in the upper Colorado River basin and one in the lower basin (FWS 2002b). The upper basin populations occur in (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River in Desolation and Gray Canyons, Utah; and (5) the Yampa River in Yampa Canyon, Colorado. The only population in the lower basin occurs in the Colorado River in Marble Canyon, the Grand Canyon, and Little Colorado River (FWS 2011a).

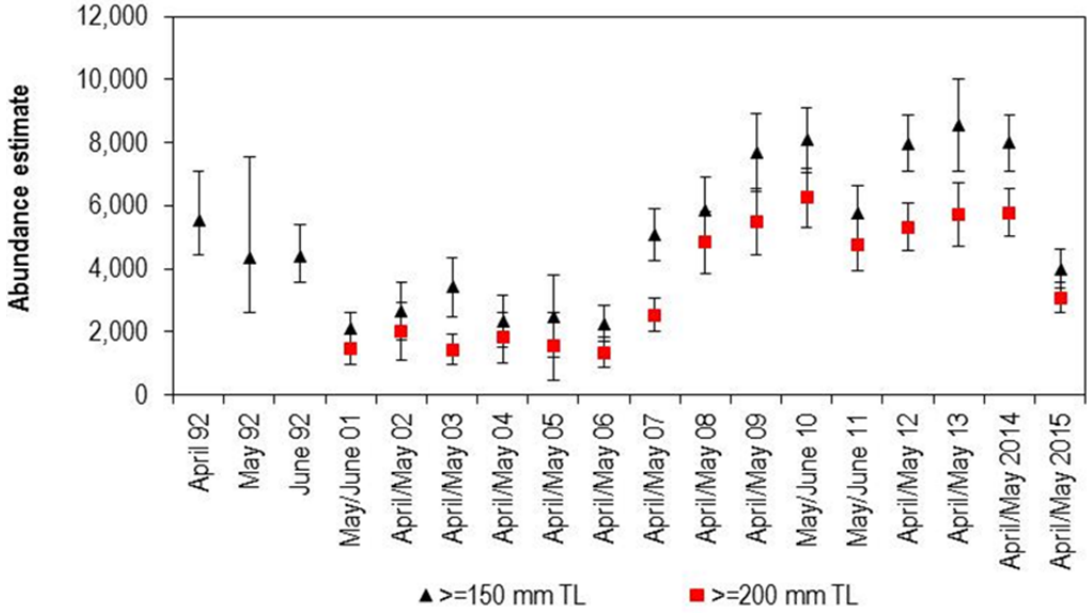
The Colorado River/Little Colorado River population is the largest of the six population centers of the humpback chub (FWS 2011c). Within the Grand Canyon, this species is most abundant in the vicinity of the confluence of the Colorado River and Little Colorado River (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; Valdez and Ryel 1995). This population is specifically referred to as the Little Colorado River aggregation of humpback chub and includes those fish residing in the Little Colorado River and in the mainstem within proximity of a few miles to the Little Colorado River mouth. In addition, there are eight other areas (aggregation areas) where humpback chub are, or have been, regularly collected; these aggregation areas are located in the mainstem at 30 Mile, Lava Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (Figure 7; Valdez and Ryel 1995; Ackerman 2008; Persons et al. 2016). In addition, since 2009, translocations of humpback chub have been made by the FWS to introduce juvenile fish upstream of Chute Falls in the Little Colorado River, and by the NPS, with assistance provided by Reclamation, to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of establishing additional spawning populations within the Grand Canyon (NPS 2013). Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have successfully spawned in Havasu Creek (NPS 2013). Humpback chub occupy approximately 3.5 mi (5.6 km) of lower Havasu Creek, from the mouth to Beaver Falls, which is a barrier to upstream movement of fish.

Sampling conducted between October 2013 and September 2014 in western Grand Canyon between Lava Falls (RM 180) and Pearce Ferry (RM 280) captured 144 juvenile humpback chub during sampling of the small-bodied fish community. In addition, 209 humpback chub larvae were collected during sampling of the larval fish community in randomly selected sites (Albrecht et al. 2014). Results were similar in larval and small-bodied fish sampling in 2015 (Kegerries et al. 2015): 285 juvenile and 67 age-0 humpback chub were captured during small-bodied and larval fish sampling, respectively, from throughout the study area. These results suggest that young humpback chub are using widespread nursery and rearing habitats between RM 180 and RM 280 in the western Grand Canyon.

2.1.2.4 Population within the Action Area

The Little Colorado River population (aggregation) of humpback chub is measured with closed and open population models. Closed models estimate the annual spring and the annual fall abundance of various size classes of chub within the Little Colorado River (Van Haverbeke et al. 2013, 2016). As such, the closed models do not account for chub that are not residing in the

A.



B.

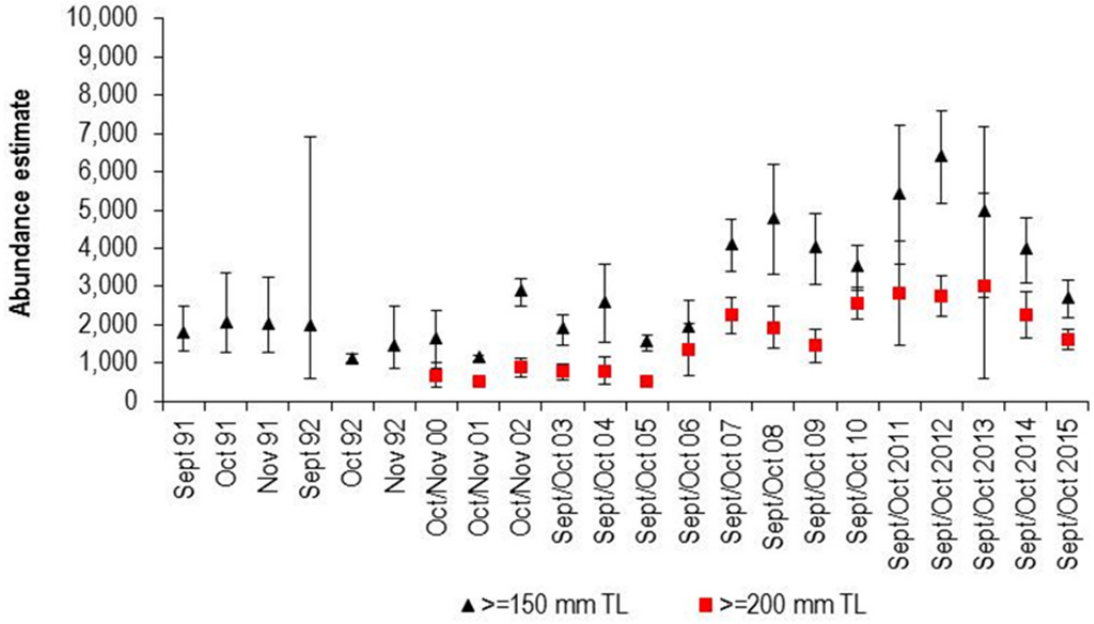


FIGURE 7 Closed Chapman Petersen Abundance Estimates (±95% CI) of Humpback Chub ≥150 mm and ≥200 mm in the Little Colorado River during (A) Spring (2001–2015) and (B) Fall Seasons (2000–2015) (Closed spring and fall abundance estimates of humpback chub >150 mm in the Little Colorado River during 1991 and 1992 are from Douglas and Marsh [1996].)

Little Colorado River during any particular year (i.e., there is always a portion of the Little Colorado River aggregation that is residing in the nearby mainstem each year). Initial closed mark-recapture population efforts in the Little Colorado River were conducted in the early 1990s (Douglas and Marsh 1996), after which there was a hiatus until they were resumed again in 2000 (Van Haverbeke et al. 2013, 2016). Results from both of these studies indicate that sometime in the mid- to late-1990s, humpback chub underwent a significant decline in the Little Colorado River (Figures 7 and 8). This was followed by a period of relatively low, but stable abundance between 2000 and 2006, and by a period (2007–2014) of significantly increased abundance levels (Van Haverbeke et al. 2013). The post-2006 increase in humpback chub ≥150 mm and ≥200 mm was visible during both spring and fall seasons, but it was more apparent during spring months (Figure 7). Spring 2015 saw a significant lowering of abundance of humpback chub ≥150 mm and ≥200 mm compared to the previous several years. The cause of this decline is unknown, but there is evidence from sampling in the mainstem during 2015 that many chub may have simply remained or emigrated into the mainstem during 2015 (i.e., the portion of the Little Colorado River aggregation of chub residing in the nearby mainstem was higher than usual).

In addition, open population models are conducted to estimate the abundance of the Little Colorado River aggregation of humpback chub (Coggins and Walters 2009; Yackulic et al. 2014), both those fish residing in the Little Colorado River and those residing in the nearby mainstem. Because the open models use capture histories of humpback chub that span across years and because most humpback chub will eventually be captured either in the Little Colorado River or in the mainstem (and thus accounted for in the open models), the open models estimate the abundance of humpback chub in the Little Colorado River as well as those residing in the nearby mainstem. As such, the open models provide annual abundance estimates that are higher than the closed model estimates described above. Open models show that from 1989 through 2001, there was a decline of adult humpback chub within the Grand Canyon, with estimated numbers of the Little Colorado River aggregation declining from approximately 11,000 adults (age 4+) in 1989 to about 5,000 adults in 2001 (Coggins and Walters 2009) (Figure 8). However, since about 2001, the downward population trend reversed, with the estimated number of adult fish increasing to approximately 8,000 fish by 2008 (Figure 8) (Coggins and Walters 2009). More recently, abundance estimates for 2009 to 2012 suggest the population has continued to increase to approximately 11,000 adults (Figure 9) (Yackulic et al. 2014). Unlike the closed models, Coggins and Walters (2009) open models suggested that the increasing trend in adult humpback chub abundance began earlier than 2007. They explain that this may be an effect of aging error, with the least biased estimates for recruitment and adult abundance trends being those most proximal to the end of the dataset being analyzed. As such, one might expect to see the adult increases in abundances beginning earlier in their open models (Figure 8). Importantly, both the closed and open population estimators provide the same trend, and that is that the humpback chub experienced a period of significant decline followed by a period of significant increase.

Aside from the Little Colorado River aggregation, based on sampling within and outside the other known aggregations of humpback chub by Persons et al. (2016), catch rates of humpback chub generally increased as well. Factors suggested as being responsible for this estimated increase are discussed later in this section. In addition, recent preliminary population estimates for humpback chub aggregations suggest that humpback chub in several aggregations

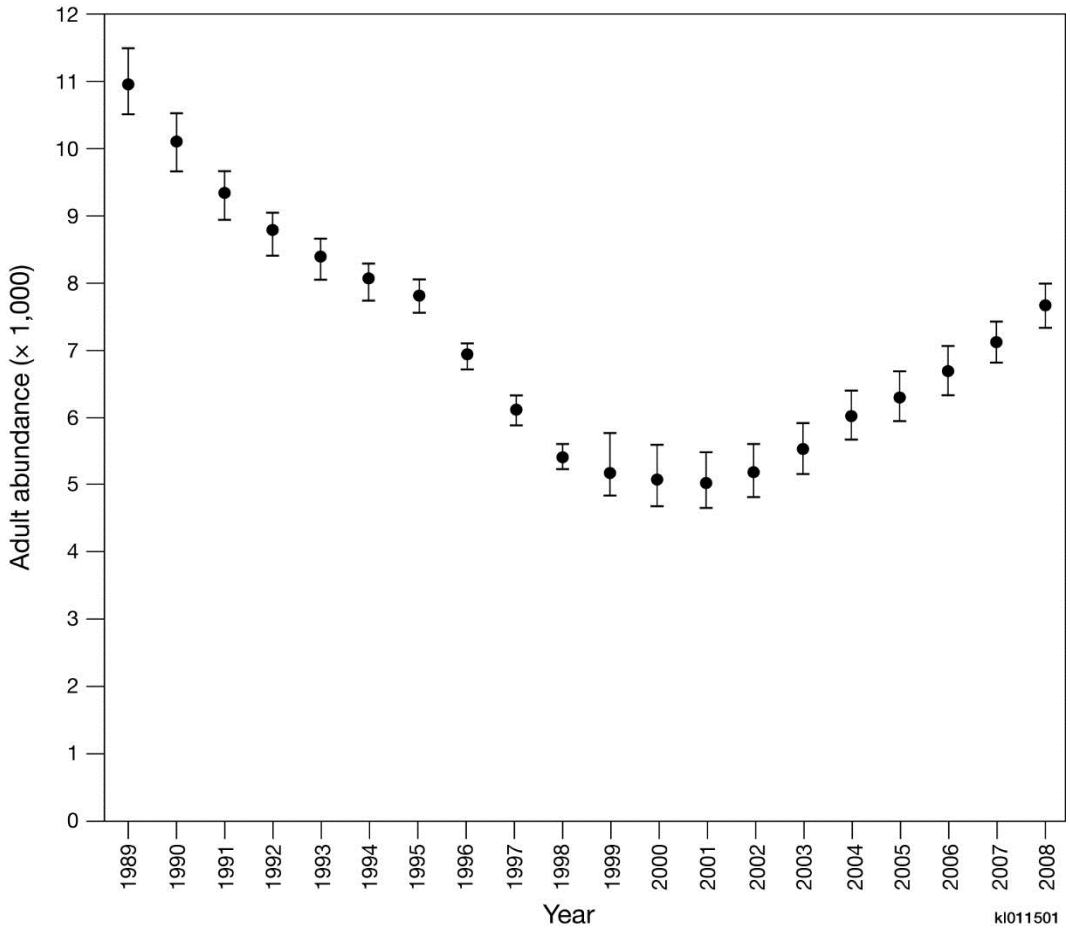


FIGURE 8 Estimated Adult Humpback Chub Abundance (Age 4+) from Age-Structured Mark-Recapture Model Incorporating Uncertainty in Assignment of Age (Error bars represent minimum 95% confidence intervals and do not consider uncertainty in growth or mortality.) (Source: Coggins and Walters 2009)

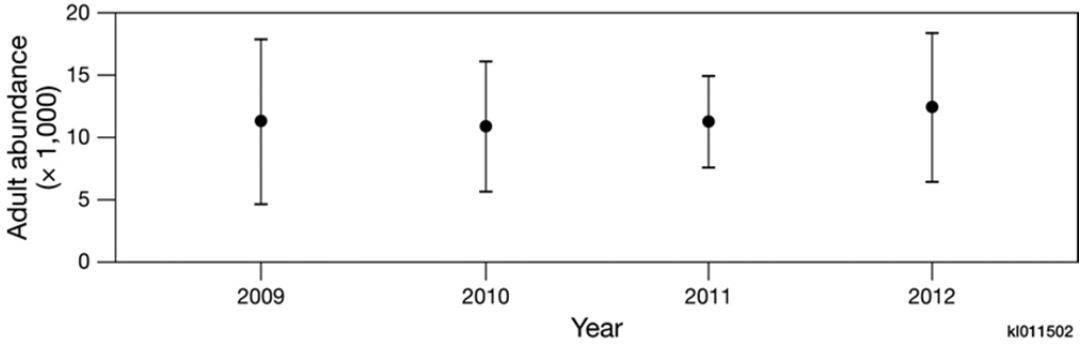


FIGURE 9 Estimated Total Adult Abundance of Humpback Chub in the Lower 8 mi of the Little Colorado River and a 2-mi Portion of the Colorado River Just Downriver of the Confluence of the Little Colorado and Colorado Rivers, for September 2009 through 2012 (Error bars represent the 95% confidence intervals.) (Source: Yackulic et al. 2014)

may have increased as a result of (1) translocations to Shinumo and Havasu Creeks; (2) good production in the Little Colorado River; (3) water temperatures that were about 1°C warmer since the early 2000s; (4) significantly warmer than normal water temperatures in 2004, 2005, and 2011; and (5) trout control implemented at the Little Colorado River inflow (NPS 2013; Yackulic et al. 2014).

The most recent humpback chub population estimate in Havasu Creek was approximately 280 individuals as of May, 2015 (Figure 10). While reproduction has been documented, the population has increased primarily as a result of continued translocations, and less attributed to recruitment.

2.1.2.5 Habitat

Adult humpback chub occupy swift, deep, canyon reaches of the river (Valdez and Clemmer 1982; Valdez and Ryel 1995), with microhabitat use varying among age-groups (Valdez 1990; Stone and Gorman 2006; Gerig et al 2014; Dodrill et al 2015). Within the Grand Canyon, the largest number of humpback chub and their primary spawning are in the vicinity of the Little Colorado River and its inflow reach (RM 57–RM 77; Persons et al. 2016; (Figure 11), with adults being associated with large eddy complexes. Mark-recapture studies in the Grand Canyon reported that most captures of humpback chub occurred in and around the Little Colorado River, with more than 80% of recaptured fish being collected in the same mainstem river reach or tributary where they were originally tagged (Paukert et al. 2006; Persons et al. 2016). However, some of the marked fish were determined to have moved as much as 154.5 km (96 mi) throughout the Grand Canyon (Paukert et al. 2006).

Valdez and Ryel (1995, 1997) reported on adult humpback chub habitat use in the Colorado River in GCNP. They found adults used primarily large recirculating eddies, occupying areas of low velocity adjacent to high-velocity currents that deliver food items. Within GCNP, adults demonstrate high microsite fidelity and occupy main channel eddies, while subadults use nearshore habitats (Valdez and Ryel 1995; Robinson et al. 1998, Stone and Gorman 2006). Adults also congregated at tributary mouths and flooded side canyons during high flows.

Recently, a study conducted in 2010 examined the habitat use and movement of 30 radio-tagged adult humpback chub in the Colorado River during 2 months of fluctuating flow followed by 2 months of steady flow (Gerig et al. 2014). The radio-tagged fish were found to use eddies extensively while avoiding runs. During both flow treatments, the tagged fish exhibited only small daily movements of about 33 ft/day, and no effect of flow was observed on either habitat selection or movement.

The main spawning area for the humpback chub within the Grand Canyon is the Little Colorado River, which provides warm temperatures suitable for spawning and shallow low-velocity pools for larvae (Gorman 1994). The species spawns primarily in the lower 13.6 km of the Little Colorado River, but occasional spawning is suspected in other areas of the Colorado River as well (Valdez and Masslich 1999; Anderson et al. 2010). Gorman and Stone (1999) found ripe adults aggregated in areas of complex habitat structure associated with clean gravel

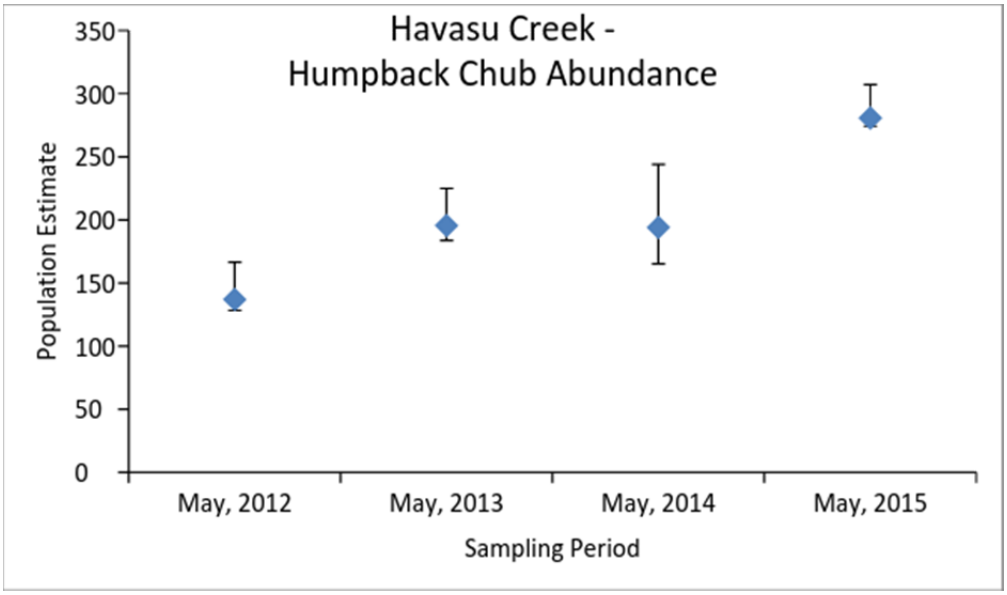


FIGURE 10 Total Abundance of Humpback Chub in Havasu Creek, Based on Annual Population Estimates between 2012 and 2015 (Error bars represent 95% confidence intervals.)

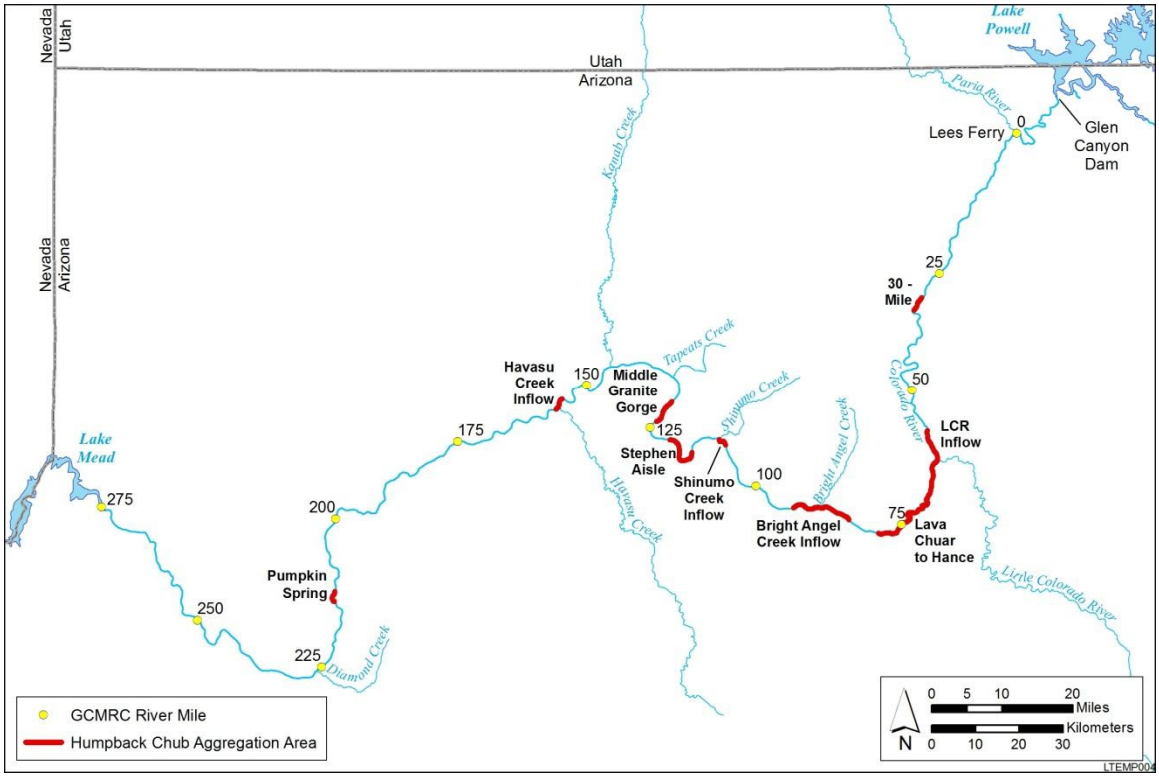


FIGURE 11 Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead (Sources: NPS 2013)

deposits among large boulders mixed with travertine masses in or near runs and eddies. While mainstem spawning is suspected near 30-Mile Spring, or in other areas in the western Grand Canyon following the detection of larval humpback chub in recent years (Albrecht et al. 2014; Kegerries et al. 2015), studies have not been completed to identify spawning areas or habitat in the Colorado River in the Grand Canyon.

Young humpback chub seek areas that provide physical cover and contain some velocity refuges, including shoreline talus, vegetation, and backwaters typically formed by eddy return current channels (AZGFD 1996; Converse et al. 1998; Dodrill et al. 2015). Backwaters can have warmer water temperatures than other habitats, and native fish, including the humpback chub, are frequently observed in backwaters, leading to a common perception that this habitat is critical for juvenile native fish conservation. However, backwaters are rare and ephemeral habitats, so they contain only a small portion of the overall population. For example, Dodrill et al. (2015)) showed the total abundance of juvenile humpback chub was much higher in talus than in backwater habitats. Moreover, when extrapolated to relative densities based on estimates of backwater prevalence directly after a controlled flood, the majority of juvenile humpback chub were still found outside of backwaters. This suggests that the role of controlled floods in influencing native fish population trends may be limited. As young humpback chub grow, they exhibit an ontogenic shift toward deeper and swifter offshore habitats. Valdez and Ryel (1995, 1997) found that young humpback chub (21–74 mm [0.83–2.9 in.] TL) remain along shallow shoreline habitats throughout their first summer, at low water velocities and depths less than 1 m (3.3 ft). They shift as they grow larger (75–259 mm [2.95–10.20 in] TL), and by fall and winter move into deeper habitat with higher water velocities and depths up to 1.5 m (4.9 ft). Stone and Gorman (2006) found similar results in the Little Colorado River, discovering that humpback chub undergo an ontogenesis from diurnally active, vulnerable, nearshore-reliant YOY (30–90 mm [1.81–3.54 in.] TL) to nocturnally active, large-bodied adults (180 mm [7.09 in.] TL), which primarily reside in deep mid-channel pools during the day and move inshore at night. This ontogenetic habitat shift may be important for smaller streams to which humpback chub have been translocated. Spurgeon (2012) found that larger humpback chub translocated to Shinumo Creek were more likely to emigrate, and in addition, most movements were nocturnal.

Young humpback chub prefer shallow, low-velocity nearshore pools and backwaters, vegetated undercut banks often harbor high densities of juvenile chub in the Little Colorado River; they move to deeper and faster areas with increasing size and age, within the Little Colorado River (AZGFD 2001). In the mainstem of the Colorado River, juvenile fish may be found in backwater and other nearshore, slow-velocity areas that may serve as nursery habitats (Valdez and Ryel 1995; Robinson et al. 1998; AZGFD 2001; Stone and Gorman 2006); however, detection probability is also higher in these areas. Juvenile humpback chub (<3 years old) have been collected in all types of nearshore habitats by the Nearshore Ecology Study, with the highest density found in backwaters in both years of the study. However, the greatest number of humpback chub were collected from talus slopes (Dodrill et al. 2015). Backwater habitats are perceived to be important to juvenile native fish in the Grand Canyon; however, they are relatively rare habitats in the Little Colorado River inflow reach, and thus support only a small proportion of the native fish there (Dodrill et al. 2015). Thus the significance of these backwater habitats to the overall population is unclear.

The low summer flow experiment conducted in 2000 studied four nearshore geomorphic unit types between the confluence of the Colorado and Little Colorado Rivers and Lava Canyon in the summer and fall of 2010, for study periods of 10 to 27 days. Five to seven sites were studied during each interval. Persistent thermal gradients greater than the 0.2°C accuracy of the instruments were not observed in any of the sampled shoreline environments. Temperature gradients between the shoreline and mainstem on the order of 4°C, believed to be important to the habitat-seeking behavior of native or nonnative fishes, were not detected (Ross and Grams 2013). Temperature differences between main channel and nearshore habitats that are isolated from the main channel can be pronounced in backwaters and other low-velocity areas. The extent of warming is variable and depends on the timing of the daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation (Korman et al. 2006). For example, summertime water temperatures in backwaters have been reported to be as high as 25°C (77°F), while main channel temperatures are near 10°C (50°F) (Maddux et al. 1987). The amount of warming that occurs in backwaters is affected by daily fluctuations that drain and fill backwater habitats with cold main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During the low summer flow experiment, temperatures in one backwater were as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer under steady flows than under fluctuating flows (Hoffnagle 1996; Trammell et al. 2002; Korman et al. 2006; Anderson and Wright 2007).

Although the use of thermal refugia such as backwaters has been documented in a variety of systems (e.g., Tyus and Haines 1991; Bodensteiner and Lewis 1992; Torgersen et al. 1999; Ebersole et al. 2001; Westhoff et al. 2014), the overall importance of backwater habitats in the Colorado River relative to humpback chub survival and recruitment is uncertain (Reclamation 2011b). While juvenile humpback chub have been reported to show positive selection for backwater habitats, the spatial extent of such habitats in the Colorado River in the Little Colorado River inflow reach is small compared to other nearshore habitats such as talus slopes (Dodrill et al. 2015). Nevertheless, the presence of backwaters and other types of nearshore habitats that may be important to native fish varies by reach in the Grand Canyon and is related to sediment deposition that is dependent on the reach geomorphology (i.e., reach width and depth, etc.; reviewed in Stevens et al. 1997b).

2.1.2.6 Life History

The humpback chub is primarily an insectivore, with larvae, juveniles, and adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily chironomids and simuliids), Thysanoptera (thrips), Hymenoptera (ants, wasps, bees), and amphipods (such as *Gammarus lacustris*) (AZGFD 2001). Donner (2011) found that 65% of humpback chub production in the Grand Canyon was attributed to chironomids and simuliids, and that the potential for competition between humpback chub and nonnative fish was high when nonnative fish abundance was high. Feeding by all life stages may occur throughout the water column as well as at the water surface and on the river bottom. Spurgeon et al. (2015) also found

that humpback chub consumed and assimilated native fish, and that they occupied a high trophic position in the food web in a Grand Canyon tributary, similar to rainbow trout.

Adult humpback chub move into the Little Colorado River from the Colorado River to spawn from March to May (Gorman and Stone 1999). Relatively little spawning and juvenile rearing occur in the mainstem of the Colorado River, primarily because of the cold mainstem water temperatures (Kaeding and Zimmerman 1983; Minckley et al. 1991); however, in recent years, some evidence of rearing has been observed in the western Grand Canyon (Albrecht et al. 2014; Kegerries et al. 2015). Optimal spawning temperature for the species is 16°C, but mainstem water temperatures typically have ranged from 7 to 12°C (45 to 54°F) near the Little Colorado, due to coldwater releases from Glen Canyon Dam (Wright et al. 2008). Drought-induced warming has resulted in mainstem water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and fall months, which may have played a role in the estimated increase in the humpback chub population in the system since that time (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014). Water temperatures in Havasu Creek typically exceed 16 degrees by April (GCMRC 2016), and humpback chub in spawning condition have been captured in mid-May during monitoring trips (Healy and Nelson 2013; Nelson et al. 2015).

Following spawning, larvae have been reported to drift in the Little Colorado River from April through June, and many drift out into nearshore habitats of the Colorado River (FWS 2008). Robinson et al. (1998) estimated about 38,000 larval humpback chub drifted from the Little Colorado River into the mainstem in May and June 1993. In addition, larval and juvenile humpback chub have been relatively common in the first 2 years of a study that includes sampling of nearshore habitats from Lava Falls (RM 180) to Pearce Ferry (RM 208; Albrecht et al. 2014; Kegerries et al. 2015). The natal source of these fish is unknown; however, data on the timing, age, and location of these larval humpback chub captures may suggest spawning in the mainstem or tributaries (Albrecht et al. 2015; Kegerries et al. 2015). Juveniles generally have lower monthly rates of movement than adults, with the exception of a high probability of juveniles being transported from the Little Colorado River to the Colorado River during high flows of the monsoon season, when numbers of juvenile humpback chub in the mainstem have been documented to increase by as much as 4,000 fish (Yackulic et al. 2014).

Although survival of larval and juvenile fish in the mainstem was once thought to be very rare because of seasonally constant, low water temperatures (Clarkson and Childs 2000), more recent information suggests that juveniles can successfully rear to adulthood in the Colorado River mainstem, at least under recent environmental conditions that include warmer water (Yackulic et al. 2014; Albrecht et al. 2014; Kegerries et al. 2015). Increasing water temperatures have been shown in the laboratory to increase hatching success and larval survival (Hamman 1982), larval and juvenile growth (Clarkson and Childs 2000), and improve swimming ability and reduce predation vulnerability (Ward 2011). Yackulic et al. (2014) postulated that, with warmer water, growth and survival of juveniles in the mainstem will be greater and result in increased mainstem recruitment, and thus contribute to the overall adult population.

2.1.2.7 Factors Affecting Distribution and Abundance in the Grand Canyon

Primary threats to humpback chub include habitat alterations associated with dams and reservoirs and the introduction of nonnative fishes (FWS 2011c), which act as competitors and/or predators of the humpback chub (Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). In addition, the Colorado River now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may infect some humpback chub and affect survival (Clarkson et al. 1997; Andersen 2009). While coldwater releases from Glen Canyon Dam have been implicated in affecting reproduction and recruitment of humpback chub (and other native fishes) in the mainstem Colorado River, warmer water temperatures in the mainstem over the last decade may be providing some temporary benefit and contributing to the improving status of the humpback chub (Reclamation 2011a). Recent studies also indicated that toxic mercury (Hg) and selenium (Se) concentrations in native fish were elevated in the Grand Canyon (Walters et al. 2015). While humpback chub were not tested in the study, elevated levels of Hg in the food web, and in particular, primary prey items, including blackfly larvae (*Simuliidae*), may result in impacts on the species (Walters et al. 2015).

Population estimates indicate that the number of adult humpback chub in the Grand Canyon has been increasing since 2000 or 2001 and has been stable for about the last 5 years (Figure 8). A number of factors have been suggested as being responsible for the observed increases, including experimental water releases, trout removal, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). In addition, translocations of juvenile humpback chub to Shinumo and Havasu Creeks have resulted in increased numbers of adult humpback chub captured in the mainstem aggregations (Persons et al. 2016). Translocations to tributaries have been shown to provide an adequate mechanism for rearing juvenile humpback chub that may later disperse to the Colorado River and augment aggregations (Spurgeon et al. 2015).

Dam discharge and river flow regimes have mixed results. They both may impact the shoreline rearing habitat, and thus survival of juvenile humpback chub (Converse et al. 1998). Releases such as HFEs can create shallow backwater habitats associated with sandbars and are thought to provide rearing habitat for native fish, because they can be warmer than the mainstem river during the summer months due to solar radiation (Behn et al. 2010, reviewed in Dodrill et al. 2015). Flow regimes include, for example, fluctuating flows, which destabilize backwater habitats and may impact warming and primary production (Behn et al. 2010). Backwater habitat is relatively rare in the Little Colorado River inflow area, and thus may be less important to maintaining the Little Colorado River aggregation of humpback chub than previously thought (Dodrill et al. 2015). Even though HFE water releases from Glen Canyon Dam between 2000 and 2008 may have improved some habitat characteristics (e.g., backwaters for humpback chub and other native fish), the limited availability of suitably warmwater temperatures in the mainstem may have constrained the potential for positive population responses (Kennedy and Ralston 2011). Some experimental releases, such as the November HFE in 2004, may have affected nonnative fish (possible humpback chub predators or competitors) and improved humpback chub habitat along the main channel (Korman et al. 2010). However, the March 2008 HFE may have improved the quality of spawning habitat for rainbow trout in the Lees Ferry reach, and the abundance of rainbow trout (using catch-per-unit-effort as a surrogate for abundance) in this reach was reported to be about 300% larger in 2009 than in 2007 (about

3.9 fish per minute versus 1.3 fish per minute, respectively) (Makinster et al. 2011). A similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little Colorado River confluence (RM 56–RM 69) (Kennedy and Ralston 2010). The effects of HFEs on trout abundance are discussed in more detail in Section 1.2.9. Complete evaluations of more recent fall HFEs, conducted in 2013 and 2014, are incomplete.

Predation by rainbow and brown trout at the Little Colorado River confluence has been identified as an additional mortality source affecting humpback chub survival, reproduction, and recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). The incidence of piscivory by brown trout has been found to be much higher than for rainbow trout in the Grand Canyon (Yard et al. 2011; Whiting et al. 2014), but rainbow trout have been much more abundant in the Colorado River, and thus may impact native fish at a similar magnitude (Yard et al. 2011). Predation by channel catfish and black bullhead are also thought to impact humpback chub in the Grand Canyon, particularly if warmer water conditions occur (NPS 2013). Because of their size, adult humpback chub are less likely to be preyed on by trout; however, emergent fry, YOY, and juvenile humpback chub are susceptible to predation in the Little Colorado River and mainstem Colorado River (Yard et al. 2011).

Experimental removal of nonnative brown and rainbow trout was conducted in the Colorado River in the Grand Canyon between 2003 and 2006. Twenty-three trips to remove trout from the vicinity of the confluence of the Little Colorado River (RM 56–RM 66) resulted in the removal of more than 23,000 fish (mostly rainbow trout). During this time, the rainbow trout population in the Colorado River in the vicinity of the Little Colorado River was reduced by more than 80% (Andersen 2009), while estimated humpback chub abundance increased during this time (Figure 9). However, this increase may be attributable to a variety of other factors, including warmer water temperatures that occurred during this time and the HFE experimental flows (Andersen 2009; Coggins et al. 2011).

As previously discussed, the coldwater temperatures in most places of the main channel are below the temperature needed for spawning, egg incubation, and growth of the humpback chub. Survival of humpback chub young in the mainstem near the Little Colorado River is thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval and juvenile growth, reduce swimming ability, and increase predation vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstem Colorado River have generally been warmer over the last decade, and warming over the summer increases downstream, due to solar radiation. For example, maximum daily temperatures exceeded 20°C (68°F) in the lower river (RM 180–RM 280), and daily average temperature was 18.3°C (65°F) in early July (Kegerries et al. 2015). There is some evidence of recruitment at the 30-mi aggregation possibly due to the presence of warm springs. Adult chub captured near RM 35 suggests the possibility of a new aggregation or expansion of the 30-mi aggregation, and during 2013 and 2014, three female humpback chub were captured near the 30-mi aggregation that expressed eggs. Ultrasonic images of several hundred adult humpback chub from many locations in the mainstem, as well as in the Little Colorado River and Havasu and Shinumo Creeks, indicated that adult female humpback chub are able to produce eggs in the mainstem Colorado River. In 2013, approximately 33% of humpback chub examined from the mainstem Colorado River, 52% of

chub examined from the Little Colorado River, and 23% of chub examined from Havasu Creek were females with eggs (GCMRC 2015).

Temperatures, particularly in the upper reaches of the Colorado River, even in warmer years, are not optimal for humpback chub spawning and growth. However, juveniles can now successfully rear to adulthood in the Colorado River mainstem, and mainstem recruitment is likely contributing to the overall adult population that increased from about 5,000 adults in 2000 to about 11,000 adults in 2012 (Yackulic et al. 2014; Figures 8 and 9). Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of drought conditions that lowered the level of Lake Powell and resulted in the release of warmer water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009, and 2011. In 2005, maximum mainstem water temperature exceeded 15°C (59°F) at Lees Ferry and approached 18°C (64°F) in the vicinity of the Little Colorado River (RM 61), the warmest temperature at those locations since the reservoir was filled in 1980. Maximum water temperature in the mainstem at Lees Ferry reached about 14°C (57°F) in 2008 (USGS 2014), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstem water temperatures at the Little Colorado River confluence (RM 61) reached about 15°C (59°F) and 16°C (61°F), respectively (Figure 12). This warmer water appears to have benefitted the humpback chub and other native fish, but they may have benefitted nonnative warmwater species as well (Andersen 2009; Coggins and Walters 2009; Kennedy and Ralston 2011). Low reservoir levels can be attributed to drought, as well as consumptive water use in the Colorado River basin.

Increased water temperatures may also affect predation of YOY humpback chub by rainbow and brown trout (Ward 2011; Yard et al. 2011; Ward and Morton-Starner 2015). Ward (2011) reported that in the laboratory, the level of attempted predation by brown trout was positively correlated with increasing water temperature, but predation success of rainbow trout on YOY humpback chub decreased as water temperature increased from 10°C to 20°C (50°F to 68°F); predation success by brown trout did not change significantly over the same temperature range (Ward 2011; Ward and Morton-Starner 2015). Yard et al. (2011) examined the effects of temperature on trout piscivory in the Colorado River and reported no relationship between water temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation was found between water temperature and the incidence of piscivory for the brown trout.

Climate change and drought have direct influences on hydrologic patterns and water temperature, thus impacting humpback chub. In the Colorado River Basin, hydrologic impacts include lower precipitation and decreased inflow to the reservoir system, resulting in more frequent lower reservoir release volumes, potentially impacting shoreline habitats and riparian areas. More frequent droughts and warmer atmospheric temperatures have the potential to result in warmer temperature of water being released from the dam. Although this may improve thermal suitability for humpback chub, any subsequent benefits may be offset by increased abundance and expansion of warmwater nonnative fish and aquatic fish parasites.

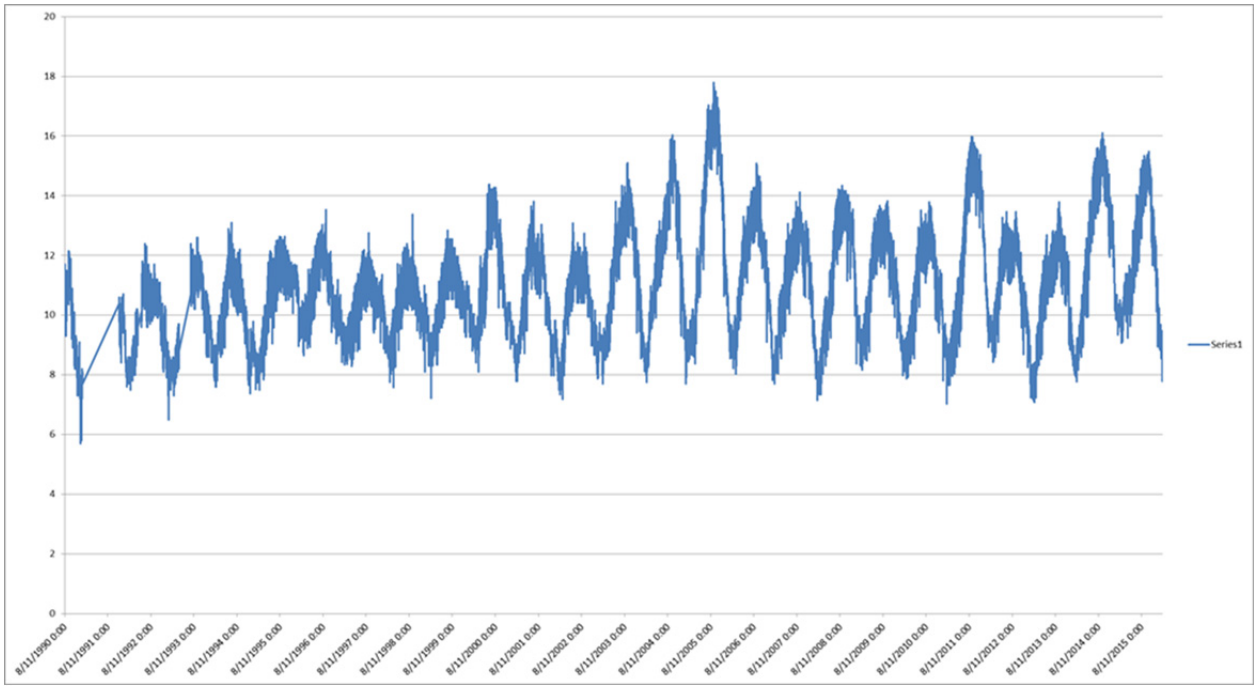


FIGURE 12 Water Temperatures at the Little Colorado River Confluence (RM 61), 1995 to Present (Source: USGS 2014)

Although the Little Colorado River stretches almost 340 m (550 km), only the headwaters and the lowermost reaches flow year-round. The lower 13 mi (21 km) of the Little Colorado River is fed by groundwater springs. This reach is occupied by the largest self-sustaining population for the species, and the lower 8 mi (13 km) is designated critical habitat. These water sources may also be vulnerable to basinwide drought and climate change impacting overall habitat availability and the population.

The development of a second population of reproducing humpback chub in the Grand Canyon was identified as an important conservation action in the 1995 EIS on the operations of Glen Canyon Dam, in case of catastrophic loss of the Little Colorado River population (Valdez et al. 2000). While some reproduction of humpback chub has been documented in Havasu Creek (Healy and Nelson 2013) near 30-mile spring (RM 30; Valdez and Masslich 1999) and may occur in the western Grand Canyon (Albrecht et al. 2015; Kegerries et al. 2015), it is likely limited in the Colorado River by water temperature, rearing habitat, or other factors.

2.1.3 Razorback Sucker

2.1.3.1 Legal Status

The razorback sucker (*Xyrauchen texanus*) was listed as endangered under the ESA on October 23, 1991 (56 FR 54957). The final rule for determination of critical habitat was

published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994. Designated critical habitat within the project area includes the Colorado River and its 100-year floodplain from the Paria River downstream through Marble and Grand Canyons to Hoover Dam, including the full pool elevation of Lake Mead.

2.1.3.2 Recovery Goals and Status

Recovery goals for razorback sucker were established in 2002 (FWS 2002b). Demographic criteria that describe numbers of populations and individuals (adults and juveniles) for downlisting and delisting are presented for upper and lower basin recovery units in the FWS's razorback sucker Recovery Goals document:

> These criteria require four genetically and demographically viable, self-sustaining populations (two in each recovery unit), based on requirements of no significant decline in numbers of adults for each population and recruitment equal to or exceeding adult mortality. In addition, a genetic refuge needs to be maintained in Lake Mohave of the lower basin recovery unit (based on the majority opinion of lower basin biologists, the number of adults for maintaining this refuge is 50,000).

Monitoring is also necessary to determine if the recovery criteria are met. Adequate habitat and sufficient range are required to support recovered populations, in addition to demographic criteria.

The 5-year status review for the razorback sucker was completed by the FWS in 2012 (FWS 2012). The recovery of the species is based on whether the reduction or removal of threats has occurred, and on whether improvement in the demographic criteria has been achieved. Based on the review, only 1 of the 10 demographic criteria had been met, 2 had been partially met, and 7 were unmet. In addition, the majority of the most meaningful threats to the species were not mitigated, as only 9 of the 29 recovery factor criteria were met. As a result, the FWS decided that a change in the species' endangered status was not warranted (FWS 2012).

2.1.3.3 Historic and Current Range

The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado River system. It is a large fish, with adults reaching lengths up to 3 ft and weighing as much as 13 lb, and it may live 40 years or more (FWS 2002b). The species is endemic to large rivers of the Colorado River Basin from Wyoming to Mexico; however, the specie's range has been substantially reduced (Figure 13; Marsh et al. 2015). Currently, it occurs in the Green River, upper Colorado River, and San Juan River subbasins; the lower Colorado River between Lake Havasu and Davis Dam; Lake Mead and Lake Mohave; and tributaries of the Gila River subbasin (FWS 2002b) and Lake Powell (Francis et al. 2015).

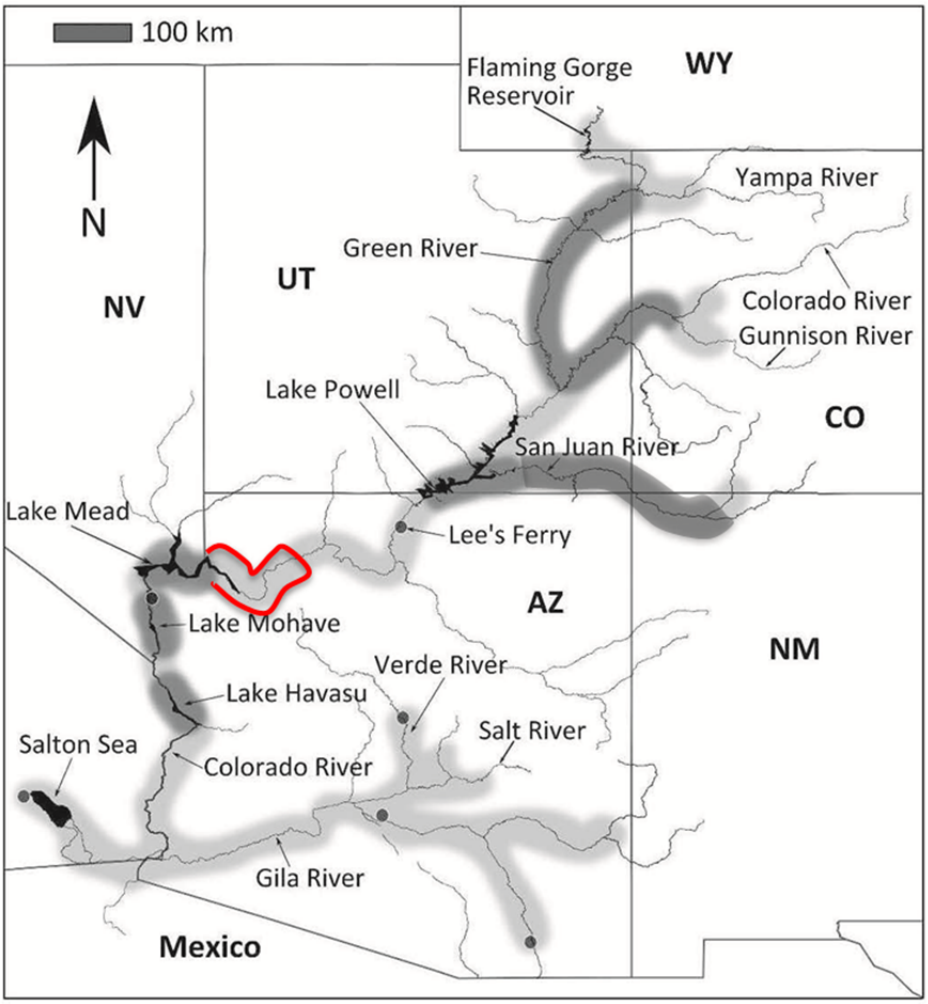


FIGURE 13 Historic (light gray) and Present Range (dark) of Razorback Sucker in the Colorado River Basin (The lower Grand Canyon/Colorado River inflow area of Lake Mead, where razorback sucker larvae have been detected is shown in red [Albrecht et al. 2014; Kegerries et al. 2015].) Source: Marsh et al. (2015)

Recent estimates of razorback sucker populations were summarized by Marsh et al. (2015), but the authors noted that the precision of many estimates was questionable given low recapture rates of marked individuals. Despite this, collectively, the number of remaining individuals is likely only a fraction of historic populations. Many populations in the upper Colorado River Basin are maintained by stocking, and in the lower basin, with the exception of Lake Mead, razorback sucker are maintained through stocking, including populations in Lakes Mohave and Havasu (Marsh et al. 2015). Recruitment has been occurring since the 1970s, sustaining the small population remaining in Lake Mead (Albrecht et al. 2010; FWS 2012; Mohn et al. 2015), which was estimated to consist of approximately 596 individuals through 2012 (95% Confidence Interval: 468–786; Albrecht et al. 2013). Low numbers of recaptures likely precluded a population estimate for the sampling period between 2013 and 2015 in

Lake Mead (Mohn et al. 2015). Lake Mead contains one of the smaller populations; rangewide, however, recruitment is rare or nonexistent in other populations (Marsh et al. 2015).

2.1.3.4 Population within the Action Area

Inventories of fish populations in the pre-dam Grand Canyon were extremely rare, and thus describing historic fish distribution and abundance is difficult (Webb et al. 2002). Within the Grand Canyon, it is likely that razorback sucker historically occurred throughout the Colorado River to Lake Mead (after Hoover Dam construction), with several documented captures in the mainstem (near Bright Angel and Shinumo Creeks), at the Little Colorado River inflow in 1989 and 1990, and from the Paria River mouth (in 1963 and 1978, as reported in NPS 2013). Until recently, the last razorback sucker collected from the Grand Canyon (RM 39.3) was caught in 1993, and the species was considered extirpated from the Grand Canyon.

Adult razorback suckers have recently been captured from the western Grand Canyon (summarized in NPS 2013). Four fish that were sonic-tagged in Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to Quartermaster Canyon (RM 260) (Kegerries and Albrecht 2012, as cited in NPS 2013). An additional untagged adult razorback sucker was captured in GCNP near Spencer Creek (RM 246) in October 2012 (as reported in NPS 2013), and another adult was captured in late 2013 (GCMRC 2014). Sampling of channel margin habitats has also documented 462 and 81 razorback sucker larvae as far upstream as RM 179 (just upstream of Lava Falls) in 2014 (Albrecht et al. 2014) and 2015 (Kegerries et al. 2015), respectively, indicating that spawning is occurring in the mainstem river in the western Grand Canyon (Albrecht et al. 2014; Kegerries et al. 2015). However, small-bodied fish sampling designed to detect juvenile razorback sucker in western Grand Canyon has failed to detect any older larval fish or those that have transformed to juveniles.

Tagged adult razorback suckers have also been located as far upstream as RM 184.4 near Lava Falls, and along with the collection of larvae, indicates that the species utilizes the Colorado River above the Lake Mead inflow area more than previously thought (Albrecht et al. 2014). In 2015, Submersible ultrasonic receivers (SURs), which are devices that detect sonic-tagged razorback suckers, were installed upstream of Lava Falls, to an area below Bright Angel Creek. No detections of razorback sucker were recorded above Lava Falls through September 2015; however, the continued collection of larval fish upstream of Lava Falls (Kegerries et al. 2015) indicates spawning is occurring in an unknown location in the mainstem or tributaries.

Occurrences since 2013 of adult and larval razorback sucker in Lake Mead and the lower Grand Canyon downstream of RM 180 indicate that the connectivity of the lake to the riverine reaches may be important to maintenance of razorback sucker in the project area.

2.1.3.5 Habitat

Razorback sucker use a wide variety of habitats, including rivers and streams and their associated floodplains, as well as reservoirs (Valdez et al. 2012a). Habitat use varies by life stage and by habitat type (i.e., lentic vs. lotic habitats). Valdez et al. (2012a) completed a comprehensive review of razorback sucker habitat use studies conducted throughout the species' range. In rivers, habitat requirements of adults in spring include low-velocity runs, eddies, backwaters, and areas of inundated vegetation (e.g., flooded off-channel areas); in summer, runs and mid-channel bars; and in winter, low-velocity runs, pools, and eddies (reviewed in Valdez et al. 2012a). Razorback suckers spawn on cobble and gravel bars in rivers, and on gravel and cobble shorelines in reservoirs. In reservoirs, adults prefer areas with water depths of 3 ft or more over sand, mud, or gravel substrates. Young require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers and coves or shorelines in reservoirs (FWS 2002a). Recent captures of larval razorback sucker in the western Grand Canyon found the highest density of larvae in isolated pools, which comprised less than 2% of all habitat sampled (Albrecht et al. 2014). Similar results were found in 2015, when the highest catch of larval razorback sucker was found in isolated pools, followed by backwaters, which composed 2.1% and 9.1% of habitats sampled, respectively (Kegerries et al. 2015). Larval razorback sucker may drift along the shoreline adjacent to the main channel until settling into warmer, shallow backwaters, or floodplain wetlands (Valdez et al. 2012a).

Critical habitat was designated for this species in 1994, and within the project area, including the Colorado River and its 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam (a distance of about 500 mi), including Lake Mead to full pool elevation (59 FR 13374).

2.1.3.6 Life History

Razorback suckers are long-lived (40+ years) and exhibit relatively fast growth the first 5 to 7 years of life in warm, food-rich environments, until adulthood, and after which growth slows and possibly stops (FWS 2002b). Both sexes are sexually mature by age 4 and can reach a maximum size of about 1 meter. As described above, spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and at water temperatures as low as 6°C (reviewed in Marsh 1985), but typically greater than 14°C (57°F) (FWS 2002b). High flow and temperature cues during spring were thought to be important to the initiation and success of spawning (reviewed in FWS 2002b). For example, vegetated floodplain wetlands and other off-channel habitats inundated by spring high flows provide warmer, food-rich rearing habitats for drifting larval razorback sucker (reviewed in Modde et al. 2001). High flows may also have flushed fine sediment from cobble bars, maintaining interstitial space for egg deposition and incubation. In reservoirs, spawning occurs over wave-swept rocky shoals and shorelines.

Historically, this species exhibited upstream migrations in spring for spawning, although current populations include groups that are sedentary and others that move extensively (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much as 62 mi to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have been reported to move 12 to 19 mi between spring spawning and summer use areas (Mueller et al. 2000). Sonic-tagged razorback sucker, either stayed near spawning areas, or have moved great distances, up to 361 km (224 mi) within the western Grand Canyon, the Colorado River inflow to Lake Mead, and throughout the lake (Kegerries et al. 2015).

Razorback sucker have high fecundity, with the average number of eggs per female ranging from 27,614 to 103,000 in various studies (reviewed in FWS 2002b). Eggs incubate for 6 to 7 days before hatching, prior to emerging from cobbles and being transported downstream to floodplains or backwaters. Hatching success is temperature dependent, with the potential for complete mortality occurring at temperatures less than 10°C (50°F; Marsh 1985; Bozek et al. 1990). Marsh (1985) found the highest survival of embryos and percentage hatched was at 20°C in laboratory studies, while Bozek et al. (1990) showed that hatching success was between 32 and 65% in 15°C water.

In the Grand Canyon, the estimated onset of spawning was in mid-February, based on back-calculation from the dates of larval collection, when average daily water temperatures were between 10 and 12°C (50 and 53.6°F; Kegerries et al. (2015). Spawning appeared to peak toward the end of March when water temperatures ranged from 12 to 14°C, but the duration of spawning was protracted—occurring between mid-February and July (Kegerries et al. 2015). A faster larval razorback sucker growth rate is thought to benefit survival by minimizing the time larvae are susceptible to predation by small-bodied fish. Growth was 50% greater at 19.5°C compared to growth in 16.5°C water, with the highest growth rates at 25.5°C (Bestgen 2008). As described above, following hatching, larval razorback sucker may drift into low-velocity, warm, backwaters or floodplain wetlands to rear. Maturity is reached in 2 to 5 years.

Both adults and immature fish are omnivorous, feeding on algae, zooplankton, and aquatic insect larvae; however, diet varies by life stage. In Lake Mohave, their diet has been reported to be dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987). Larval razorback sucker feed on planktonic organisms, switching to benthic organisms as their sub-terminal mouth develops, with chironomid larvae being a primary food item (FWS 2002b).

2.1.3.7 Factors Affecting Distribution and Abundance in the Grand Canyon

The decline of the razorback sucker in the Grand Canyon and throughout its range has been attributed primarily to habitat modification due to dam construction (including coldwater dam releases, habitat loss, and migration impediments), streamflow regulation, and predation by nonnative fish species, which have resulted in a lack of recruitment (FWS 2002b; Gloss and Coggins 2005). For example, the estimated 80% rangewide reduction in distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River (Valdez et al. 2012a). Similar to the humpback chub, as described above, cold hypolimnetic releases from dams,

including Glen Canyon Dam, have also contributed to reproductive failure in razorback sucker (Gloss and Coggins 2005). Flow regulation and water diversions have decreased the magnitude of spring peak runoff, which is closely linked to reproduction of the razorback sucker. The loss or drastic reduction in peak flows, along with channelization or disconnection of floodplain nursery habitats with the main channel (as a result of loss of peak flows), have resulted in the elimination of reproduction and recruitment (FWS 2002b). In 2012, the FWS (2012) determined that flow regimes necessary to establish and maintain razorback sucker populations in the lower basin, including flows that provided adequate spawning cues and spawning and nursery habitat, had not been established. Similar to impacts on humpback chub, elevated Hg and Se described by Walters et al. (2015) may be another factor that may impact razorback sucker. While not tested, other native suckers with similar diets were found to have high levels of Hg and Se in the Grand Canyon (Walters et al. 2015).

The large reservoirs formed by dams also provide habitat for nonnative sport fishes, which were stocked with nonnative sport fish predators. Competition with and predation by nonnative fishes have also been identified as important factors in the decline of this razorback sucker (Minckley et al. 1991; FWS 2002a). The reduced sediment supply and resulting clear water due to dam operations also is thought to favor sight-feeding nonnative predators, over razorback sucker and other native fish that evolved in highly turbid conditions (reviewed in Gloss and Coggins 2005). Large-scale nonnative fish control and management programs have been implemented to meet recovery goals for razorback sucker in the upper basin, including control of small- and large-bodied predators in the San Juan and Upper Colorado River Basins, and revising nonnative fish stocking procedures (FWS 2012). Marsh et al. (2015) professed that only complete elimination of nonnative fish from razorback sucker spawning and nursery areas, such as off-channel ponds, would lead to successful conservation of the species in Lake Mohave. The success of stocking programs has been limited by the presence of nonnative predators. For example, Schooley and Marsh (2007) found that few individuals survived out of millions of small razorback suckers that had been stocked in the lower basin, likely because of predation by nonnative fish, and larger stocked fish had a much higher likelihood of survival.

In the Grand Canyon, the decline of native fish, including razorback sucker, has been attributed in large part to an increased diversity and abundance of nonnative fishes, along with the effects of Glen Canyon Dam on water temperatures, flow, and sediment (Gloss and Coggins 2005). As described above, recent efforts to better understand the use of the western Grand Canyon by razorback sucker has revealed that the species is more widespread there than previously thought. Spawning has occurred in unknown locations in the river or tributaries from Lake Mead to at least to areas upstream of Lava Falls in the Grand Canyon, or in the inflow areas of tributaries to Lake Mead, which has led to the maintenance of a small, but recruiting population in the project area (Albrecht et al. 2014). It is unclear whether razorback sucker spawning had been occurring previous to larval fish studies initiated in the western Grand Canyon in 2014.

Through the first 2 years of the first phase of a study to determine the habitat suitability and status of razorback sucker in the Grand Canyon (see NPS 2013), it was found that adult razorback sucker moved throughout the study area, and spawned, but no habitat preference could be inferred. Larval razorback sucker catches were higher in isolated pools and backwaters than

other nearshore habitats that were sampled (Kegerries et al. 2015). Despite the presence of adults and larval fish, no juvenile razorback sucker had been captured (Kegerries et al. 2015). Plausible explanations for this, assuming appropriate habitats are sampled for juvenile suckers, could be that all larval suckers are consumed by nonnative fish prior to their transformation to juveniles, or suitable low-velocity nursery habitats with sufficient food and water temperatures may not be available in the western Grand Canyon. However, relatively few nonnative fish have been sampled in the past 2 years in nearshore habitats from Lava Falls to Pearce Ferry, compared to native fish (Albrecht et al. 2014; Kegerries et al. 2015), and Valdez et al. (2012a) observed that there were backwaters similar to those on the San Juan River that are used by razorback sucker larvae, downstream of Lava Falls. Since the flow and temperature regime of the Colorado River in the Grand Canyon has been altered (i.e., reduced sediment supply, lack of high annual peaks, daily fluctuating flows, and cold dam releases), leading to less backwater stability and more frequent flushing (Behn et al. 2010), these backwaters may be less suitable for rearing than under stable summer flows (see Trammell et al. 2002; Vernieu and Anderson 2013). Alternatively, larval razorback sucker may drift out of the Grand Canyon and rear in the Colorado River Inflow of Lake Mead, which may provide suitable cover (turbidity) and temperatures (Valdez et al. 2012b; Kegerries et al. 2015). Captures of an age-2 and an age-3 immature razorback sucker, and an age-0 juvenile in or near the Colorado River Inflow of Lake Mead, suggests that some recruitment is occurring associated with the Colorado River in the Grand Canyon (summarized in Kegerries et al. 2015), despite altered habitats.

The presence of razorback suckers and their use of habitats in the Grand Canyon have only recently been investigated, and it is unclear how long spawning has been occurring, since larval fish studies were not conducted prior to 2014. Recent warming river temperatures due to lower Lake Powell elevations, attributed to drought and consumptive water use, may have resulted in more suitable habitats in the western Grand Canyon. For example, in 2015, river temperatures were within the acceptable range needed for razorback sucker spawning and successful hatching, particularly farther downstream (Kegerries et al. 2015). In addition, fish community composition in the lower river below Diamond Creek has changed dramatically from one dominated by nonnative species, to native species (reviewed in Kegerries et al. 2015). However, the cause of the change in fish community composition is unknown. The drop in nonnative predator abundance, combined with periodically warmer water temperatures, may have allowed for the expansion of razorback sucker into the western Grand Canyon. Additional research and monitoring are needed to better understand the management implications for recovery of razorback sucker in this reach of its range (Albrecht et al. 2014).

More frequent droughts and warmer atmospheric temperatures as a result of climate change and warmer temperature of water being released from the dam are likely to impact razorback suckers in the Grand Canyon. Razorback suckers are currently located in the lower reaches of the canyon where backwater habitat is more available. Warmer water temperatures may create more suitable habitat for larvae and juveniles. However, these effects may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. Also, lower reservoir releases may result in fewer backwater habitats available for spawning and rearing of razorback sucker.

2.1.4 Southwestern Willow Flycatcher

2.1.4.1 Legal Status

The southwestern willow flycatcher (*Empidonax traillii extimus*) is one of four currently recognized willow flycatcher subspecies (Phillips 1948; Unitt 1987; Browning 1993). On March 29, 1995, the southwestern willow flycatcher was listed as endangered (60 FR 10694) in its entire range, which is known to include Arizona, California, Colorado, New Mexico, Texas, Utah, and Mexico. In August 2002, the FWS released the "Final Recovery Plan for the Southwestern Willow Flycatcher." The Recovery Plan establishes six recovery units that are further subdivided into management units. These Recovery and Management Units are based on watershed and hydrologic units within the breeding range of the flycatcher (FWS 2002c).The Grand Canyon is within the Lower Colorado Recovery Unit. This Recovery Unit encompasses the Colorado River and its tributaries from Glen Canyon Dam downstream to the Mexican border. Despite the large size of this Recovery Unit, the unit contains only 146 known territories (15% of the rangewide total) (FWS 2002c).

2.1.4.2 Recovery Goals and Status

The Recovery Plan and goals for the southwestern willow flycatcher were completed in 2002 (FWS 2002c). The recovery objective for the species is to attain a population size and distribution of habitat sufficient to maintain metapopulations over the long term. Threats to the species must be addressed to achieve this goal. In general, the minimum number of territories needed and maintained over a 5-year period is 1,950 (approximately 3,900 individuals), distributed geographically to allow for functioning metapopulations. In addition, the total known population would need to be increased to 1,500 territories (3,000 individuals) distributed geographically among the Management Units and Recovery Units, so that the species is no longer in danger of extinction.

The 5-year status review for the southwestern willow flycatcher was completed by the FWS in 2014 (FWS 2014). It was determined that the status of the species had improved due to an increase in the number of known territories since it was listed in 1995. However, ongoing threats related to the spread of tamarisk leaf beetle and land management remained concerns. Due to these ongoing threats, a decline in the rangewide distribution of the species, and anticipated future adverse effects of the tamarisk leaf beetle to its habitat, the FWS determined that no change in status was warranted.

2.1.4.3 Historic and Current Range

The southwestern willow flycatcher is a neotropical migrant that breeds in the southwestern United States and migrates to Mexico, Central America, and possibly northern South America during the non-breeding season (Phillips 1948; Stiles and Skutch 1989; Peterson 1990; Ridgely and Tudor 1994; Howell and Webb 1995). The Pacific lowlands of

Costa Rica appear to be a key winter location for the southwestern willow flycatcher, although other countries in Central America may also be important (Paxton et al. 2011). Historically, the range of the flycatcher in Arizona included portions of all major watersheds (FWS 2002c); however, these watersheds have changed in many cases. As a result, most of the areas where flycatchers were locally abundant now support few or no individuals (FWS 2002c). Habitat and population numbers of southwestern willow flycatchers have declined in recent decades due to several factors, including loss, degradation, and fragmentation of riparian habitat; invasion by nonnative plants; brood parasitism by brown-headed cowbirds; and loss of wintering habitat (Stroud-Settles et al. 2013).

2.1.4.4 Population within the Action Area

Seventeen flycatcher sites were identified in the 2002 Recovery Plan (FWS 2002c) within the Grand Canyon. Flycatcher territories in the Grand Canyon are generally located in the tamarisk-dominated riparian vegetation along the river corridor but not in the mesquite-acacia and hackberry-dominated habitats higher on the slopes (Sogge et al. 1997a). The flycatcher's nesting habitat is dynamic in that it varies in occupancy, suitability, and location over time. In GCNRA, southwestern willow flycatchers are uncommon restricted migrants in riparian areas, rare summer residents, and probable breeders (Spence et al. 2011). Historic and recent nesting site locations in the Grand Canyon have been documented below Lees Ferry in Marble Canyon and in lower Grand Canyon below Diamond Creek (RM 225.5–RM 277) (Appendix B). No southwestern willow flycatcher nests or nesting behavior have been identified in the inner gorge (RM 77.9–RM 116.5); however, migrant birds have been documented. Because river channels, river flows, and floodplains are varied and can change over time, the location and quality of nesting habitat may also change over time. This is especially noticeable in the lower Grand Canyon where dropping lake levels in Lake Mead have resulted in high walls (approximately 10 to 20 ft high in many areas) of sediment topped with tamarisk bordering the Colorado River. The backwaters and saturated soils preferred by southwestern willow flycatchers have become rare.

Numbers of southwestern willow flycatcher detections in the Grand Canyon have declined since the 1980s, which is based on studies referenced below. There is little information on the number of willow flycatchers along the river before the construction of the Glen Canyon Dam. However, what data are available suggest that southwestern willow flycatchers were not common breeders along the Colorado River in the Grand Canyon (Brown 1988a,b; Brown 1991; Sogge et al. 1997b). Studies conducted along the river from 1982 to 1991 between Lees Ferry and Phantom Ranch found a total of 47 adult southwestern willow flycatchers—14 pairs, and 15 nests (Brown 1988a; Sogge et al. 1997a). From 1992 to 2001, the breeding population fluctuated between 1 and 4 breeding pairs per year with a total over the 10 years of 66 adult southwestern willow flycatchers, 14 pairs, and 20 nests (Brown 1988a,b; Brown 1991; Sogge et al. 1997a; Sogge and Tibbitts 1992; Sogge et al. 1993; Sogge and Tibbitts 1994; Sogge et al. 1995; Petterson and Sogge 1996; Sogge 1998; Yard 2001, 2002, 2003). Appendix B summarizes southwestern willow flycatcher observation data, territories, and nesting sites located in the Grand Canyon from 1909 to 2011. Although surveys were conducted in 2012, southwestern willow flycatchers were not detected. Survey methods followed the most recent

USGS survey protocol, at the time of survey, and involved the use of broadcast calling to elicit southwestern willow flycatcher responses (Sogge et al. 2010). Nest searches were not conducted during the 2010–2012 surveys at the Grand Canyon; however, due to behavior and timing of southwestern willow flycatcher detections at RM 275 in 2010, two breeding pairs were suspected to be present. Appendix A and Appendix B provide information on the locations of birds and nests from 1982 to 2011. Data are based on the following monitoring reports: Sogge et al.1997a; McKernan and Braden 1997, 1998, 1999, 2000, 2001, 2002, 2004; Paradzick et al. 2001; Smith et al. 2002, 2003, 2004; Koronkiewicz 2004, 2005, 2006, 2007, 2008; Yard et al. 2004; Albert 2005; Laczek-Johnson and Ward 2006; Ward and Haynes 2007; Northrip et al. 2008; Slayton et al. 2009; Palarino et al. 2010; Stroud-Settles and Lawrence 2011.

After the 2004 survey season, the USGS and GCMRC elected to discontinue their monitoring of known southwestern willow flycatcher nesting habitat in the Grand Canyon. Beginning in 2005, the Grand Canyon conducted annual surveys from Lees Ferry to Phantom Ranch, but funding prevented surveying the isolated habitat patches between Phantom Ranch and Diamond Creek. From 2004 to 2008, only two southwestern willow flycatchers were detected between Lees Ferry and Phantom Ranch.

2.1.4.5 Lees Ferry to Diamond Creek

Suitable habitat is located disjunctly through the river corridor from approximately RM 28.3 to RM 275. Surveys conducted between 1992 and 2004 indicated a small resident breeding population between Lees Ferry and Cardenas Marsh (RM 71), but no territories from RM 71 through RM 246 have been located. Recent (2007–2009) surveys have only detected non-resident/migratory flycatchers between Lees Ferry and Phantom Ranch (Palarino et al. 2010). Formal nest searches have not been conducted above Diamond Creek since 2004 (Stroud-Settles et al. 2013).

From 1993 to 2004, flycatchers were consistently present during the breeding season at RM 50.5–RM 51.5, but have not been present since 2004 (Ward and Haynes 2007; Northrip et al. 2008). In 2003, 2004, and 2010, the area around RM 28–RM 29 was occupied. Another area of importance in the mid-1990s was RM 71–RM 71.5; however, this area does not appear to have been occupied for the last 17 years. In 2004, the Grand Canyon instituted an emergency closure at two sites. This closure was in effect between May 1 and July 15 and included closure of visitor use, including hiking, camping, and river landings at RM 28.1–RM 28.5, river left, and RM 50.2–RM 50.6, river left. Closures at RM 28 and RM 50 have been put in place intermittently in the past; closure at Cardenas (RM 71) was instituted in the early and mid-1990s.

2.1.4.6 Lower Grand Canyon

Koronkiewicz et al. (2004) reported that the Colorado River in the Grand Canyon downstream of Separation Canyon (RM 234) is strongly influenced by water levels in Lake Mead. Potential southwestern willow flycatcher habitat in this area has changed dramatically in

the last several years as the result of a 105-ft drop in the level of Lake Mead since 2000. Areas that were inundated in the late 1990s are now well above the current water level, and the existing riparian vegetation in many of these areas is dead or dying. A 5-year boost in detections along this stretch of river that occurred from 1997 to 2001 is likely due to favorable water levels of Lake Mead in combination with increased survey effort (Stroud-Settles et al. 2013). The river corridor continues to provide essential habitat for migrating southwestern willow flycatcher (Stroud-Settles et al. 2013).

Southwestern willow flycatchers have been detected in the lower Grand Canyon below RM 234 since 1995 with the exception of 2002, 2003, 2011, and 2012 (Appendix B). In 2004, Koronkiewicz et al. identified approximately 76 hectares of suitable habitat at several sites between RM 239 and RM 275 within the Grand Canyon. These disjunct habitat patches have been inconsistently monitored during the past 11 years for both flycatcher presence and habitat suitability. Suitability ranking of these sites has proven to be largely dependent on current hydrological conditions of the Colorado River. As a result, a habitat assessment survey conducted during one year may result in a habitat ranking that is deemed suitable, but a revisit to the same site during a different year may rank the site as only potential habitat.

2.1.4.7 Life History and Habitat

The southwestern willow flycatcher eats insects and needs riparian habitats to complete its life cycle. It breeds and forages in dense, multi-storied riparian vegetation near saturated soils, slow-moving water, or surface water (Sogge et al. 1995). The southwestern willow flycatcher breeds across the lower Southwest from May through August (Reclamation 2007b). The southwestern willow flycatcher arrives on the breeding grounds throughout May and early June, eggs are generally laid beginning in May, and fledging occurs between June and August (Sogge et al. 1997a, 2010). Occupied sites most often have a patchy interior of dense vegetation or dense patches of vegetation intermingled with openings. Most often, this dense vegetation occurs within the first 3 to 4 m above the ground (FWS 2002c). The structures of occupied patches vary, with a scattering of small openings, shorter vegetation, and open water. Occupied patches can be as small as 2 acres and as large as several hundred acres, but are typically >10 m wide (Reclamation 2007b).

The southwestern willow flycatcher breeds in dense riparian habitats from sea level in California to approximately 8,500 ft in Arizona and southwestern Colorado. Throughout its range, the southwestern willow flycatcher arrives on breeding grounds in late April and May (Sogge and Tibbitts 1992; Sogge et al. 1993; Sogge and Tibbitts 1994; Muiznieks et al. 1994; Maynard 1995; Sferra et al. 1995, 1997). Nesting begins in late May and early June, and young fledge from late June through mid-August (Willard 1912; Ligon 1961; Brown 1988a,b; Whitfield 1990; Sogge and Tibbitts 1992; Sogge et al. 1993; Muiznieks et al. 1994; Whitfield 1994; Maynard 1995). The entire breeding cycle, from egg laying to fledging, is approximately 28 days. Nesting occurs during the spring and early summer months (May 1–August 31) in the Grand Canyon.

Historical egg/nest collections and species descriptions throughout its range identify the southwestern willow flycatcher's widespread use of willow (*Salix spp*.) for nesting (Phillips 1948; Phillips et al. 1964; Hubbard 1987; Unitt 1987; San Diego Natural History Museum 1995). Other habitats are also used, including nonnative species such as tamarisk (*Tamarix spp*.) and Russian olive (*Eleagnus angustifolia*). Throughout the southwestern willow flycatcher's current range, suitable riparian habitats tend to be rare, widely separated small and/or linear locales separated by vast expanses of arid lands.

2.1.4.8 Factors Affecting Distribution and Abundance in the Grand Canyon

The southwestern willow flycatcher has experienced extensive loss and modification of habitat and is also endangered by other factors, including brood parasitism by the brown-headed cowbird (*Molothrus ater*). The southwestern willow flycatcher was listed primarily due to riparian habitat reduction, degradation, and elimination as a result of agricultural and urban development. Other reasons for the decline/vulnerability of the flycatcher include the fragmented distribution and low numbers of the current population; predation; and other events such as fires and floods that are naturally occurring, but have become more frequent and intense as a result of the proliferation of exotic vegetation and degraded watersheds, respectively.

The Grand Canyon does not provide extensive stands of dense riparian habitat suited for breeding southwestern willow flycatchers. The majority of habitat patches in the Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result, the majority of flycatcher habitats in the Grand Canyon are marginal and, unless current hydrological conditions change, these patches will likely continue to decline. Furthermore, the recent arrival of the tamarisk leaf beetle has transformed and will continue to transform the patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013). Effects of climate change and continued dry basin hydrology may further diminish habitat for the flycatcher due primarily to lower water levels within riparian areas.

2.1.5 Yuma Ridgway's Rail

2.1.5.1 Legal Status

The Yuma Ridgway's rail (*Rallus obsoletus yumaensis*) was listed as endangered on March 11, 1967 (32 FR 4001). A 5-year review of the species was completed in 2006, and currently the 1983 Recovery Plan is in the revision process; a draft was released in 2010 for public review (FWS 2009b), and finalization is expected in 2016. It is categorized as a subspecies with a high degree of threat and low recovery potential due to habitat loss.

2.1.5.2 Recovery Goals and Status

Recovery goals and objectives for Yuma Ridgway's rail are based on the need to achieve and maintain a viable population level and to protect and maintain a sufficient amount of core and other habitats to support the population. The primary threat to the species is that water sources supporting its habitat are not managed and protected, and as a result, habitat may be lost. The draft recovery goal is "To achieve population stability and habitat protection sufficient to downlist and/or delist the Yuma Ridgway's rail" (FWS 2009b).

The 5-year status review for Yuma Ridgway's rail was completed in 2006 (FWS 2006). Based on the review, it was determined that the population in the United States is small, and limited information is available to determine the species' demographic status. Habitat loss in a Mexican population's range and accumulation of selenium in the environment remain significant threats, and thus no change in status was warranted.

2.1.5.3 Historic and Current Range

The Yuma Ridgway's rail occurs along the lower Colorado River and tributaries (Muddy, Virgin, Bill Williams, Lower Gila and Salt Rivers) in Arizona, California, Nevada, and Utah; the Salton Sea in California; and the Cienega de Santa Clara and Colorado River Delta in Mexico (FWS 2009b). Significant breeding areas in the United States include Mittry Lake (Arizona), Imperial Reservoir, Imperial National Wildlife Refuge, Bill Williams River National Wildlife Refuge, Topock Gorge and Topock Marsh in Havasu National Wildlife Refuge, Cibola National Wildlife Refuge along the lower Colorado River and Imperial Wildlife Area, Sonny Bono Salton Sea National Wildlife Refuge at the Salton Sea in California, and the Cienega de Santa Clara in Mexico. There is a small population in southern Nevada/northwest Arizona on the Muddy and Virgin Rivers.

2.1.5.4 Population within the Action Area

McKernan and Braden (1999) reported the presence of Yuma Ridgway's rails between Spencer (RM 246) and the boundary of the Grand Canyon (RM 277); these observations were made while conducting southwestern willow flycatcher surveys in the area. Specifically, McKernan and Braden (1999) report at least one rail observed between May 26, 1996, and June 30, 1996, and they indicate that nesting was confirmed. They report at least one rail observed between May 14, 1997, and June 17, 1997, but indicate that nesting was not confirmed (McKernan and Braden 1999). Surveys for the southwestern willow flycatcher in the lower Grand Canyon from 2003 to 2008 under the Lower Colorado River Multi-Species Conservation Program (LCRMSCP) did not record any incidental detections of Yuma Ridgway's rails (LCRMSCP 2008). GCNP surveys for southwestern willow flycatchers in the lower Grand Canyon in 2010 to 2012 did not have any incidental detection; however, the method of surveying used would be unlikely to pick up rail vocalizations.

The LCRMSCP mapped marsh habitat in the lower Grand Canyon/upper Lake Mead from aerial imagery taken in 2004; that mapping extended from RM 249 (401 km) to RM 277 (446 km), all within the boundary of GCNP. Koronkiewicz et al. (2004) and LCRMSCP (2004) report the presence of live cattails at Spencer Canyon (RM 246) and Burnt Springs (RM 259.5). The persistence of the cattail patches identified in the 2004 imagery and as documented in 2004 and 2005 is unknown. The continuing fall in Lake Mead elevation (60 ft to 18 m from 2004–2015) results in a longer reach of the river, and shallow bays or coves along the channel have become dewatered. Further, within the full-pool of Lake Mead, sediments have built up over time during higher lake elevations forming a delta. The retreating lake flows allows the erosive action of the river to cut through those sediments and move them downstream. The result can be steep eroding banks with riparian and marsh vegetation on top beginning to dry out as the water recedes with the lowered channel as more and more sediment is removed. With these changes, it is not known if cattail marsh habitat is present in sufficient quantity to allow for nesting.

Because of the limited information about the Yuma Ridgway's rail and its habitat in the Grand Canyon, managers must rely heavily upon the limited information available. Given that Yuma Ridgway's rails have been recorded historically at the Grand Canyon but have not been surveyed consistently or recently, managers presume that the Yuma Ridgway's rail may be present in the lower Grand Canyon during the lifetime of the LTEMP.

2.1.5.5 Habitat and Life History

The Yuma Ridgway's rail is a secretive species and is not often seen in the wild; however, it does have a series of distinctive calls and is most often identified by those. This bird inhabits freshwater or brackish stream sides and marshes under 4,500 ft (1,372 m) in elevation. It is associated with dense riparian and marsh vegetation, dominated by cattails (*Typha sp.*) and bulrush (*Scirpus ssp*.) with a mix of riparian tree and shrub species. Yuma Ridgway's rails may climb into a shrub or tree, but overall, they do not perch above the ground (FWS 2009b). Rails are capable of swimming and are also known to dive underwater, and may hold onto submerged vegetation to avoid threats or use its wings to "swim" (Todd 1986; Ripley 1977 cited in Eddleman and Conway 1998). The rail requires a wet substrate such as a mudflat, sandbar, or slough bottom that supports cattail stands of moderate to high density adjacent to shorelines. Other important factors are the presence of vegetated edges between marshes and shrubby riparian habitat (tamarisk or willow thickets) and the amount and rate of water-level fluctuations. Nests are built 3 to 6 in. (8 to 16 cm) above the surface in sloughs and backwaters that support dense stands of bulrush and cattails, and breeding occurs from March to early July. Along the lower Colorado River, males begin calling in February and pair bonding occurs shortly after. Nonnative crayfish provide the primary food base for the rail today; prior to the introduction of crayfish, isopods, aquatic and terrestrial insects, clams, plant seeds, and small fish likely dominated their diet (LCRMSCP 2008).

Eddleman (1989) determined that vocalizations are significantly reduced in winter, and telemetry data indicated that the majority of rails do not migrate. There is evidence that some populations may be more migratory than others, and this could be based on habitat and a stable food source (Eddleman 1989; Corman and Wise-Gervais 2005). Very little is known about the

dispersal of adult or juvenile birds, but the expansion of the population northward along the lower Colorado River (to Lake Mead, the Salton Sea, and up the Gila and Salt Rivers in central Arizona over the last 80 years) indicates that dispersal does occur (FWS 2009b).

2.1.5.6 Factors Affecting Distribution and Abundance in the Grand Canyon

Historically, the primary concentrations of Yuma Ridgway's rails were likely to be found in cattail/bulrush marshes in the Colorado River Delta. Unfortunately, due to diversions from the river for agriculture and municipal uses, the freshwater flows down the lower Colorado River, necessary to maintain marsh habitat, have virtually been eliminated (FWS 2009b). The majority of Yuma Ridgway's rail habitats that exists today are mostly human-made, such as the managed ponds at the Salton Sea (FWS 2009b). Without active management and protection of water resources to address land use changes in floodplains, human activities, environmental contaminants, and reductions in connectivity between core habitat areas, these habitats will be permanently lost to the Yuma Ridgway's rail (FWS 2009b). Effects of climate change and continued dry basin hydrology may further diminish habitat for the Yuma Ridgway's rail due primarily to lower water levels within riparian areas.

Another specific threat to the Yuma Ridgway's rail includes selenium in crayfish, the major prey item of the species. Selenium levels in crayfish collected in Yuma Ridgway's rail habitat were high enough to cause concern for the rail's reproductive success (FWS 2009b). No adverse effects from selenium have been observed; however, due to the rail's secretive nature, nests are very difficult to find and young birds difficult to observe (FWS 2009b).

2.2 BASELINE TAKE RESULTING FROM HANDLING AND GCDAMP RESEARCH

2.2.1 Humpback Chub

Fisheries monitoring and research are important aspects of ongoing research in the Grand Canyon that assesses the impacts of adaptive management and experimental treatments upon humpback chub and other resources. An extensive fisheries monitoring and research program is being implemented by the GCDAMP through the USGS and GCRMC throughout the project area, which will continue under the LTEMP proposed action. While stress upon individual humpback chub may result in occasional fatality, an objective of monitoring is to gather information in order to ensure that LTEMP goals for humpback chub are met.

Stress upon individual humpback chub related to sampling using netting and electro-fishing gears, as well as handling by researchers, is also a potential source of injury or mortality to individuals. No immediate mortality of humpback chub has been documented during tempering prior to release, hoop-netting, or electro-fishing during monitoring associated with NPS translocation projects in Shinumo and Havasu Creeks. Humpback chub were captured and handled 1,068 times between June 2010 and September 2012 in Shinumo and Havasu Creeks (Healy et al. 2014), for example. However, some minimal mortality has occurred during juvenile

collection efforts at the Little Colorado River for translocations and refuge development, although it is generally less than 5% (Van Haverbeke 2012). Five to 10 fish out of 500 to 800 generally die during transport in route to hatchery rearing facilities and during parasite and disease treatments; however, approximately 60 (10%) were lost at a hatchery facility during disease treatments and tagging prior to translocations in 2011. In 2014, approximately 30 out of 600 died during transport to the hatchery facility due to excessive cooling. Mortality of humpback chub captured during monitoring by all management agencies and researchers is reported to the FWS annually.

Incidental fatality was reported to the FWS by the USGS and GCMRC biology program manager (S. VanderKooi) and is summarized here. In 2012, 22 incidental fatalities out of 7,755 total humpback chub captures (0.28% mortality rate from capture) were associated with fish monitoring in the Colorado River using a variety of gear types. Another 4 humpback chub were lost out of 725 captures in the lower sections of the Little Colorado River (0.55%). Incidental mortalities of subadult or juvenile humpback chub (< 200 mm TL) included 88 in 2013 and 36 in 2014. The highest mortality rate was associated with experimental collections and rearing of larval humpback chub to be used in translocations (close to 30% of fish captured). Larval humpback chub collections may continue, or potentially increase slightly, to support translocations and Tier 1-triggered conservation actions included in the proposed action; however, the number collected would be similar to baseline conditions due to hatchery capacity constraints. Larval fish have an extremely low survival rate, and the risk to the humpback chub population of collecting several hundred larval fish is low (Pine. 2013). Nevertheless, collections for translocations or refuge development would be guided by FWS guidance documents (Translocation Framework, Van Haverbeke et al. 2016) and population viability modelling (Pine 2013). While inter-annual variability in incidental fatality due to handling occurs, the research program is not expected to change substantially through the LTEMP, and thus no change in impacts relative to the baseline condition is expected.

2.2.2 Razorback Sucker

Research designed to determine the status of razorback sucker in the lower Grand Canyon has resulted in mortality of larval razorback sucker and other native fish. While the mortality of up to several hundred individual razorback sucker larvae would be expected under the proposed action through collection and sacrifice of larval razorback suckers, with continued monitoring, the population-level impact would be minimal. For example, a single female razorback sucker could produce more than 100,000 larvae. While a final science plan for monitoring razorback sucker has not been developed, given the interest in determining and monitoring the impacts of TMFs and other actions included in the preferred alternative, mortality of larval fish and handling of juvenile fish (if present) may be expected to increase. However, these impacts would not likely impact the population, and monitoring would assist managers in determining the extent of impacts of flows on the species, potentially leading to adjustments in operations to benefit the species, or minimize large-scale impacts on habitat.

3 EFFECTS ANALYSIS OF PROPOSED ACTION

3.1 EFFECTS OF THE PROPOSED ACTION ON KANAB AMBERSNAIL

3.1.1 Direct and Indirect Effects

Aspects of the proposed action that have the potential to affect Kanab ambersnail individuals and habitat include sediment-related experiments (HFEs) and nonnative vegetation management. Other experiments or changes in dam operations included in the proposed action—such as changes in base operations, trout management flows, nonnative fish control, low summer flows, and sustained low flows for invertebrate production—would have no impact on the Kanab ambersnail, because these activities would not occur in locations known to contain populations or habitat. The impacts of changes in base operations, low summer flows, and sustained low flows for invertebrates would be limited to areas within the river channel, where no habitat or individuals occur. Nonnative fish control would occur in the river, in the vicinity of the Little Colorado River inflow, which does not contain habitat for Kanab ambersnail. No fish control would occur in off-channel springs.

3.1.1.1 Effects of Sediment-Related Experiments

Within the Grand Canyon, populations of the Kanab ambersnail occur at Vasey's Paradise and Elves Chasm. Because the Elves Chasm population is located above the 100,000 cfs stage (FWS 2008), this population would not be affected by any of the proposed actions. At Vasey's Paradise, the proposed action will have no effect on the water flow from the side canyon spring that maintains wetland and aquatic habitat at Vasey's paradise. Some Kanab ambersnail habitat could be adversely affected by scouring at Colorado River flows exceeding 17,000 cfs (Kennedy and Ralston 2011). The HFE may reach flows of up to 45,000 cfs. These flows will inundate Kanab ambersnail habitat up to that stage and likely scour the vegetation and carry some snails downstream.

Very little Kanab ambersnail habitat and only a few individuals occur below the 25,000 cfs stage (Meretsky and Wegner 2000; Sorensen 2009). Most Kanab ambersnail habitat is located above the 33,000 cfs stage (Reclamation 2011b). HFEs may scour or inundate portions of Kanab ambersnail habitat. Surveys conducted after HFEs revealed no substantial declines in the Kanab ambersnail population (Kennedy and Ralston 2011). Kanab ambersnails can survive up to 32 hours underwater in cold, well-oxygenated water (FWS 2011a), so as long as they are not washed away, they could survive inundation from short-term HFEs.

Recovery of Kanab ambersnail habitat scoured by HFEs can take up to 2.5 years (Sorensen 2009). Therefore, frequent HFEs may result in long-term loss of Kanab ambersnail habitat (FWS 2011a). Under the proposed action, HFEs would occur more frequently than they would under baseline conditions. Based on modeling results, only five HFEs would occur under the baseline condition, due to the expiration of the HFE protocol (Reclamation 2011b), but an

HFE would be expected to occur almost every year under the proposed action (19.3 HFEs over the LTEMP period). Loss of habitat due to scouring could extend several years beyond the LTEMP period. In addition, impacts on individuals, including fatality, could occur during HFEs, if the individuals are dislodged from habitat and swept into the river. Depending on the elevation of maximum dam discharge during trout management flows, temporary scouring of habitat may occur, but it is unlikely to reach Kanab ambersnail habitat that is above the 30,000 cfs elevation. However, the snail population at Vasey's Paradise survived and persisted through natural pre-dam floods and the 1983 flood, which were much larger in magnitude and longer in duration than the HFEs proposed under the LTEMP (Reclamation 1995; Kennedy and Ralston 2011).The amount of habitat and number of snails that would be unaffected by the proposed action are sufficient to maintain the population.

3.1.1.2 Effects of Vegetation Management

It is possible that vegetation management may occur, on rare occasions, near or within habitat at Vasey's Paradise, which may disturb individuals in small areas. Some nonnative vegetation may encroach on the spring, in which case careful manual removal of the vegetation would occur. To mitigate potential impacts on individual Kanab ambersnails, vegetation biologists would complete surveys and relocate any individuals detected on nonnative vegetation within the treatment areas. It is possible that some individuals could be killed during the treatment, but pre-treatment surveys would minimize this risk.

3.1.1.3 Effects of Climate Change

Climate change has the potential to affect the Kanab ambersnail habitat. The water source at Vasey's Paradise consists of waterfalls emanating from groundwater and emerging from the cliff face. In 2014 and 2015 the flow was noticeably reduced, likely as a result of basin-wide drought. Consequently, the usually dense vegetation at Vasey's Paradise is notably diminished. Climate change and drought will likely diminish the water source supporting Vasey's Paradise and consequently the vegetation and habitat available to the Kanab ambersnail.

Consequently, Reclamation has concluded the proposed action **may affect and is likely to adversely affect the Kanab ambersnail**.

3.2 EFFECTS OF THE PROPOSED ACTION ON HUMPBACK CHUB

The evaluation of potential impacts of the proposed action on humpback chub included consideration of the results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of native fish (e.g., Coggins and Walters 2009; Albrecht et al. 2014; Gerig et al. 2014; Kegerries et al. 2015), as well as studies of the effects of nonnative fish (Coggins et al. 2011; Yard et al. 2011; Whiting et al. 2014), experimental flows (such as HFEs and other flows), and water temperature on native fish (e.g., Grams et al. 2010;

Makinster et al. 2011; Trammell et al. 2002; Ward 2011; Ward and Morton-Starner 2015; Valdez and Speas 2007).

Several aspects of the proposed action may affect humpback chub directly or indirectly through direct impacts on individuals or habitat; or indirectly by influencing the abundance and distribution of nonnative predators and competitors, or by influencing macroinvertebrate production. Dam operations have the potential to influence river temperatures, the quantity and quality of nearshore rearing habitats (e.g., backwaters), aquatic insects that are food for humpback chub, and nonnative species abundance. These operations may also result in direct fatality to juvenile humpback chub through stranding. Flow-related actions that are analyzed below, which may impact humpback chub, include base operations, operational flexibility incorporated into base operations, sediment-related experiments, and aquatic resource experiments including trout management flows, low summer flows, and sustained low flows for benthic invertebrate production. Other non-flow actions that may impact humpback chub directly or indirectly, and that are analyzed below, include triggered humpback chub conservation actions (Appendix D), mechanical removal of nonnative fish, conservation measures, and continued fisheries research and monitoring under the GCDAMP. Some actions may have negative impacts on individuals, but beneficial effects at a population level.

Sediment monitoring and research and efforts to manage riparian vegetation are not expected to have impacts on humpback chub individuals or habitat. Riparian vegetation management would occur in only small, localized areas within the project area. Although riparian vegetation can play an important role in small stream ecosystems, particularly in providing cover, shade, or habitat for terrestrial invertebrates for fish to feed upon, riparian vegetation is less important for providing cover, shade, or energy inputs in larger rivers (Vannote and Sweeney 1980). Thus, riparian vegetation management would have large impacts on humpback chub and the species' habitat in the Colorado River.

3.2.1 Direct and Indirect Effects

3.2.1.1 Effects of Base Operations

Base dam operations are expected to change with the implementation of the proposed action. Changes will include more consistency across months, and thus more stability throughout the year, in monthly dam release volumes. The daily fluctuation in discharge would be proportional to the volume (i.e., lower fluctuations during lower flows), with a maximum discharge fluctuation range of 8,000 cubic feet/second, which would be the same as the current maximum fluctuation range. The daily downramp rate would be increased, compared to the current condition, by 67% (from 1,500 cfs/hr to 2,500 cfs/hr). Year-round, fluctuating flows throughout the life of the LTEMP period may continue to have detrimental, long-term direct impacts on humpback chub, humpback chub habitat, and aquatic invertebrate prey (food base).

Stranding of fish is a potential outcome of daily hydropeaking (Bunn and Arthington 2002; Nagrodski et al. 2012). Increasing downramp rates under the proposed action

may increase the risk of stranding humpback chub. Stranding could include fish being temporarily (i.e., until flows come back up hours later) restricted to isolated habitats away from the main channel, which may or may not become desiccated, as a result of dropping water levels. Desiccation of these isolated habitats would result in fatality of any juvenile humpback chub present. Factors that may influence the probability of stranding fish in a river with altered flow regimes—such as below hydroelectric plants—include the rate of flow reduction, water temperature, channel geomorphology, and substrate composition, as well as biotic factors including fish life stage and size (as reviewed in Nagrodski et al. 2012). Increasing drawdown rates under the proposed actions will increase the risk of negative impacts; however, humpback chub may be less reliant upon river margin habitats that are sensitive to flow fluctuations (e.g., backwaters; Dodrill et al. 2015) than other native fish, at least in the Little Colorado River inflow reach. The potential for, and the effect of, stranding on individual humpback chub survival has not been directly investigated; however, a summary of stranding literature indicated that fish stranding as a result of hydroelectric and irrigation projects is well documented (Nagrodski et al. 2012).

Daily fluctuating flows will continue to degrade nearshore habitats under the life of the LTEMP, particularly cobble shoals, riffles, and backwaters in wider, sections of the canyon, and where low-angle shorelines susceptible to flow fluctuations are prevalent. For example, cobble riffles and shoals, which are important spawning areas for fish, but also invertebrate production areas, would be dewatered daily. Generally, low catch rates of larval and small-bodied juvenile native fish have been observed in these types of habitats below Lava Falls (Albrecht et al. 2014; Kegerries et al. 2015). Although backwaters were not found to be common in the Little Colorado River inflow aggregation reach during a low steady flow experiment, humpback chub were found at higher densities in these habitats than in others (Dodrill et al. 2015). Backwaters may be more prevalent in other areas of the canyon, outside of the Little Colorado River inflow.

Base operations have been, and will continue to be, characterized as hydropeaking or load-following, which is an operational regime that has been demonstrated to have long-term detrimental impacts on aquatic invertebrates below hydroelectric dams in the western United States (Kennedy et al. 2016). Kennedy et al. (2016) found that hydropeaking was a primary factor implicated in reduced aquatic insect diversity; the Grand Canyon was found to have among the lowest insect diversity and the highest hydropeaking index among 16 dammed rivers. A diverse source of invertebrates colonize the Colorado River among the Grand Canyon's tributaries (Oberlin et al. 1999; Whiting et al. 2014), but hydropeaking and an altered temperature and flow regime will continue to negatively impact the food base for humpback chub over the life of the LTEMP.

Under base operations, through the life of the implementation of the LTEMP proposed action, river temperatures are expected to continue to be more suitable for coldwater nonnative species than for warmwater nonnative fish, particularly closer to the dam. In general, the estimated average main channel temperatures modeled for the LTEMP EIS indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61), where temperatures would be more suitable to cold- or

coolwater nonnative fish (e.g., brown and rainbow trout); this is consistent with past surveys that have found more warmwater nonnative fish species in those areas than upstream.

Colder water temperatures restrict growth of YOY humpback chub, which prolongs the time during which individuals are vulnerable to trout predation (Yackulic et al. 2014). Essentially, juvenile humpback chub do not grow at temperatures under 12°C. Larger, older juvenile humpback chub may be able to avoid, withstand, or escape predation by rainbow trout under warmer and turbid conditions; however, temperature and size did not afford the same advantage in escaping brown trout predation (Ward and Morton-Starner 2015).

Unless the water can be warmed to above 12°C, it should be expected that the reduced water temperatures will result in increased egg incubation time (Hamman 1982), greatly reduced egg and fry survival (Hamman 1982), reduced larval-to-juvenile transition time (Clarkson and Childs 2000), and reduced growth rates of all life stages (Clarkson and Childs 2000; Coggins et al. 2011). From Glen Canyon Dam to the Little Colorado River inflow, water temperatures are generally <12°C. Consequently, there will be little or no spawning of humpback chub in this reach of the mainstem, unless it occurs at isolated locations such as 30-mile springs (RM 30) or springs at RM 34. There is little opportunity for larval fish to grow in Marble Canyon, unless the limited backwaters provide some thermal opportunities. In the Little Colorado River to Diamond reach, backwaters are more prevalent due to the more open geomorphology. Recently, temperatures have reached or exceeded 16°C at about RM 160 during September. This may provide opportunities for mainstem spawning activity and growth.

HFEs build sandbars, which can cause additional—but temporary—backwater habitats. Following the 2014 HFE, 22 sandbars and resultant backwaters throughout the Canyon became larger, 11 sites showed no change, and 5 sites became smaller. Although these sandbars erode within 6 to 12 months, they do not return to the pre-flood stage (Grams 2015). Three fall HFEs have occurred (2012, 2013 and 2014) in November; temperatures are unlikely to significantly increase in backwaters at this time, which is outside the spawning period for humpback chub. Spring HFEs may provide more thermal refuge in backwaters, particularly in the lower Canyon. However, relative densities of humpback chub, based on estimates of backwater prevalence directly after a controlled flood, showed the majority of juvenile humpback chub were found outside of backwaters. This suggests that the role of controlled floods in influencing native fish population trends may be limited (Dodrill et al. 2015).

It is possible that within the LTEMP period uncontrolled warm water releases may occur as a result of the elevation and subsequent water temperature of withdrawals from Lake Powell. Increased temperatures may benefit humpback chub spawning and growth, but would also allow numbers and species of warmwater nonnative species to expand in the system. A new conservation measure for LTEMP will explore new technologies for controlling the temperature of water discharged into the Colorado River and technologies to prevent the passage of fish through the dam.

Reclamation developed a risk assessment model to evaluate effects of a selective withdrawal structure on aquatic resources in the Grand Canyon area. It indicates there may be benefits for all native fishes from warmer water, as well as benefits for many nonnative fish

species that may compete with or prey upon native species. Results also indicate that there may be more suitable conditions for warmwater fish parasites (Valdez and Speas 2007). Species that occur in the Colorado River are listed in Table 5, along with their spawning, incubation, growth, and lethal temperature tolerances.

The impacts of the proposed action on temperature suitability for coldwater nonnative trout were assessed to determine the potential for increased trout populations, and thus increased likelihood of competition or predation upon humpback chub. Using the temperature suitability model, generally, temperature regimes would be suitable—although not optimal—for brown and rainbow trout under the proposed action. Temperature suitability for brown and rainbow trout would be similar to the baseline at most locations downstream of Glen Canyon Dam. However, main channel temperatures at and downstream of RM 61 would be more suitable for trout than at locations closer to the dam. The abundance of trout is lower in those locations because other habitat characteristics (e.g., substrate composition and water clarity) are less suitable at these downstream locations.

Previous studies have shown that rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (Avery et al. 2015; AZGFD 1996; McKinney and Persons 1999; McKinney et al. 2001a,b; Makinster et al. 2011; Wright and Kennedy 2011; Korman et al. 2011, 2012). Increases in abundance have been attributed to the changes in flows beginning with interim flows in 1991 and later the implementation of MLFF in 1996. These changes both increased minimum flows and reduced fluctuations in daily flows, which created more stable and productive nursery habitats for rainbow trout in Glen Canyon (McKinney and Persons 1999). Declines in abundance (such as those observed from 2001 to 2007) have been attributed to the combined influence of warmer water releases from Glen Canyon Dam, high abundance, increased intraspecific competition, and periodic dissolved oxygen deficiencies, along with possible limitations in the food base (Makinster et al. 2011). Episodic emigration from the Lees Ferry reach toward the Little Colorado River was likely related to trout density, trout condition, and turbidity during the rainbow trout natal origins study (Korman et al. 2015).

In summary, under base operations, continued hydropeaking flows with increased downramp rates compared to the existing condition under coldwater conditions will continue to degrade nearshore rearing habitats, prevent the establishment of aquatic invertebrates (food base), and increase the risk of stranding juvenile humpback chub over the long term (throughout the life of the LTEMP).

3.2.1.2 Effects of Dam Operational Flexibility

Operational flexibility in dam operations is necessary to account for unforeseen changes in basin-wide hydrologic conditions, dam maintenance needs, water distribution, resource-related issues, or hydropower-related issues. Flexibility in dam operations would not change from the current conditions. These minor operational changes are not expected to measurably impact humpback chub, because no known impacts have been identified related to the current regime.

TABLE 5 Temperature Requirements for Spawning, Incubation, Growth, and Lethality of 36 Native and Nonnative Fish Species of the Colorado River and Its Tributaries in and near the Project Area[a]

	Spawning			Incubation				Growth			Lethal	
Species	Minimum	Maximum	Optimum	Minimum	Maximum	Optimum	Days	Minimum	Maximum	Optimum	High	Low
Black bullhead	19	22	20	21	24	23	6	20	22	21	3	35
Black crappie	14	18	16	15	22	17	4	24	30	27	0	34
Bluehead sucker	15	25	18	17	23	20	7	15	21	18	0	29
Bluegill	19	27	20	20	26	20	3	15	25	23	0	35
Brown trout	7	14	10	8	20	10	41	12	20	15	0	27
Bonytail	18	22	20	18	28	21	4	18	24	20	0	35
Common carp	18	30	23	20	30	24	4	15	30	27	0	38
Channel catfish	21	29	27	20	30	27	7	21	30	28	3	38
Colorado pikeminnow	16	24	22	19	25	22	5	18	23	25	0	35
Flathead catfish	22	29	26	22	29	27	8	24	30	26	5	40
Fathead minnow	16	30	25	16	29	25	5	18	27	25	2	33
Flannelmouth sucker	14	25	19	14	23	18	6	16	22	20	0	35
Grass carp	18	24	19	18	24	19	1	18	22	20	0	35
Green sunfish	19	31	22	19	24	23	5	26	31	30	0	35
Gizzard shad	15	27	20	17	27	24	4	16	26	21	5	35
Humpback chub	16	22	18	16	27	19	3	16	22	18	0	35
Little Colorado spinedace	16	20	18	16	20	18	6	16	30	27	3	35
Largemouth bass	16	20	18	16	20	18	6	16	30	27	3	35
Mosquitofish	18	30	22	20	24	22	25	14	28	22	4	43
Plains killifish	20	30	28	20	30	28	21	20	30	25	5	40
Razorback sucker	14	22	18	14	25	19	7	18	24	20	0	30
Rainbow trout	8	13	10	7	15	10	31	12	21	16	0	25
Redside shiner	10	18	15	12	20	18	8	15	22	18	0	24
Red shiner	15	30	23	15	25	24	4	18	28	24	0	40
Roundtail chub	14	22	16	16	22	18	5	18	24	18	0	35
Smallmouth bass	13	18	17	14	18	15	9	20	26	23	0	35
Speckled dace	18	25	20	18	23	20	6	18	22	20	0	35
Sand shiner	16	30	24	18	26	24	4	18	28	24	0	38
Striped bass	14	24	18	16	26	18	3	23	30	24	5	33
Threadfin shad	20	25	21	20	27	20	5	22	35	25	5	37
Blue tilapia	21	28	23	21	28	26	5	25	32	27	8	46
Utah chub	12	20	16	14	20	18	6	16	30	23	0	35
Walleye	6	13	7	6	14	13	7	18	23	21	0	33
Yellow bullhead	19	24	20	21	24	23	7	21	23	22	3	35
Zuni bluehead sucker	10	15	13	10	15	13	6	15	21	20	0	29

[a] All temperatures are in °C. Days are provided as average time for incubation of eggs (Valdez and Speas 2007).

3.2.1.3 Overall Implementation Process for Experiments

As discussed in the preferred action section, an adaptive management approach is being taken to implement all experimental elements of the LTEMP. Prior to the implementation of any experiment, potential impacts on humpback chub (and other resources) would be considered by the DOI, and deliberations would include the FWS and other DOI subject experts. This would help to identify and minimize the risk of impacts on humpback chub as a result of the implementation of an experimental treatment. Each experiment's specific effects on humpback chub and humpback chub habitat are discussed for each set of experiments below.

3.2.1.4 Effects of Sediment-Related Experiments

Experimental flows under the proposed action include: (1) sediment-triggered spring and fall HFEs through 3.2.1.3 the entire 20-year LTEMP period; (2) 24-hr proactive spring HFEs in high volume years (≥10 maf release volume); and (3) extension of the duration of up to 45,000 cfs fall HFEs for as many as 250 hr depending on sediment availability. These experimental flows have the potential to affect humpback chub indirectly by increasing sandbar area and shoreline habitats; however, the importance of these habitats to humpback chub rearing and recruitment is uncertain. The aquatic invertebrate community may also be impacted by sediment experiments (Cross et al. 2011). Recruitment of rainbow trout in Glen Canyon may be affected by spring HFEs, which may potentially indirectly affect humpback chub by increasing competition with, and predation upon, humpback chub.

HFEs under the proposed action were designed to increase and retain fine sediment for ecological purposes in Grand Canyon. Sediment is a fundamental component of the riverine ecosystem, and the sediment regime has been drastically altered by Glen Canyon Dam. Sand deposits were redistributed during pre-dam annual floods, creating substrate for riparian vegetation, and sandbars and backwater habitats for native fish (reviewed in Grams et al. 2010). Slow-water habitats that may be important to native fish, including humpback chub that are dependent upon sand bar development, include backwaters and embayments. For example, relatively high densities of humpback chub were found in backwaters in the Little Colorado River inflow reach (Dodrill et al. 2015), and when 10 habitats were sampled in 2015, more larval humpback chub were caught in embayments than in most other habitat types (Kegerries et al. 2015). However, in 2014, catch rates for larval humpback chub did not differ significantly among habitats sampled in western Grand Canyon (Albrecht et al. 2014). It is uncertain how the availability of these habitats influences juvenile humpback chub survival and recruitment to adult life stages.

HFEs have been shown to build sandbars that substantially increased the total area and volume of backwater habitat (Grams et al. 2010). The increased elevation of backwaters also increased the degree of isolation from the main channel, which would likely result in a higher degree of warming in backwater habitats (Trammell et al. 2002; Vernieu and Anderson 2013), which may be important to native fish in the summer (Albrecht et al. 2014; Kegerries et al. 2015). However, studies of habitat used by juvenile humpback chub have been mainly limited to the Little Colorado River inflow reach, and it is unclear how important

backwater or embayment habitats are to humpback chub throughout other reaches of the Grand Canyon. Beaches and backwaters are not common in the Little Colorado River reach and, although young chub occurred in higher densities in backwaters, their overall abundance in the Little Colorado River reach was higher in talus (Dodrill et al. 2015). Although talus slopes may be important to humpback chub rearing, and are not maintained by sediment deposition expected to occur as a result of HFEs, predation risk to juvenile humpback chub may be higher in talus compared to backwaters under low- and intermediate-turbidity conditions (Dodrill et al. 2016).

Modeling of sediment resources and the impacts of the proposed action focused on areas upstream of RM 87, but literature suggested that the impacts in this area would be indicative of impacts throughout the project area. Sandbars and backwaters cannot be built or maintained without high flows, and sediment-triggered HFEs result in the largest impacts under the proposed action. Substantial improvements in the ability to build and maintain sandbars over the baseline condition are expected for the LTEMP preferred alternative, because no HFEs would occur under the baseline condition after 2020 (existing HFE experimental protocol expires; Reclamation 2011a). The maintenance of backwater, under the proposed action may therefore benefit juvenile humpback chub rearing habitat. However, depending on the frequency and intensity of impacts of TMFs, as described below, and because daily downramp rates will increase under the preferred alternative, the potential for backwater habitats to be dewatered—stranding juvenile humpback chub—remains. In addition, the Near Shore Ecology project concluded that backwaters are likely not important to the Little Colorado River chub aggregation because they are not a significant habitat component in that area (Pine 2011).

HFEs have the potential to affect benthic aquatic invertebrates, which comprises the primary food base for humpback chub, but spring and fall HFE effects may differ. Much of what is known related to the effect of HFEs on the aquatic food base was determined through research in Glen Canyon, but some food base studies have been initiated recently in the Little Colorado River inflow reach. Cross et al. (2011) found that a spring HFE resulted in an overall reduction in invertebrate biomass and production, mainly reflected by declines in two nonnative invertebrates (New Zealand mudsnail, *Gammaris* sp.), but an increase in rainbow trout was also observed; this corresponded with an increase in blackflies and midges, which are prey items for fish. The effects of fall HFEs are less certain, but the aquatic invertebrate community appeared to have responded differently to fall HFEs that were implemented in 2012–2014, compared to effects described in Cross et al. (2011).

Under the proposed action, we could expect there to be 19.3 to 21 HFEs (maximum of 38 HFEs) during the 20-year LTEMP period. The more frequent HFEs are expected to favor blackfly and midge production; however, spring and fall HFEs may differ in their effects, so it is unclear what long-term impacts of annual (i.e., 19.3–21 out of 20 years) HFEs may have on the food base. Under the preferred alternative, up to four of the fall HFEs could be long-duration HFEs (lasting up to 250 hr). These extended-duration HFEs would be of higher magnitude and could increase benthic scouring, compared to short-duration HFEs. Drift from an extended-duration fall HFE may be elevated due to increased biomass of benthic invertebrates that may develop over the summer months The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-duration fall HFE, could scour the remaining primary producers and

susceptible invertebrates and further delay the recovery of the aquatic food base. For this reason, implementation of a spring HFE in years that follow an extended-duration fall HFE would be carefully considered.

Due to increased turbidity and other factors at the Little Colorado River inflow that differ from those at Glen Canyon, food base dynamics may not be comparable to those observed in Glen Canyon, and it is unclear what impacts HFEs have had upon the food base at the Little Colorado River. In terms of food base impacts upon humpback chub, recent preliminary USGS unpublished data indicate that as invertebrate drift declines (2014–2015), adult humpback chub body condition may also decline. Cross et al. (2013) found that native fish may be limited by food production, because all of the produced midges and blackflies are consumed. However, it is unclear how declining condition may be reflected in adult humpback chub survival, reproduction, and future recruitment of juveniles. It is possible that skipped spawning may be more prevalent in adults when food is limited, for example.

No current published research is available to show what factors may have correlated to the decline in invertebrate drift at the Little Colorado River in 2014 and 2015, compared to 2012–2013, but flow, temperature, and turbidity are likely factors. However, annual variation in drift since 2012 (potentially related to these factors) is likely much less detrimental to the food base for humpback chub than long-term loss of taxa that has likely resulted from hydropeaking or load-following (Kennedy et al. 2016; see base operations above). Despite the apparent impact on adult humpback chub body condition that may be correlated to food availability, humpback chub population dynamics will likely not respond to variations in food availability in a similar manner to the response shown for rainbow trout (see Cross et al. 2011). Humpback chub evolved in a system with limited autochthonus production due to high turbidity in the pre-dam Colorado River, and thus may have relied more heavily on terrestrial invertebrates or other allochthonous food items washed into the river during floods. In addition, other aspects of the species' life history, including high adult longevity, skip spawning, and higher relative fecundity compared to species in more stable environments, may moderate the effects of highly variable environment, including variation in food availability, on long-term population dynamics of the species. Many fish species evolved in variable environments, with a "boom and bust" life history strategy (see periodic life history strategy: Winemiller and Rose 1992). However, the more stable post-dam environment may also favor nonnative species (Olden et al. 2006; see discussion below). Nevertheless, spring and fall HFEs may not be tested in years when there would appear to be unacceptable risks to key resources including the aquatic food base, and the results of experimental flows will be discussed with FWS prior to implementation to minimize indirect effects on humpback chub.

Proactive spring HFEs would occur in high volume years with planned equalization releases (≥10 maf) in order to protect the sand supply from equalization releases. Fall HFEs longer than 96 hr in duration will be implemented when there is sufficient Paria River sediment input in the fall accounting period (July–October) to achieve a positive sand mass balance in Marble Canyon. Spring HFEs and high and steady flows (Avery et al. 2015), have both demonstrated an increase in rainbow trout production in the Colorado River, especially in the 16-mi reach below the dam (Lees Ferry reach). This increase in survival of juvenile rainbow trout was attributable to an improvement in habitat conditions and food availability in

Glen Canyon for recently emerged trout (Korman et al. 2011). Flows and temperature were modeled over the LTEMP period to assess how rainbow trout recruitment and the potential for emigration downstream toward the Little Colorado River may be impacted by flow experiments. Under the preferred alternative, emigration of trout is expected to increase by 11%, which could increase the likelihood of negative impacts on humpback chub through competition and predation, particularly in cold water release years. To provide a means of controlling trout recruitment following tests of spring HFEs, TMFs would be experimentally implemented and tested for efficacy as early in the LTEMP period as possible. In addition, if a tiered trigger approach to reversing declines in possible humpback chub recruitment fails, mechanical trout control may be implemented at the Little Colorado River inflow. Although both TMFs and mechanical trout control are considered experimental actions, they are expected to offset risks of trout predation upon juvenile chub at the Little Colorado River. In addition, basin-wide drought and the low Lake Powell levels expected to occur occasionally over the next 20 years would result in warmer dam releases, which also mitigate effects of rainbow trout predation upon juvenile humpback chub (Ward and Morton-Starner 2015).

The impacts of spring and fall HFEs on humpback chub are incorporated into the modeling described in the LTEMP EIS. In general, HFE impacts incorporated into the model are focused on influences of the flow and temperature regime changes upon rainbow trout population dynamics and indirect effects on humpback chub as a result of competition and predation. The output of the model for the preferred alternative represents a range of potential outcomes that may occur over the next 20 years for humpback chub, including a "worst-case scenario" that may be defined as colder/coldest dam discharge and high rainbow trout abundance. However, although humpback chub declines may occur during years with cold temperatures and high trout abundance, TMFs and mechanical control of trout are expected to mitigate these negative impacts; therefore, it is unlikely that actual declines in humpback chub would cause the population to reach the low levels displayed by the model (around 1500 individuals) over the life of the LTEMP.

Nonnative brown trout, or warmwater species occurrence or abundance, may also be influenced by the HFEs. Brown trout spawning occurs mostly in tributaries, primarily in Bright Angel Creek (Reclamation 2011a,b); consequently, reproduction would not be significantly affected by the flow operations of the dam. However, recent increases in brown trout recruitment in 2014–2015 have occurred in the Lees Ferry reach of the Colorado River in Glen Canyon (Stewart 2016). Brown trout were observed to be spawning near the 4-mile bar in Glen Canyon during the fall of 2014, and an increase in age-1 brown trout, likely as a result of spawning and recruitment in 2014, was observed in 2015 (Korman et al. 2015). Spawning of brown trout was also observed during October and November of 2015 near the 4-mile bar in Glen Canyon (Korman et al. 2015). It is unclear if flow operations, including recent fall HFEs, caused an increase in brown trout in recent years. The YOY of fall-spawning brown trout would benefit from increased food availability, similar to rainbow trout (Cross et al. 2011), if the fall HFEs' effects on benthic invertebrates are similar to those of the spring HFE. As discussed above, an increase in blackfly and midge production following fall HFEs has not been observed; therefore, it does not appear that recent fall HFEs have resulted in conditions that facilitated increased brown trout reproduction in Glen Canyon.

Although increases in brown trout recruitment do not appear to be related to HFEs, it is possible that the establishment of green sunfish in 2015 in a warmwater slough downstream of Glen Canyon Dam may be related to dam operations. Based on this assumption, and combined with expected occasional warmwater flow release periods during drought years, an increase in the likelihood of warmwater nonnative fish occurrence is expected below Glen Canyon Dam. Rapid increases in dam discharge from baseflow to up to 45,000 cfs during HFE implementation may increase the chance that abundant warmwater nonnative fish near the intakes become entrained in the bypass tubes. The risk would increase during periods of low Lake Powell levels because when this occurs intakes are closer to the surface and lake littoral zones, where smallmouth bass or green sunfish are present. During basin-wide drought years, warmer discharge would increase the risk further, because warm water could facilitate reproduction of these species in the Grand Canyon, potentially near the Little Colorado River inflow. To offset this risk, the conservation measures discussed below were developed. These include the investigation of means to prevent warmwater species' passage through the dam, completion of planning and compliance to make a warmwater slough less hospitable to warmwater nonnative fish, and the development of a rapid response protocol that includes chemical control methods and others not included in the NPS CFMP.

In summary, sediment experiments have the potential to negatively affect humpback chub individuals and habitat by increasing rainbow trout emigration to the Little Colorado River reach. This may increase predation or competition effects, alter the food base, or increase the risk of establishment of warmwater nonnative fish. However, these negative impacts may be offset by conservation actions and triggered mechanical removal of nonnative fish (trout or warmwater nonnative fish) to benefit juvenile humpback chub rearing, the development of a rapid response protocol, and warmwater species' habitat modification. Further, backwaters and embayments created following HFEs may provide warm rearing habitat for juvenile humpback chub, but the benefit may be minimal for the Little Colorado River inflow aggregation. Finally, these sediment treatments will not continue to be tested if they are not effective in achieving their purpose or have unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources.

3.2.1.5 Effects of Trout Management Flow Experiments

TMFs will be implemented when there is predicted high trout recruitment in the Glen Canyon reach, but tests may be implemented when trout are at low densities, early in the LTEMP period. TMFs are designed to cause fatality in YOY rainbow trout by inundating low-angle, nearshore habitats for several days, and then quickly reducing dam discharge, which would strand YOY fish; however, there is also potential for stranding and increased fatality of juvenile humpback chub. Although the Lees Ferry reach trout population is the target of TMFs, an examination of USGS hydrograph data from Lees Ferry (RM 0) and National Canyon (approximately RM 166) indicated there may be little attenuation of stage changes due to flows downstream in the Marble and Grand Canyons. YOY humpback chub are found primarily in the Little Colorado River inflow reach, as well as further downstream, in unknown numbers. Stranding may occur, including stranding of endangered humpback chub and razorback sucker. TMFs are proposed to occur from May through August, in years when the experimental

treatment would be tested or implemented, including up to three cycles per month of high steady flows to draw juvenile fish into shallow nearshore waters, followed by rapid drops in discharge to strand fish.

Modeling conducted for the LTEMP EIS evaluated the number of trout recruits in the Glen Canyon reach, and the numbers of trout and humpback chub in the Little Colorado River reach to determine when TMFs would be triggered under the proposed action. It was estimated that triggers for TMFs would be met approximately every 3 years (32% of years).

Although indirect benefits of TMFs for humpback chub at the Little Colorado River are expected under the proposed action as a result of reduced competition and predation by rainbow trout, an unknown number of YOY humpback chub may also suffer fatality as a result of being stranded during TMFs, including those at the Little Colorado River inflow and downstream in the Grand Canyon. Stranding impacts may be difficult to observe, particularly lesser studied, sublethal impacts upon growth (Nagrodski et al. 2012). However, due to the geomorphological features of the Little Colorado inflow reach, fewer shoreline habitats such as backwaters, which are susceptible to fluctuations, are present, and may support only a small portion of juvenile humpback chub in that reach (Dodrill et al. 2015). It is less likely that TMFs would affect adult or juvenile chub, because they have a greater ability to swim out of confined spaces as flows dropped. Small YOY or larval fish, which already have a high mortality rate, could suffer increased mortality as a result of TMFs. TMFs could occur throughout the summer, overlapping with periods when larval humpback chub are found in nearshore habitats (May–August; Albrecht et al. 2014; Kegerries et al. 2015) and would be susceptible to extreme flow fluctuations under TMFs.

The extent of humpback chub mortality due to stranding and the benefits of reduced trout recruitment in a given year as a result of repeated (every third year) TMFs in Marble and Grand Canyons over the life of the LTEMP are uncertain. These impacts may depend on the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and abundance of humpback chub in sensitive habitats, the timing and number of TMFs, and the degree of attenuation of flows downstream. The beneficial effects of TMFs for humpback chub may depend on the effectiveness of flows in reducing recruitment of YOY trout and emigration to the Little Colorado reach, as well as on the strength of the interaction between humpback chub and rainbow trout, which is mediated by water temperature (see Ward and Morton-Starner 2015). Stranding has not been observed during previous flow experiments, but no studies have been completed, so the degree of stranding is uncertain. The impacts of TMFs throughout GCNP will be monitored to assess effectiveness of the action and the detrimental impacts on native fish and other resources. TMFs will not continue to be tested if there is little or no reduction in trout recruitment after at least three tests, or if there are unacceptable adverse impacts on the humpback chub population or other resources. Consultation with the FWS would be conducted prior to implementation of the experiment. Thus, with “offramps” in place, long-term negative impacts on humpback chub would not be expected.

3.2.1.6 Effects of Triggered Conservation Actions and Mechanical Removal of Nonnative Fish Experiments

Under the proposed action, mechanical removal of nonnative rainbow and brown trout (and other nonnative predators) would be implemented through a triggered, tiered approach (see Appendix D) near the confluence of the Little Colorado River and the Colorado River if conservation actions designed to reverse declines in the Little Colorado River humpback chub aggregation are ineffective. This approach was developed by biologists with the FWS, USGS-GCMRC, AZGFD, NPS, and Reclamation, using the best available science and professional judgement. Conservation actions designed to improve rearing and recruitment of juvenile humpback chub would be implemented when adult humpback chub abundance declines to a threshold, or if recruitment of subadult humpback chub does not meet or exceed estimated adult mortality. Conservation actions would include expanded translocations of YOY humpback chub within the Little Colorado River to grow-out areas (i.e., above Chute Falls, Big Canyon), or larval fish would be taken to a rearing facility and released in the mainstem Little Colorado River inflow area once they reach 150–200 mm. If these conservation actions fail to reverse the declining trends and adult abundance dropped below 7000, mechanical removal of nonnative fish would be implemented in the Little Colorado River inflow area to lessen the effects of competition and predation upon humpback chub by nonnative fish.

Based on a humpback chub population model, which is primarily driven by temperature and rainbow trout population dynamics, it is likely that humpback chub populations may fluctuate over the life of the implementation of LTEMP (20 years). If model assumptions are correct, adult humpback chub populations could decline as low as 1800 individuals, coinciding with cold temperatures and high rainbow trout abundance. For example, expected emigration of rainbow trout from Glen Canyon was estimated to be 11% higher than under the current dam operations. This would increase predation upon juvenile humpback chub, potentially leading to reduced recruitment.

Tier 1 conservation actions would involve collecting 300–750 larvae or YOY—age classes that are vulnerable to predation by nonnative fish and that would naturally have relatively high mortality rates (see Pine 2013)—and rearing them to less vulnerable sizes before releasing them. Alternatively, YOY would immediately be translocated for rearing to areas with few predators, such as Big Spring or above Chute Falls. In the past, fish were successfully translocated within the Little Colorado River and to tributaries; the translocated fish in these locations experienced high survival and/or growth rates (Healy et al. 2014a; Spurgeon et al. 2015; Van Haverbeke et al. 2016), and there is a high likelihood for humpback chub to benefit through augmentation of the adult population as a result of Tier 1 actions. Detrimental effects on humpback chub, including fatality, could occur during handling, transport, or tempering; however, these occurrences are generally low, see Section 2.2.

Mechanical removal of nonnative fish would be implemented at the Little Colorado River inflow if declines in adult humpback chub continued, which would help minimize mortality of juvenile humpback chub. Past studies have indicated that trout predation upon humpback chub could be significant (Yard et al. 2011), and humpback chub are particularly vulnerable to predation at cold water temperatures (Ward and Morton-Starner 2015). It is somewhat uncertain

whether mechanical removal in the vicinity of the Little Colorado River would be successful in reversing declines in humpback chub, because (a) at high immigration rates into the Little Colorado River reach, mechanical removal may not be successful in reducing trout abundance (Coggins et al. 2011), and (b) other factors beyond trout predation and competition may be negatively impacting humpback chub survival and abundance. Past removal efforts appeared to be effective in controlling rainbow trout, and humpback chub recruitment increased; however, the removal effort coincided with a system-wide decline in trout abundance and warming dam discharge, which confounded results (Coggins et al. 2011). Nevertheless, TMFs designed to reduce Glen Canyon rainbow trout recruitment, and thus emigration downstream, would likely result in low immigration rates of trout to the Little Colorado River reach, thereby increasing the effectiveness of mechanical removal and benefitting humpback chub recruitment. The adaptive management approach taken to adjust trout removal targets and thresholds for action would also help ensure the effectiveness of this strategy in stemming humpback chub declines.

As designed, the tiered, adaptive approach to responding to humpback chub declines described here is expected to offset potentially negative impacts of management actions and experiments under the LTEMP. If conservation actions are ultimately successful in improving rearing success, these tools could be implemented proactively, and could potentially lead to long-term beneficial impacts on humpback chub in the Little Colorado River inflow aggregation.

3.2.1.7 Effects of Low Summer Flow Experiments

Low summer flow experiments involve holding flows low (approximately 8,000 cfs) and relatively steady, compared to base operations during warm summer months. Flows may continue to fluctuate 1000 cfs in a day, which would be less fluctuation than under base operations. The goal of the experiment is to achieve warmer river temperatures to benefit humpback chub; however, more stable shoreline habitats may also occur, which could also improve juvenile humpback chub rearing habitat. Lower flows have the potential for more warming via heat transfer from the air compared to higher flows. Low summer flows will be tested when the water temperature has been <12°C for 2 consecutive years, and a target temperature of ≥14°C can only be achieved if flows are dropped with the objective of testing the efficacy of low summer flows on warming and humpback chub growth. Low summer flows will only be tested after the first 10 years, and only under specific, rarely occurring, conditions. This test will not continue if there is no increase in growth and recruitment of humpback chub, if there is an increase in warmwater nonnative species or trout at the Little Colorado River; or if there are unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources.

Under this design (1 to 2 years of testing), the effect of the low flow experiment upon humpback chub growth, rearing, and recruitment will be difficult to determine, because results are likely to be confounded by other factors (variation in annual precipitation, turbidity, etc.). In addition, the tests would be conducted only when humpback chub populations are healthy and stable; this would decrease the test's effectiveness in determining how low flows may improve humpback chub rearing during periods when the population is unhealthy or in decline.

Nevertheless, in addition to benefits associated with warming waters described in previous sections, stable nearshore habitats may benefit rearing, depending on the use of habitats that are sensitive to flow fluctuations (backwaters, embayments, cobble bars, riffles, etc.). The role of backwaters or similar habitats in humpback rearing is discussed in more detail in Section 3.2.1.4. However, reduced fluctuations under the low summer flow experiment would reduce stranding potential for humpback chub, and benefit the food base.

Low summer flows may allow for a prolonged test of the effect of steady flows on the diversity and abundance of aquatic invertebrates, similar to the intent of the low steady weekend flows for macroinvertebrate production experiment (Section 1.2.12). Base operations have been, and will continue to be, characterized as hydropeaking or load-following, which is an operational regime that has been demonstrated to have long-term detrimental impacts on aquatic invertebrates below hydroelectric dams in the Western United States (Kennedy et al. 2016). A diverse source of invertebrates to colonize the Colorado River is found among Grand Canyon's tributaries (Oberlin et al.1999; Whiting et al. 2014), but hydropeaking and an altered temperature and flow regime will continue to negatively impact the food base for humpback chub over the life of the LTEMP. Consistently more stable flows over the summer could result in successful egg-laying and reproduction by sensitive macroinvertebrate taxa (e.g., mayflies), which would also be important prey for humpback chub. However, the experiment may only be implemented 1–3 times in the second year of LTEMP, which would limit the ability of this experiment to benefit humpback chub food base over the long term. Only short-term (within the year of the test) beneficial effects on the food base would be expected.

It is possible that warming as a result of the implementation of low summer flows may increase the risk of warmwater nonnative fish establishment, threatening humpback chub populations. However, these tests are unlikely to increase the risk significantly, because they would occur infrequently (1–3 times out of 20 years), and due to low Lake Powell levels, water temperatures are already within the spawning range of warmwater nonnative species during some part of the year in the lower river (see Kegerries et al. 2015). Basin-wide hydrology that influences the Lake Powell level and dam discharge temperatures would likely overwhelm the effects of dam operations on river temperatures.

Although benefits to humpback chub may be realized as a result of this experiment on habitats and food base, the effect may be of short duration and may be insignificant over the life of the LTEMP (1–3 years out of 20). However, if the experiment has beneficial effects, it may be implemented more frequently beyond the life of the LTEMP period, if additional planning and compliance is completed.

3.2.1.8 Effects of Low Steady Weekend Flows for Macroinvertebrate Production Experiments

Experimental steady flows on weekends, in an attempt to increase invertebrate production and diversity, may benefit nearshore habitats by providing stability and some warming in habitats that are more isolated from the mainstem (low flows would be held steadier plus/minus 1000 cfs fluctuation); however, this would be limited to approximately 34 days over the summer.

This experiment will not be conducted during first 2 years of LTEMP. The goal is to replicate it two to three times to determine its effectiveness.

Kennedy et al. (2016) demonstrated that hydropeaking flows in rivers below hydroelectric facilities may prevent the maintenance of viable populations of many aquatic invertebrates (e.g., mayflies, stoneflies, caddisflies) that would constitute important components of the food base for humpback chub. Many shoreline egg-laying invertebrates were absent from western rivers with higher degrees of hydropeaking fluctuations. This experiment may allow some shoreline egg-laying invertebrates to avoid desiccation, which results in a high degree of egg mortality (Kennedy et al. 2016), and potentially will allow for increased production and possibly diversity of aquatic invertebrates.

In addition to potential benefits of increased aquatic food base production, steady flows on weekends may help to improve the quality of nearshore habitats for juvenile humpback chub. However, it is unclear whether 2 days per week of nearshore habitat stability will result in a measureable impact on juvenile growth, rearing, and recruitment.

Sustained low flows for benthic invertebrate production may benefit humpback chub by providing additional aquatic insect prey. It may also provide stable nearshore habitats for rearing, for 2 days per week. This treatment will be discontinued if there is no observed benefit to the food base, the trout fishery, or native fish; if there is an increase in warmwater nonnative species or trout at the Little Colorado River; or if there is an unacceptable adverse impact on the trout fishery, humpback chub population, or other resources.

3.2.1.9 Effects of Ongoing Conservation Measures

Conservation measures from the 2011 Biological Opinion were evaluated and adapted for the LTEMP, where necessary, and included in the preferred alternative. Some additional conservation measures were developed specifically for the LTEMP and were incorporated into the preferred alternative. The intention of conservation measures is to mitigate or offset potential impacts on ESA-listed species that may result due to the implementation of the LTEMP preferred alternative. These conservation measures were developed in consultation with the FWS and biologists from the NPS. Effects on humpback chub are discussed for each conservation measure below.

Humpback Chub Translocations

Humpback chub translocations were included as conservation measures in the 2008 and 2011 Biological Opinions on the operation of Glen Canyon Dam and on the Nonnative Fish Control and HFE plans, respectively. The preferred alternative includes the continued implementation of humpback chub translocations from the Little Colorado River to other areas in the Little Colorado River or to other tributaries of the Colorado River in the project area in order to (a) improve rearing and growth and provide additional rearing opportunities, or (b) establish additional spawning populations. As discussed in previous sections of this document,

translocations have been conducted above Chute Falls in the Little Colorado River, to Shinumo Creek, and to Havasu Creek. Translocations may result in increased growth or improved rearing and survival of juvenile humpback chub.

Translocations of juvenile humpback chub were first conducted in 2003. They involved moving fish from the lower reaches of the Little Colorado River to areas above Chute Falls (Van Haverbeke et al. 2013). These translocations have continued through recent years. Compared to juvenile humpback chub in the lower Little Colorado River, fish above Chute Falls grew much faster.

Prior to 2014, beginning in 2009, approximately 300 juvenile humpback chub per year were translocated to Shinumo Creek. Estimated growth and survival of translocated humpback chub generally was consistent with, or exceeded, growth and survival estimates of juvenile humpback chub in the Little Colorado River and Colorado River, although emigration rates exceeded 50% (Spurgeon et al. 2015; Healy et al. 2014b). In May of 2014, an NPS-managed fire started by lightning, burned approximately 10% of the Shinumo Creek watershed. Flooding and ash appeared to have extirpated the remaining humpback chub from Shinumo Creek in July and August 2014.

Havasu Creek translocations were initiated in June 2011 and have continued annually through May 2016. Approximately 300 fish were released in Havasu Creek annually. Biannual monitoring of translocated fish indicated that survival and growth objectives were met. In addition, evidence of reproduction, including ripe adult fish and untagged juveniles (age-1+), was observed annually beginning in 2013. Data collected from the May 2016 monitoring trip indicated that multiple year classes of untagged (non-translocated) humpback chub were observed (Nelson et al. 2016).

Through 2016, translocations to Havasu Creek have been limited to the lower 3.5 mi—from the Havasupai Reservation/NPS boundary to the confluence with the Colorado River—on NPS lands. A new effort will be pursued during the LTEMP to conduct initial fish surveys and complete a feasibility study to translocate humpback chub to Havasupai Reservation lands above Beaver Falls. Although the activities are subject to permission and support from the Havasupai Tribe, if habitat is suitable, translocations to this area could lead to an expanded spawning population at Havasu Creek. Larger populations would be more likely to persist in tributaries (Pine 2013).

Genetics management principles outlined in FWS guidance documents (FWS Genetics Management Plan 2010; Van Haverbeke et al. 2016) and the NPS CFMP (NPS 2013) would be followed to maintain genetic diversity and minimize detrimental genetic effects on translocated populations. For example, genetic monitoring would be conducted in tributary spawning populations established through translocations, and new migrants would be introduced occasionally (NPS 2013). As a result, no loss of genetic diversity is expected.

As part of the ongoing humpback chub translocation effort, Reclamation has committed to funding nonnative fish control in tributaries, where necessary, to maximize survival of translocated humpback chub. Control methods would vary depending on the tributary and the

existing nonnative fish species. Complete eradication of a nonnative species would likely provide the most beneficial impact on humpback chub translocated to the tributary; however, no specific plans for chemical piscicides have been identified, and piscicide use would require additional planning and compliance activities.

No detrimental population-scale impacts are expected as a result of translocations. In general, as demonstrated by previous or ongoing translocations, successful rearing and potential additional spawning populations can be developed or augmented through translocation of juvenile humpback chub, thereby benefitting the population. In addition to the continuation of the Chute Falls translocations under the preferred alternative, Havasu, Shinumo, and Bright Angel (pending successful trout control) creeks would continue to be the focus of translocations efforts outside the Little Colorado River. Although translocations can result in mortality of individual juveniles during collection from the Little Colorado River, transport to rearing facilities, disease treatment, or tempering and release (thus far, Chute Falls only), no detrimental population-level impacts on the adult population in the Little Colorado River has been observed. In addition, based on population viability modeling (Pine 2013), collection methods have been further refined to mitigate this risk by targeting life stages (e.g., larval) that would have a high mortality rate in the wild.

Humpback Chub Refuge

A refuge population of humpback chub was established at the FWS SNARRC facility in Dexter, New Mexico. The goal of the refuge is to maintain a genetically diverse population of 1000 humpback chub to be used for propagation in the case of a catastrophic loss of the Grand Canyon population. Impacts would be similar to those described for translocations, in that a small number of larval chub may be lost during collection, transport, and disease treatment; however, no detrimental impacts on the population would be expected.

Mainstem Humpback Chub Aggregations

Conserving mainstem humpback chub aggregations was a focus of past conservation measures related to dam operations. In the LTMEP, Reclamation will continue to assist the FWS, NPS, and GCDAMP to ensure that a stable or upward trend of humpback chub mainstem aggregations can be achieved. Actions include continued monitoring of the Little Colorado River humpback chub aggregation using the juvenile chub monitoring protocol developed following the natal origins project (see Pine et al. 2011); monitoring the mainstem aggregations annually; developing a methodology for locating additional aggregations and individual humpback chub; evaluating "drivers" of recruitment, potential spawning, and natal origins; and exploring a means of expanding humpback chub populations outside the Little Colorado River inflow aggregation.

Mainstem monitoring is critical to understanding how base operations and other experiments under the LTEMP impact humpback chub. Understanding more about the ecology and population dynamics of mainstem aggregations outside the Little Colorado River, including

the impacts of dam operations, may lead to improved management and conservation of those aggregations.

The impacts on individual humpback chub that may occur as a result of monitoring are covered below in Section 2.2. Monitoring under this action would be designed to assess trends in humpback chub in the mainstem Colorado River, and to assess impacts of experimental and management actions on humpback chub. Results of monitoring may allow managers to adapt actions to ensure that projects goals for humpback chub are met.

Disease and Parasite Monitoring

Reclamation intends to fund the GCDAMP to conduct disease and parasite monitoring in humpback chub and other fish in the mainstem Colorado River, in addition to ongoing disease and parasite monitoring conducted by USGS/GCMRC in the Little Colorado River.

It is unclear how this monitoring will be accomplished or how it may benefit humpback chub over the long term; however, understanding the impacts of parasites may inform future conservation actions.

Razorback Sucker Conservation Measures

Studies designed to help understand the status of the razorback sucker population in the Grand Canyon and Lake Mead would continue with the implementation of the preferred alternative. Although the focus of these studies is on razorback sucker, seining for larval and small-bodied YOY and juvenile fish may lead to an increased understanding of juvenile and larval humpback chub habitat use and spawning areas (at a course scale) in the Grand Canyon.

Fatality of individual larval humpback chub would occur as a result of this sampling regime; however, high larval mortality rates are likely in the wild, and thus, this effort would not be expected to impact the adult population. In the first 2 years of the larval and small-bodied fish study conducted from Lava Falls (RM 180) to Pearce Ferry above Lake Mead (RM 280), indicated that reproduction may be occurring (larval humpback chub with yolk sac attached).

No population-scale impacts on humpback chub would be expected, and the study may provide important information for conservation of the species in the western Grand Canyon.

Nonnative Species Conservation Measures

Nonnative fish will continue to threaten humpback chub in the Grand Canyon under the LTEMP preferred alternative. Under the continued colder temperature regimes and clear water that result from dam construction and operations, particularly in Glen and Marble Canyons, nonnative cool-/coldwater species are expected to proliferate and continue to prey upon and compete with humpback chub. Brown trout are a particular threat due to their piscivorous nature

(Yard et al. 2011; Whiting et al. 2014). However, with continued basin-wide drought, and lower Lake Powell levels, warmer water releases from Glen Canyon dam are expected occasionally. For example, in late fall 2015 (November) water released from Glen Canyon dam approached 15°C, which is within the range of suitable temperatures for smallmouth bass spawning. In addition, temperatures in western/lower Grand Canyon reached or exceeded 20°C in 2015. Warmer temperatures may allow for highly piscivorous warmwater nonnative species such as smallmouth bass to proliferate in the project area. Smallmouth bass were identified as a major threat to native fish in the Yampa River, and have caused major declines and extirpation of humpback chub there (Johnson et al. 2008).

Conservation measures that were developed to specifically address nonnative species threats to humpback chub include (a) continued nonnative trout (brown and rainbow) removal efforts at Bright Angel Creek and its inflow, or other areas where expanded populations have been found; (b) feasibility study, and planning, and compliance for chemical piscicide renovation at Bright Angel and Shinumo creeks; (c) study of efficacy of a temperature control device on the dam to address future conditions under climate change; (d) potential research and development of a means to prevent passage of warmwater nonnative fish through Glen Canyon Dam; (e) planning, compliance, and implementation of a plan to address (make less suitable) the suitability of warmwater nonnative fish habitat in a slough below Glen Canyon dam; and (f) completion of a plan for rapid response to nonnative fish invasions, using tools not approved in the NPS CFMP (e.g., chemicals). Finally, the use of flows (e.g., TMFs) to inhibit brown trout spawning and recruitment in Glen Canyon, or other mainstem locations, will be explored over the life of the LTEMP. This measure is necessary to prevent recently detected spawning of brown trout in Glen Canyon from further expanding or increasing in abundance.

Control of brown and rainbow trout in Bright Angel Creek and the Bright Angel Creek inflow reach of the Colorado River would be continued under the proposed action. In 2017, results of control efforts implemented between 2012 and 2017, including trends in abundance of both native and nonnative fish, would be reviewed, and methodology for continued control efforts may be adapted to ensure trout control objectives are met. Brown trout catch-per-unit effort in the Colorado River outside of Bright Angel Creek appears to have declined in recent years (Stewart 2016), concurrent with trout control activities, and declines of brown trout abundance and biomass in Bright Angel Creek (Nelson 2016). Brown trout are defined as high-risk nonnative predators (NPS 2013), and continued control in and around Bright Angel Creek—and in other areas where they expand—would minimize a major threat to humpback chub by reducing predation risk. Long-term beneficial impacts for humpback chub would be expected as a result of continued control of brown trout and reduced predation risk.

The other nonnative fish conservation measures could all lead to beneficial impacts on humpback chub as a result of reduced the risk of invasion and establishment of warmwater nonnative species. The outcome will depend on the effectiveness of the actions, including whether feasible options are developed to manage slough habitat and prevent the passage of warmwater nonnative fish through the dam; no technology currently exists for this.

3.2.1.10 Effects of New Conservation Measures

New conservation measures for humpback chub will explore additional tributaries for potential translocations including consulting with the Havasupai Tribe for potential translocations above Beaver Falls in Havasu Creek. Razorback sucker measures will include continued monitoring of larval and small-bodied fish; these measures will determine the extent of hybridization of flannelmouth and razorback sucker larvae from the western Grand Canyon through genetic analysis. Additional measures to address nonnative fish include evaluation of new technologies for temperature-controlled releases from the dam and methods to prevent fish passage through the dam. Reclamation will support planning and compliance for the development and implementation of a rapid response control effort for new and established nonnative invasive species. This includes modifying the backwater slough at RM 12 to prevent establishment of warmwater invasive species. Reclamation will also explore the use of flow such as TMFs to inhibit brown trout spawning and recruitment in mainstem locations.

3.2.1.11 Effects of Native and Nonnative Plant Management Experimental Actions

Under the proposed action, exotic plant species that are spread or favored by dam operations would be mechanically removed, and potentially treated with herbicides, in selected areas within the project area.

Herbicides may be poisonous to fish and aquatic species; however, standard practices for herbicide application would be followed. This would minimize any risk of impacts on humpback chub or their habitat as a result of contact with the chemicals.

3.2.1.12 Effects of Activities to Preserve and Protect Historic Properties and Cultural Sites

Under the preferred alternative, various mitigation and erosion control measures would be implanted at cultural sites along the river corridor. Sites that would be treated would generally be located above the Colorado River high water mark and outside of humpback chub habitat. Thus, these activities would be expected to have no impacts on humpback chub individuals or habitat.

3.2.1.13 Effects of Climate Change

Climate change and drought have direct influences on hydrologic patterns and water temperature, thus impacting humpback chub. In the Colorado River Basin, hydrologic impacts include lower precipitation and decreased inflow to the reservoir system, resulting in more frequent lower reservoir release volumes, which could potentially impact shoreline habitats and riparian areas. More frequent droughts and warmer atmospheric temperatures have the potential to result in warmer water being released from the dam. Although this may improve thermal suitability for humpback chub, any subsequent benefits may be offset by increased abundance

and expansion of warmwater nonnative fish and aquatic fish parasites (see Section 3.6). Uncontrolled warmer water releases may occur as a result of the elevation and subsequent water temperature of withdrawals from Lake Powell. Increased temperatures may allow numbers and species of warmwater nonnative species to increase in the system.

Springs that supply the Little Colorado River within critical habitat may be vulnerable to basin-wide drought and climate change impacting overall habitat availability and the largest self-sustaining population for the species.

3.3 EFFECTS OF THE PROPOSED ACTION ON RAZORBACK SUCKER

The evaluation of potential impacts of the proposed action on razorback sucker included consideration of the results of previous investigations of the species' ecology (Albrecht et al. 2014; Kegerries et al. 2015), as well as studies of the effects of nonnative fish (Coggins et al. 2011; Yard et al. 2011; Whiting et al. 2014), experimental flows (such as HFEs and other flows) and water temperature on native fish and native fish habitat (e.g., Grams et al. 2010; Makinster et al. 2011; Trammell et al. 2002; Ward 2011; Ward and Morton-Starner 2015).

Several aspects of the proposed action may affect razorback sucker directly or indirectly through direct impacts on individuals or habitat; or indirectly by influencing the abundance and distribution of nonnative predators and competitors, or by influencing macroinvertebrate production. Dam operations have the potential to influence river temperatures, the quantity and quality of nearshore rearing habitats (e.g., backwaters), aquatic insects that are food for razorback sucker, and nonnative species abundance; operations may also result in direct mortality to larval or juvenile razorback sucker through stranding. Flow-related actions are analyzed below that may impact razorback sucker; these include base operations, sediment-related experiments, and aquatic resource experiments including trout management flows, low summer flows, and sustained low flows for benthic invertebrate production. Because identified impacts of operational flexibility under current dam operations have been identified for native fish, no effects are expected that are not considered for other dam operations. Other non-flow actions, which may impact razorback sucker directly or indirectly and are analyzed below, include mechanical removal of nonnative fish, conservation measures, and continued fisheries research and monitoring under the GCDAMP. Some actions may have negative impacts on individuals, but beneficial effects at a population level.

Efforts to manage riparian vegetation, humpback chub translocations, and sediment monitoring and research are not expected to have impacts on razorback sucker individuals or habitat. Riparian vegetation management would occur in only small, localized areas within the project area. Although riparian vegetation can play an important role in small stream ecosystems, particularly in providing cover, shade, or habitat for terrestrial invertebrates for fish to feed upon, riparian vegetation is less important in larger rivers for providing cover, shade, or energy inputs (Vannote and Sweeney 1980). Thus, riparian vegetation management would have large impacts on the razorback sucker and the species' habitat in the Colorado River.

3.3.1 Direct and Indirect Effects

3.3.1.1 Effects of Base Operations

Base dam operations are expected to change with the implementation of the proposed action. Changes will include more consistency across months, and thus more stability throughout the year, in monthly dam release volumes. The daily fluctuation in discharge would be proportional to the volume (i.e., lower fluctuations during lower flows), with a maximum discharge fluctuation range of 8,000 cfs; this would be the same as the current maximum fluctuation range. The daily downramp rate would be increased, compared to the current condition, by 67% (from 1,500 cfs/hr to 2,500 cfs/hr). Under base operations, year-round, fluctuating flows throughout the life of the LTEMP period may have detrimental, long-term direct impacts on juvenile razorback sucker and rearing habitat, razorback back sucker spawning habitat, and aquatic invertebrate prey (food base).

Stranding of fish is a potential outcome of daily hydropeaking (reviewed in Bunn and Arthington 2002; Nagrodski et al. 2012). Increasing downramp rates under the preferred alternative may increase the risk of stranding larval razorback sucker. Thus far, juvenile (older than larval) life stages of razorback sucker have not been sampled in 2 years of study in the Grand Canyon (Albrecht et al. 2014, Kegerries et al. 2015). It is unclear whether larval razorback sucker experience near 100% mortality prior to transformation to juveniles, or if larvae drift to Lake Mead and rear in the lake. Thus, effects are mainly discussed for larval age classes. Stranding could include fish being temporarily (i.e., until flows came back up hours later) restricted to isolated habitats away from the main channel, which may or may not become desiccated, as a result of dropping water levels. Desiccation of these isolated habitats would result in fatality of any larval razorback sucker present. Factors that may influence the probability of stranding fish in a river with altered flow regimes, such as below hydroelectric plants, include the rate of flow reduction, water temperature, channel geomorphology, and substrate composition, as well as biotic factors including fish life stage and size (reviewed in Nagrodski et al. 2012). Larval razorback sucker have limited swimming ability, and thus are at risk of stranding. Increasing drawdown rates under the preferred alternative will increase the risk of fatality. Larval sampling in the lower Grand Canyon found razorback sucker larvae to be distributed throughout most shoreline habitats from Lava Falls to Pearce Ferry from May to July. The highest densities of larvae were found in isolated pools, which composed less than 2% of all habitats sampled. These pools have a high likelihood of desiccation with daily flow fluctuations; however, survival rates among different habitats have not been studied. The potential for, and the effect of stranding on, individual razorback sucker survival has not been directly investigated; however, a summary of stranding literature indicated that fish stranding as a result of hydroelectric and irrigation projects is well documented (Nagrodski et al. 2012).

Razorback sucker spawn on cobble bars and other gravel substrates near or associated with riffles. Riffles and spawning bars may occur in wider, shallower areas of the channel. Therefore, they are susceptible to flow fluctuations. Continued daily flow fluctuations combined with increased downramp rates will likely increase the risk of desiccation of spawning areas and

incubating razorback sucker eggs, leading to increased mortality rates of eggs. Adult razorbacks can swim off of bars as flows decline, and therefore are at less risk.

Under base operations, through the life of the implementation of the LTEMP preferred alternative, river temperatures are expected to continue to be more suitable for coldwater nonnative species than for warmwater nonnative fish, particularly closer to the dam. In general, the estimated average main channel temperatures modeled for the LTEMP EIS indicated that temperature conditions would be most suitable for warmwater nonnative species, as well as native fish such as razorback sucker at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61), where temperatures would be more suitable to cold or coolwater nonnative fish (e.g., brown and rainbow trout); this is consistent with past surveys that have found more warmwater fish species in those areas than upstream.

Habitat requirements for the endangered razorback sucker, explained in detail in Section 2.1.3, are summarized here. Suitable water temperatures for spawning, egg incubation, and growth range from 14 to 25°C (FWS 2002b), with estimated optimal temperatures of 18°C for spawning, 19°C for egg incubation, and 20°C for growth (Valdez and Speas 2007). Hatching success is temperature dependent, with the potential for complete mortality occurring at temperatures less than 10°C (FWS 2002b). Young razorback suckers require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs (FWS 2002b). Razorback sucker are distributed within the project area, from the Colorado River inflow of Lake Mead and at least upstream as far as an area above Lava Falls in Grand Canyon. The upstream distribution of adult razorback sucker is unknown. During May of 2014, razorback sucker larvae were found in the Colorado River as far upstream as RM 173 (upstream of Lava Falls), which is the farthest upstream razorback sucker spawning has been documented in the Grand Canyon (Albrecht et al. 2014). Warm temperatures may be even more critical for larval razorback suckers than other native suckers to transform into juveniles (see Bestgen 2008). Therefore, continued cold temperatures under base operations during the LTEMP implementation period will continue to negatively impact razorback sucker over the long term. However, experimental stable flows may provide some benefit to offset these impacts (see the following sections).

As described for humpback chub, under base operations and fluctuating flows the food base will continue to be degraded throughout the life of the LTEMP.

In summary, under base operations and coldwater conditions, continued hydropeaking flows with increased downramp rates compared to the existing conditions will continue to degrade nearshore rearing habitats, prevent the establishment of aquatic invertebrates (food base), and increase the risk of stranding larval or juvenile razorback sucker in the long term (throughout the life of the LTEMP). In addition, daily fluctuating flows will degrade razorback sucker spawning habitat, river-wide, throughout the life of the plan.

3.3.1.2 Effects of Sediment-Related Experiments and Low Summer Flows

Base flow fluctuations may impact rearing habitat for larval or juvenile razorback sucker. Juvenile fishes in rivers generally rely on low-velocity nearshore environments for rearing. Backwaters potentially created by both HFEs and low summer flows are one such nearshore habitat frequently used by native fishes in the Grand Canyon, and these habitats and their use by native fishes have been a major focus of several investigations. For example, during and after the 2008 HFE physical scientists described the number and area of backwaters that were created during this flood disturbance, and documented how normal operations under MLFF eroded these features to pre-HFE levels within 6 months (Grams et al. 2010). These backwaters, although short lived, may provide ideal rearing conditions for native fishes because water temperatures are often much greater than in the mainstem, particularly when flows are steady. During the 2000 Low Steady Summer Flow experiment, which included steady flows of 8,000 cfs from June through September 2000, mainstem temperatures were 1.4–3°C higher than under previous dam operations, and backwaters were 0.3–5.3°C warmer (Trammell et al. 2002). Similarly, NPS sampling of 47 backwaters distributed from RM 115 to 220 under steady flows in September 2009 showed that at least 21 backwaters were at least 2°C warmer than the adjacent mainstem (Speas and Trammell 2009). The longer residence time of water in nearshore and backwater habitats with steady flows results in warmer temperatures than in the mainstem (Behn et al. 2010), potentially affecting rearing habitat for larval or juvenile razorback sucker.

Although very few studies in the Grand Canyon have specifically investigated razorback sucker habitat, biologists have demonstrated that densities of juvenile native fishes were greatest in backwater habitats compared to other habitats (Dodrill et al. 2015). However, in the Little Colorado River confluence reach where these investigations occurred, backwaters represent a small percentage of available nearshore habitat. Therefore, investigators concluded that maintenance of backwater habitats was not critical to the persistence of the Little Colorado River confluence aggregation of humpback chub. Nonetheless, no studies have evaluated habitat use by larval or juvenile native fishes in downstream reaches where backwaters are larger and more persistent than in the Little Colorado River confluence aggregation (Grams et al. 2010). Few studies have investigated the use of backwaters or other shoreline habitats that may be important to native fish rearing in the western Grand Canyon, where water temperatures are not ideal, but are more suitable for native fish rearing than closer to Glen Canyon Dam. However, shoreline habitats have the potential to provide warmer rearing habitat than the mainstem under certain conditions (Grams et al. 2010; Trammell et al. 2002). It is likely that prolonging the "turnover" of water in nearshore and backwater habitats with steady flows resulted in warmer temperatures than in the mainstem (Behn et al. 2010). Given the need for warm, productive floodplain or backwater habitats for rearing larval and juvenile native fishes, and the lack or low abundance of nonnative fish found in recent backwater sampling (Albrecht et al. 2014; Kegerries et al. 2015), reduced fluctuations, lower flows, or low summer flows may be beneficial for razorback sucker by providing warm and persistent backwater habitats. Thus, low summer flows included under the proposed action as an experiment after the first 10 years of the LTEMP period would likely increase warming and overall stability in these nearshore habitats, thereby benefitting razorback sucker in Grand Canyon. However, the implementation of the experiment may occur only under rare conditions. Benefits to razorback sucker would be minimal if the experiment was implemented only once or a few times in the LTEMP period.

Due to the impact that HFEs and low summer flows have on the creation and maintenance of backwater habitats important to larval or juvenile razorback sucker, these experiments would be expected to benefit razorback sucker in a similar manner to humpback chub. Low summer flows could potentially create or maintain warm backwater habitat beneficial to razorback sucker rearing. Spring HFEs may also create backwater habitat during a time period that may coincide with spawning and emergence of larval fish.

3.3.1.3 Effects of Low Steady Weekend Flows for Macroinvertebrate Production Experiments

Experimental low steady flows on weekends to attempt to increase macroinvertebrate production and diversity may benefit nearshore habitats by providing stability and some warming in habitats that are more isolated from the mainstem (low flows would be held steadier plus/minus 1,000 cfs fluctuation); however, this would be limited to approximately 34 days over the summer. This experiment will not be conducted during first 2 years of LTEMP. The goal is to replicate it two to three times to determine its effectiveness.

The scientific background for this experimental action is discussed in Section 1.2.12 (and see Kennedy et al. 2016). In addition to potential benefits of increased aquatic food base production, steady flows on weekends may help improve the quality of nearshore habitats for larval or juvenile razorback sucker. However, it is unclear whether 2 days per week of nearshore habitat stability will result in a measureable impact on juvenile growth, rearing, and recruitment. Nevertheless, it does not currently appear that razorback sucker are successfully recruiting from the larval to juvenile life stages, possibly due to cold temperatures and lack of stable rearing habitats. Because larval razorback sucker need stable, low-velocity, warm, productive habitats for rearing, a beneficial effect is expected under this experiment, combined with HFEs to build bars and backwaters.

Sustained low flows for benthic invertebrate production may benefit razorback sucker by providing additional aquatic insect prey and stable nearshore habitats for rearing 2 days per week. This treatment will be discontinued if there is no observed benefit to the food base, trout fishery, or native fish; if there is an increase in warmwater nonnative species or trout at the Little Colorado River; or if there are unacceptable adverse impacts on the trout fishery, humpback chub population, or other resources.

3.3.1.4 Effects of Trout Management Flow Experiments

The potential for TMFs to strand and cause mortality in razorback sucker would increase under the proposed action. The extent of mortality due to stranding of razorback sucker in a given year in Marble and Grand Canyons as a result of TMFs is unknown; it may depend on the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and abundance of juvenile fish in sensitive habitats, the timing and number of TMFs, and the degree of flow attenuation downstream. TMFs could be implemented from May through August, which would overlap with the presence of larval razorback sucker. Given that razorback sucker

spawning was documented for the first time in in the study area in 2014 (and continued in 2015; Kegerries et al. 2015) and studies are ongoing, potential impacts on the species are particularly difficult to predict. Larval or juvenile razorback sucker may be particularly sensitive to the drastic and rapid fluctuations associated with TMFs, because those life stages may be more reliant than other native species on low-velocity backwater habitats. For example, in both 2014 and 2015, catch-per-unit-effort of razorback sucker larvae was higher in isolated pools and/or backwaters (Albrecht et al. 2014; Kegerries et al. 2015).

In addition, although the location or habitat preference for spawning adult razorback suckers has not been identified or defined in the Grand Canyon, the species is known to spawn on clean cobble bars in other systems (reviewed in FWS 2002b), and Valdez et al. (2012b) identified potential spawning bars in the Grand Canyon at tributary inflows and canyon mouths including Diamond Creek (RM 226), Spencer Canyon (RM 246), and Surprise Canyon (RM 248.3). These and other shallow cobble bars important for spawning and egg incubation may be sensitive to flow variation under the proposed action. Large fluctuations during the spawning period (February or March to July; Kegerries et al. 2015) associated with TMFs implemented between May and August may impact spawning and incubation habitat by dewatering.

In summary, TMFs will have negative, wide-ranging impacts on razorback sucker juveniles or larvae that would continue to occur for the duration of the action. Similarly to humpback chub, risk to razorback sucker would likely vary by location depending upon the level of stage changes experienced and the steepness of shallow nearshore areas. Monitoring of the impacts of trout management flows throughout GCNP would be implemented to assess the effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

3.3.1.5 Effects of Triggered Conservation Actions and Mechanical Removal of Nonnative Fish Experiments

Under the preferred alternative, mechanical removal of nonnative rainbow and brown trout (and other nonnative predators) would be implemented through a triggered, tiered approach (see Appendix D) near the confluence of the Little Colorado River and the Colorado River if conservation actions designed to reverse declines in the Little Colorado River humpback chub aggregation were ineffective.

Razorback sucker have not been sampled near the Little Colorado River inflow since the 1980s or early 1990s. Although removal of nonnative fish would benefit razorback sucker, this action would likely have limited beneficial impacts on the razorback sucker. Warmer and more turbid waters characterize the lower Grand Canyon where evidence of razorback sucker spawning has been found. These areas are less suitable to trout, so removal of nonnative trout near the Little Colorado River would likely have negligible impacts on razorback sucker.

Similar, Tier 1 conservation actions developed to conserve humpback chub, including actions to enhance rearing and translocations, would have no impact on razorback sucker because actions would occur within the Little Colorado River and its inflow, and no negative impacts of humpback chub upon razorback sucker have been noted.

3.3.1.6 Effects of Conservation Measures

Conservation measures from the 2011 Biological Opinion were evaluated and adapted for the LTEMP, where necessary, and included in the preferred alternative. Some additional conservation measures were developed specifically for the LTEMP, and were incorporated into the preferred alternative. The intention of conservation measures is to mitigate or offset potential impacts on ESA-listed species that may result with the implementation of the LTEMP preferred alternative. These measures were developed in consultation with the FWS and biologists with the NPS. Effects on razorback sucker are discussed for each conservation measure below.

Humpback Chub Translocations, Disease, and Parasite Monitoring (in humpback chub), Humpback Chub Refuge, Mainstem Humpback Chub Aggregations

Humpback chub translocations may result in increased growth or improved rearing and survival of juvenile humpback chub, but would likely have minimal impacts on the razorback sucker. Although adult humpback chub may prey upon larval or juvenile native fish, it is unlikely that a population-level impact would be expected on suckers, including the razorback sucker. For example, as the translocated humpback chub population has grown in Havasu Creek, bluehead sucker have continued to recruit and possibly increase in number (Nelson et al. 2016).

Reclamation intends to fund the GCDAMP to conduct disease and parasite monitoring in humpback chub and other fish in the mainstem Colorado River, in addition to ongoing disease and parasite monitoring conducted by USGS/GCMRC in the Little Colorado River. No impacts on razorback sucker would be expected because no razorback sucker would be targeted for parasite monitoring.

A refuge population of humpback chub was established at the FWS SNARRC facility in Dexter, New Mexico. The goal of the refuge is to maintain a genetically diverse population of 1000 humpback chub to be used for propagation in the case of a catastrophic loss of the Grand Canyon population. As for disease and parasite monitoring, no effects on razorback sucker are expected because they would not be targeted for refuge development.

Conserving mainstem humpback chub aggregations was a focus of past conservation measures related to dam operations. In the LTMEP, Reclamation will continue to assist the FWS, NPS, and GDAMP to ensure that a stable or upward trend of humpback chub mainstem aggregations can be achieved. The impacts on individual razorback sucker that may occur as a result of monitoring are covered in Section 2.2.

Razorback Sucker Conservation Measures

Studies designed to understand the status of the razorback sucker population in the Grand Canyon and Lake Mead would continue with the implementation of the preferred alternative. Actions include (a) studies to determine the extent of hybridization in flannelmouth and razorback sucker larvae collected; (b) studies to determine habitat use and distribution of different life stages of razorback sucker to assist in future management of flows that may help to conserve the species (including identification of habitats sensitive to flow fluctuations), and (c) studies to assess the effects of trout management flows and other dam operations on the species.

Although some fatality of individual razorback sucker may occur as a result of these studies, including fatality of larval fish, as has occurred in 2014 and 2015 related to larval studies (Albrecht et al. 2014; Kegerries et al. 2015), the information gained will be critical to understanding population-level impacts on the species due to dam operations and experimental actions under the preferred alternative. The adaptive management structure of the LTEMP will allow for adjustments in management actions throughout the life of the LTEMP. Thus, negative effects on individuals would likely be offset by population-level benefits that may be expected if adjustments in operations are made as a result of these studies.

Nonnative Species Conservation Measures

Nonnative fish will continue to threaten razorback sucker in the Grand Canyon under the LTEMP preferred alternative. As a result of continued colder temperature regimes and clear water from of dam construction and operations, particularly in Glen and Marble Canyons, nonnative cool-/coldwater species are expected to proliferate and continue to prey upon and compete with native fish. However, razorback sucker may be more at risk from warmwater nonnative fish that may become established because they have been primarily found in the lower river. Warmer temperatures, which have been occurring in the lower river recently, may allow for highly piscivorous warmwater nonnative species such as smallmouth bass to proliferate. Smallmouth bass were identified as a major threat to native fish in the Yampa River, and have caused major declines in native fish (Johnson et al. 2008).

Conservation measures that were developed to specifically address nonnative species threats to humpback chub and, secondarily, to benefit razorback sucker, include (a) continued nonnative trout (brown and rainbow) removal efforts at Bright Angel Creek and its inflow, or other areas where expanded populations have been found; (b) feasibility study, and planning and compliance for chemical piscicide renovation at Bright Angel and Shinumo creeks; (c) study of efficacy of a temperature control device on the dam to address future conditions under climate change; (d) potential research and development of a means to prevent passage of warmwater nonnative fish through Glen Canyon Dam; (e) planning, compliance, and implementation of a plan to address (make less suitable) the suitability of warmwater nonnative fish habitat in a slough below Glen Canyon dam; and (f) completion of a plan for rapid response to nonnative fish invasions, using tools not approved in the NPS CFMP (e.g., chemicals). Finally, the use of flows (e.g., TMFs) to inhibit brown trout spawning and recruitment in Glen Canyon or other

mainstem locations will be explored over the life of the LTEMP. This measure is necessary to prevent recently detected spawning of brown trout in Glen Canyon from further expanding or increasing in abundance.

Among nonnatives present in the project area, rainbow trout recruitment and abundance would be the species most influenced by changes in dam operations. In the context of impacts on the razorback sucker, interactions between rainbow trout would be expected to be less frequent, because habitat for rainbow trout is less suitable where razorback sucker were found recently (Lava Falls to Lake Mead). Nevertheless, critical habitat for razorback sucker extends into Marble Canyon and the Paria River, where rainbow trout are abundant, and where razorback sucker were detected in the 1990s. As described above, trout emigration through Marble Canyon to the Little Colorado River reach may be higher under the proposed alternative. The magnitude of the impacts of rainbow trout on razorback sucker may depend on the extent of the current distribution of razorback sucker in upstream areas of the project area (currently relatively unknown, and habitat is less suitable), the effects of TMFs on trout recruitment, and the effectiveness of triggered mechanical removal in the vicinity of the Little Colorado River. However, TMFs may have a greater negative impact on larval or juvenile razorback sucker that prefer still, warmer, nearshore habitats in areas near Lava Falls and downstream, compared to the potential benefits of reducing rainbow trout through TMFs.

As discussed above for impacts on humpback chub, it is unclear what factors (e.g., potential flow regime changes) have influenced populations of brown trout within the project area and their expansion to Glen Canyon. Brown trout have the potential to impact razorback sucker more than rainbow trout; however, the species is primarily found near Bright Angel Creek, near Tapeats Creek, and recently expanding in Glen Canyon. The continuation of brown trout control efforts, as described under the NPS CFMP, would likely maintain low levels of brown trout near areas where their distribution overlaps with razorback sucker. In addition, because brown trout tend to be far-ranging, it is possible the reductions of brown trout at their source (Bright Angel Creek) could benefit razorback sucker in other areas of the canyon by reducing predation risk slightly. The mainstem area near Tapeats Creek is less suitable for trout due to increased turbidity, and it is unlikely that flow regime changes under the proposed action would influence brown trout in that area.

Warmwater nonnative fish are a primary threat to razorback sucker, range-wide (FWS 2002b). Since the 1990s, a shift in species composition from nonnative to native species for unknown reasons has been noted below Diamond Creek (reviewed in Kegerries et al. 2015). Nevertheless, modeled temperature suitability for warmwater nonnative species in the lower river (RM 157 or 225), where razorback sucker may be spawning, would be expected to change little compared to the baseline condition. Regardless, a response to new or expanded populations of warmwater nonnative fish may become necessary in the lower river in the future. The rapid response plan may allow for additional tools to suppress or remove warmwater nonnative fish, reducing negative impacts due to predation upon razorback sucker.

In summary, the nonnative fish conservation measures could all lead to beneficial impacts on razorback sucker by reducing the risk of invasion and establishment of warmwater nonnative species, or allowing for control of new invasions. The outcome will depend on the

effectiveness of the actions, including whether feasible options are developed for management of slough habitat, and prevention of passage of warmwater nonnative fish through the dam, for which no technology currently exists.

3.3.1.7 Effects of Climate Change

More frequent droughts and warmer atmospheric temperatures as a result of climate change and warmer water being released from the dam are likely to impact razorback suckers in the Grand Canyon. Razorback suckers are currently located in the lower reaches of the canyon where backwater habitat is more available. Warmer water temperatures may create more suitable habitat for larvae and juveniles. However, these effects may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. In addition, lower reservoir releases may result in fewer backwater habitats available for spawning and rearing of razorback sucker.

3.4 EFFECTS OF THE PROPOSED ACTION ON SOUTHWESTERN WILLOW FLYCATCHER

The southwestern willow flycatcher nests and forages in habitats ranging from dense, multi-storied riparian vegetation (such as cottonwood/willow stands with a mix of trees and shrubs) to dense tamarisk stands with little layering of vegetation. However, changes in the availability of suitable habitat may not necessarily translate into changes in the southwestern willow flycatcher populations. Despite the abundance of woody riparian vegetation (e.g., tamarisk) since construction of the Glen Canyon Dam, numbers of nesting southwestern willow flycatchers in the Grand Canyon have declined since the 1980s and no nests have been confirmed in the Grand Canyon since 2007 (Stroud-Settles et al. 2013). Consequently, the effect of the proposed action will have no effect on willow flycatchers because they do not occur in the Grand Canyon; however, the proposed action may have effects on habitat the flycatchers could potentially occupy.

The proposed action features several types of HFEs: (a) proactive spring HFEs, (b) sediment-triggered spring HFEs, and (c) sediment-triggered fall HFEs. Proactive spring HFEs in April, May, or June coincide with the nesting period of the southwestern willow flycatcher. However, these flows are only anticipated to occur approximately two times (10%) during the 20-year life of the LTEMP. These HFEs could coincide with the southwestern willow flycatcher nesting period (May and June). However, southwestern willow flycatcher nests in the Grand Canyon have typically been located above the elevation of 45,000 cfs (Gloss et al. 2005), the maximum HFE flow. The action proposes approximately <5 years (<25%) of spring HFEs triggered by sediment loading. However, these HFEs occur in March or April, prior to nest initiation for the southwestern willow flycatcher and would have no direct impact on the species. Both types of HFEs that occur in the fall (sediment triggered and extended duration) occur long after nesting and fledging dates of the southwestern willow flycatcher and would have no direct impact on the species.

This action is not expected to result in important structural changes in riparian habitat or vegetation productivity that could affect the southwestern willow flycatcher. In addition, invertebrates with only terrestrial life stages are not expected to be affected. The action should result in no impacts on the southwestern willow flycatcher's ability to forage effectively and sustain a nest.

Low summer flows, if tested, would occur for 3 months (July, August, and September). This test could overlap with the nesting period (May to August) during the months of July and August. Low summer flows have monthly average low flows of 10,000 cfs or more during the nesting period, which could sustain some inundated riparian nesting habitat, depending on the topography. Low summer flow experiments under this alternative are not expected to have long-term effects on nesting habitat.

The effects of climate change and continued dry basin hydrology may further diminish habitat for the flycatcher, due primarily to lower water levels within riparian areas.

3.5 EFFECTS OF THE PROPOSED ACTION ON YUMA RIDGWAY'S RAIL

Yuma Ridgway's rail nests can be found on small raised mud hummocks, or in the crotches of small shrubs, just above water in dense cattail and tamarisk habitat (Abbott 1940). The Grand Canyon has very little true cattail/marsh habitat, but it does contain considerable stands of dense tamarisk, both near and in the water. However, most potential habitat in the lowest portion of the Grand Canyon where Yuma Ridgway's rails have been detected is now 10 feet or more above the flowing river level; this is a result of Lake Mead water levels dropping in recent years.

Although they are only anticipated to occur approximately two times (10%) during the 20-year life of the plan, this alternative features proactive spring HFEs in April, May, or June that coincide with the nesting period of the Yuma Ridgway's rail. This alternative also proposes approximately <5 years (<25%) of spring HFEs triggered by sediment loading. There is a possibility that these HFEs, when they coincide with the Yuma Ridgway's rail nesting period (April and May), could impact nests and suitable habitat if they are along the river edge. However, it is unlikely that the nests or habitat would be close enough to the river to be impacted by HFEs because HFEs have minimal stage change in this broad floodplain habitat for the rail. Both types of HFEs that occur in the fall (sediment triggered and extended duration) occur long after nesting and fledging dates of the Yuma Ridgway's rail and would have no direct impact on the species. Low summer flows would occur under this alternative. Lower flows during the May to August nesting and fledging period could impact Yuma Ridgway's rail habitat by decreasing the density of vegetation in the marsh habitat within the rail's preferred nesting and predator avoidance areas. Low summer flow experiments under this alternative are not expected to have long-term effects on potential Yuma Ridgway's rail habitat. Designated critical habitat for the Yuma Ridgway rail does not occur in the area of the proposed action. Effects of climate change and continued dry basin hydrology may further diminish habitat for the rail, due primarily to lower water levels within riparian areas.

3.6 CUMULATIVE EFFECTS

Cumulative effects include the effects of future state, local, private, or tribal management actions that may occur in the project area during the duration of the plan (20 years). Future federal actions that have not been previously approved are not included in this section because additional ESA Section 7 consultation would be required. For example, several federal actions are being planned that would require Section 7 consultation including continued permitting of the Navajo Generating Station and the Red Gap Ranch Pipeline. Existing or previously implemented actions are discussed in Section 2. The following projects were considered when analyzing cumulative effects of the proposed action, and other non-federal actions, upon endangered species.

3.6.1 Grand Canyon Escalade

The Navajo Nation has proposed a 420-ac development project, known as the Grand Canyon Escalade, on the Grand Canyon's eastern rim on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado rivers. The development would include a 1.4-mi-long, eight-person tramway (gondola) to transport visitors 3,200 ft from the rim to the canyon floor. On the rim, the development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking for cars and recreational vehicles. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk (with an elevated walkway) along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts on the local economy through increased tourism and job creation. The Little Colorado River contains critical spawning habitat for humpback chub.

The Grand Canyon Escalade Project and its associated facilities near the confluence of the Little Colorado River could cause both a localized loss of wildlife habitat and source of wildlife disturbance due to human presence. Wildlife species in the Grand Canyon are currently exposed to various sources of man-made noise ranging from human conversation to aircraft flyovers. The potential effects of noise on wildlife include acute or chronic physiological damage to the auditory system, increased energy expenditures, physical injury incurred during panicked responses, interference with normal activities (e.g., feeding), and impaired communication (AMEC Americas Limited 2005). The response of wildlife to noise would vary by species; physiological or reproductive condition; distance; and the type, intensity, and duration of the disturbance. Regular or periodic noise could cause adjacent areas to be less attractive to wildlife and result in a long-term reduction in use by wildlife in those areas. Responses of wildlife to disturbance often involve activities that are energetically costly (e.g., flying or running), altering their behavior in a way that might reduce food intake, communication, and nesting (Hockin et al. 1992; Brattstrom and Bondello 1983; Cunnington and Fahrig 2010; Francis et al. 2009; Maxell 2000).

3.6.2 Uranium Mining on State and Private Lands

Uranium mining peaked in the 1980s in the Grand Canyon region, but there is now a renewed interest due to increases in uranium prices. Increased uranium mining (on state and private lands) could increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Uranium, other radionuclides, and metals associated with uranium mines can affect the survival, growth, and reproduction of aquatic biota.

Aquatic biota and habitats most likely to be affected during mine development and operation are those associated with small, ephemeral, or intermittent drainages. Impacts on aquatic biota and habitats from the accidental release of regulated or hazardous materials into ephemeral drainages would be localized and small, especially if a rapid response to a release is undertaken. The accidental spill of uranium ore into a permanent stream or river such as Kanab Creek would potentially pose a localized short-term impact on the aquatic resources. However, the potential for such an event is extremely low. Most ore solids would settle in the waterbody within a short distance from a spill site (Edge Environmental, Inc. 2009). It is expected that expedient and comprehensive cleanup actions would be required under U.S. Department of Transportation regulations and that an emergency response plan would be in place for responding to accidents and cargo spills (Edge Environmental, Inc. 2009). Overall, the potential for impacts on aquatic biota from an accidental spill would be small to negligible. Spencer and Wenrich (2011) estimated that if an ore load is washed into the Colorado River and is pulverized and dissolved (a scenario that is extremely unlikely to impossible), the uranium concentration in the river would increase from the current 4.0 ppb to only 4.02 ppb (undetectable against natural variations). Predicted no-chemical-effect concentrations for aquatic vascular plants, aquatic invertebrates, and fish are ≥5.0 ppb; the lowest chronic concentrations are well above that concentration (see Hinck et al. 2010). For these reasons, the impacts from uranium mining on aquatic biota in the Colorado River or its major tributaries would be localized and would not reduce the viability of affected resources.

In the past, uranium mining led to localized peregrine falcon nest failures in areas such as Kanab Canyon and its multiple side canyons, where numerous mining claims existed (Payne et al. 2010). Although 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel) was withdrawn from locatable mineral exploration and development (i.e., uranium mining), increased uranium mining on non-federal (state and private) lands remaining open to mining could locally affect wildlife habitat (e.g., habitat loss and fragmentation) and increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Edge habitat associated with uranium mines and associated access roads may provide habitat for brown-headed cowbirds (Payne et al. 2010), which are brood parasites of songbirds. In general, any impacts on wildlife from uranium mining would be localized and should not affect the viability of affected resources, especially with the use of best management practices to control mine discharges and proper mine reclamation.

3.6.3 Increased Municipal and Agricultural Water Demand

As the population in the Basin States grows and expands, municipal, industrial, and agricultural water demand continues to increase. A Reclamation study in 2012 showed that the demand for Colorado River Basin water may exceed demand before 2060 (Reclamation 2012b), which may result in lower Lake Powell levels and changes in flow, sediment, and water temperature regimes in the Grand Canyon.

Population and industrial growth, coupled with climate change, will act in concert to increase water demand in the region (Schindler 2001) and lower flows downstream of Glen Canyon Dam. This could stress existing riparian and wetland vegetation, leading to plant community alterations that would affect both wildlife habitats and the wildlife prey base. Climate change would not affect all wildlife species uniformly. Some species would experience distribution contractions and likely shrinking populations, while other species would increase in suitable areas and thus possibly experience increases in population numbers. Generally, the warmer the current range is for a species, the greater the projected distributional increase (or lower the projected loss) will be for that species due to climate change (van Riper et al. 2014).

3.6.4 Urban and Agricultural Runoff

Urban runoff, industrial releases, and municipal discharges are considered some of the leading nonpoint sources of contaminants to surface waters (EPA 2004). Areas of intensive agriculture can have an adverse effect on the water quality as a result of the salinity, nutrients, pesticides, selenium, and other trace elements that are common constituents in agricultural runoff. For example, elevated selenium found in aquatic organisms in Colorado River in Grand Canyon is thought to be partly due to agricultural runoff from areas with soils containing selenium (Walters et al. 2015). It is unclear how contamination due to agricultural and urban discharge may change in the future.

3.6.5 Nonnative Vegetation and Defoliating Nonnative Insect Expansion

The highly flammable tamarisk has created a fire hazard previously absent along the river. This threatens breeding bird populations, as well as other wildlife. In addition, if native or mixed habitat stands burn, monotypic tamarisk will likely recolonize, eliminating the crucial structure necessary for southwestern willow flycatchers and other nesting birds (e.g., thermal buffering through shading becomes insufficient and will be further exacerbated by warming climate trends) (Schell 2005). Additional factors that could affect riparian wildlife habitat include the tamarisk leaf beetle and splendid tamarisk weevil, which occur along much of the Colorado River below Glen Canyon Dam and result in defoliation and mortality of tamarisk. Widespread tamarisk mortality would likely result in a net loss in riparian habitat for at least a decade or more (Paxton et al. 2011). It seems unlikely that the effects of large-scale defoliation in areas dominated by tamarisk will be compensated for by use of tamarisk beetles as a food resource by birds (Puckett and van Riper 2014).

3.6.6 Cumulative Effects Summary

3.6.6.1 Aquatic Species – Humpback Chub, Razorback Sucker, and Kanab Ambersnail

The incremental effects of the LTEMP proposed action on razorback sucker and humpback chub are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Examination of the various hydrologic traces used to model effects of the proposed action on aquatic resources indicated that hydrology (i.e., whether a 20-year trace was drier or wetter on average) had a greater influence on the model results than did the operational differences among alternatives. Similarly, climate change has the potential to have greater effects on fish resources than any of the alternatives because of its direct influences on hydrologic patterns. For example, more frequent droughts and warmer atmospheric temperatures have the potential to result in greater increases in the temperature of water being released from the dam than the operational actions being considered, and this in turn may improve thermal suitability for humpback chub, humpback chub aggregations, and native fish. However, any subsequent benefits may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. There are a number of other actions being taken within the Colorado River Basin that could also contribute to significant cumulative effects on fish populations or fish communities. For example, actions to increase the number of self-sustaining populations of humpback chub within the basin (e.g., translocation of humpback chub from the Little Colorado River to other tributaries within the Grand Canyon) have the potential to increase overall numbers of humpback chub and could provide some level of protection against catastrophic events in the Little Colorado River that could greatly reduce or eliminate the population of humpback chub in the Grand Canyon.

3.6.6.2 Wildlife

The effects of the LTEMP proposed action on wildlife are relatively small compared to the effects of other factors, especially future hydrology, and they are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. The proposed action would have little effect on most wildlife species.

3.6.7 Summary of Climate-Related Changes

The general picture for climate change as it relates to Colorado River Basin hydrology includes decreased inflow to the reservoir system (e.g., lower precipitation) and greater losses (e.g., evapotranspiration associated with higher temperatures and increased demand from the growing population). Climate change is expected to result in more frequent and severe drought conditions in the Southwest. Meeting increasing water needs (e.g., the Lake Powell Pipeline project and the Page-LeChee water supply project) will likely lead to lower reservoir levels in Lake Powell, which may already be affected by increased evaporation associated with higher air temperatures. As discussed in the baseline, the decreasing the elevation of Lake Powell can lead

to warmer water discharges from Glen Canyon Dam and increased water temperatures downstream.

Water discharge from springs supports the vegetative habitat upon which Kanab ambersnail relies. Changes in spring discharge due to reduced snowpack, in addition to impacts of HFEs, may further reduce habitat at Vaseys Paradise. The Southwest is already experiencing the effects of climate change (Garfin et al. 2014). The decade from 2001 to 2010 was the warmest on record, with temperatures almost 1.1°C higher than historic averages (Garfin et al. 2014; World Meteorological Organization 2014). Higher temperatures in the Colorado River Basin have resulted in less precipitation falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011). Such effects are likely to continue well into the foreseeable future (NAS 2007).

Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; FWS 2011c). Lower water levels in Lake Powell may also result in increases in the composition and density of zooplankton downstream of Glen Canyon Dam, because waters would be withdrawn closer to the surface (Reclamation 1995). However, warmer temperatures, particularly in winter, may allow many invertebrate species to complete their life cycles more quickly (Schindler 2001). For example, if stream temperatures are raised by only a few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in February or March and face death by freezing or be prevented from mating because they are inactivated by low air temperatures. In addition, increases in stream temperatures may cause an exaggeration in the separation of the emergence of males and females (e.g., males may emerge and die before females emerge) (Nebeker 1971). Temperatures above the optimum can lead to the production of small adults and lower fecundity (Vannote and Sweeney 1980).

Warmer water temperatures can expand the distribution of nonnative species adapted to warmer temperatures. This includes fish parasites such as the Asian tapeworm, anchor worm, and nonnative crayfish. Increased zooplankton due to climate change may increase abundance of cyclopoid copepods. All cyclopoid copepod species appear to be susceptible to infection by, and therefore serve as intermediate hosts for, the Asian tapeworm (Marcogliese and Esch 1989). Crayfish can prey on fish eggs and larvae and can diminish the abundance and structure of aquatic vegetation such as filamentous algae through grazing (FWS 2011c). Nonnative crayfish are present in Lake Powell (northern or virile crayfish [*Orconectes virilis*]) and Lake Mead (red swamp crayfish [*Procambarus clarkii*]). Warmer temperatures may allow the crayfish to expand into the mainstem of the Colorado River either downstream of Lake Powell or upstream of Lake Mead.

Higher temperatures in the Colorado River Basin have resulted in less precipitation falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011). These effects in turn have exacerbated competition among users (farmers, energy producers, urban dwellers), as well as effects on ecological systems, during a time when due to a rapidly

rising population water demand has never been higher (Garfin et al. 2014). The combination of decreasing supply and increasing demand will present a challenge in meeting the water delivery commitments outlined in the Colorado River Compact of 1922 (apportioning water between the Upper and Lower Basins) and the United States–Mexico Treaty of 1944 (which guarantees an annual flow of at least 1.5 million ac-ft to Mexico). In 2007, DOI adopted interim guidelines (Reclamation 2007a) to specify modifications to the apportionments to the Lower Basin states in the event of water shortage conditions.

Changes in temperature and precipitation patterns attributed to climate change could also take a toll on the region's rich diversity of plant and animal species (e.g., widespread loss of trees due to wildfires).

As described above, depending on the extent of drought in the Colorado River basin, lower Lake Powell levels may result in the discharge of warmer than anticipated water into Glen and Grand Canyons. This could increase the likelihood that warmwater nonnative predators will become established.

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4 CONCLUSIONS AND DETERMINATIONS OF EFFECT

A summary of effects determinations for the five listed species is presented in Table 6. Analysis of effects determination are based 50 CFR 402.02, in which "[e]ffects of the action refers to the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process."

4.1 LISTED SPECIES DETERMINATIONS

For the purposes of Section 7 consultation under the ESA, the following definitions are used when determining the level of anticipated effect for each listed species and its habitat (FWS and NMFS 1998a).

No effect: The proposed action will not affect listed species or designated critical habitat.

May affect, but is not likely to adversely affect: Effects of the proposed action on listed species is expected to be discountable, insignificant, or completely beneficial.

- Discountable effects are those extremely unlikely to occur. Based on best judgment, a person would not (1) be able to meaningfully measure, detect, or evaluate insignificant effects; or (2) expect discountable effects to occur.

- Insignificant effects relate to the size of the impact and should never reach the level where incidental take may occur.

- Beneficial effects are contemporaneous positive effects without any adverse effects on the species. In the event that the overall effect of the proposed action is beneficial to the listed species, but also likely to cause some adverse effects, then the proposed action "is likely to adversely affect" the listed species.

May affect, and is likely to adversely affect: Effects of the proposed action on listed species may occur as a direct or indirect result of the proposed action or its interrelated or interdependent actions, and the effect is not discountable, insignificant, or beneficial.

Jeopardize the continued existence of a species: Effects of the proposed action would be expected, directly or indirectly, to appreciably reduce the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species (50 CFR 402.02).

TABLE 6 Summary of Effects Determinations for the Five Listed Species

Determination	Basis for Determination
Humpback chub (*Gila cypha*)	
May affect, is likely to adversely affect	The stranding of young chub could occur during TMFs and downramp rates, but longer-term beneficial impacts on older age classes may result from reduced trout.
	Impacts on habitat include direct, minor, short-term reductions in nearshore habitat could occur in the vicinity of the Little Colorado River with changes in flow stage, but long-term benefit is expected from sand re-deposition that rebuilds and maintains nearshore and backwater nursery habitats. Base operations will continue to degrade the food base.
	Increased predation from expanded population of rainbow trout is expected under cold water discharge, especially with spring or multiple HFEs. Translocations, brown trout control, triggered mechanical removal, triggered proactive conservation actions, and other conservation measures may offset impacts at the population level.
Razorback sucker (*Xyrauchen texanus*)	
May affect, is likely to adversely affect	Potential for creation of warm, productive nursery habitats from increased reshaping of nearshore deposits and backwater development.
	Potential short-term dewatering of spawning areas during TMFs.
	Stranding of larval and young-of-year razorback sucker in nearshore habitats may occur as a result of TMFs and base operations (daily fluctuating flows, including increased downramp rates).
Kanab ambersnail (*Oxyloma kanabensis*)	
May affect, is likely to adversely affect	Potential habitat would be frequently inundated during HFEs that would occur almost annually.
	Proportionally less habitat area would be scoured and fewer snails would be displaced by lower magnitude HFEs.
	Sequential HFEs could re-inundate and scour primary habitat prior to full recovery from previous HFE.
Southwestern willow flycatcher (*Empidonax traillii extimus*)	
May affect, not likely to adversely affect	Not expected to be in the action area during the spring HFE release window (March–April) and high flows of 45,000 cfs or less are not likely to adversely affect their nesting and feeding sites.
Yuma Ridgway's rail (*Rallus obsoletus yumaensis*)	
May affect, not likely to adversely affect	Spring HFEs may flood nesting habitat; however, nesting habitat is rare, and likely above the level HFE effects due to dropping Lake Mead levels.

4.2 HUMPBACK CHUB

Based on the evaluation contained in this BA, Reclamation has determined that the proposed action **may affect and is likely to adversely** affect the humpback chub, and may adversely affect its designated critical habitat. This determination is based on adverse effects on habitat, related to fluctuating flows (increased downramp rates), the potential for increases in negative interactions with rainbow trout, and the potential for TMFs to impact larval and juvenile individuals occupying shallow stream margin habitats. Fluctuating flows under base operations would also continue to limit the diversity and abundance of aquatic invertebrate prey. These combined effects could result in lower survival of young fish and less recruitment to the adult population. The unintended consequence of an increased rainbow trout population that could result from HFEs, especially those in spring, would likely increase downstream dispersal of trout into the vicinity of the Little Colorado River where they could prey on and compete with young humpback chub. This effect would also reduce recruitment of humpback chub and possibly the overall population size. However, TMFs may also reduce negative effects on humpback chub related to downstream emigration and predation or competition by rainbow trout, but their effectiveness is uncertain. Mechanical control of nonnative fish would be initiated if adult or subadult humpback chub abundance declined, and proactive conservation actions to improve rearing fail to reverse population declines downstream of Glen Canyon Dam; this could reduce nonnative trout abundance and their effects on competition with and predation on humpback chub. Trout control in Bright Angel Creek and the Bright Angel inflow is also expected to reduce brown trout in the project area; however, the potential to control brown trout spawning in other areas is less certain.

The HFEs are also expected to have long-term beneficial effects on the humpback chub population. Although periodic high flows would likely temporarily affect habitat and reduce the food base, multiple HFEs would be expected to rebuild and maintain backwater habitats—so long as sufficient fine sediment was available—and stimulate productivity in backwaters and nearshore habitats. Experimental sustained low flows for benthic invertebrate production may improve the food base; however, the success of this experiment is highly uncertain. The number of consecutive HFEs that would benefit the ecosystem (e.g., rebuilding and maintenance of habitat, stimulate food base productivity) or adversely modify or alter the ecosystem from periodic scouring is unknown. In addition to the effects of low flows to benefit the food base, this will be investigated as part of the LTEMP.

Low summer flows could lead to stable, more productive nearshore habitats, increased likelihood of the establishment of a more diverse and productive food base, and warmer water temperatures in the Little Colorado River reach and further downstream, as well as contributing to enhanced growth rates of young humpback chub. However, this experimental treatment would be used only rarely, if a single test in the second 10 years of the LTEMP period proves it to be a useful tool for improving humpback chub habitat. It is thought that the potential benefit of an increase in temperature would be greatest if a water temperature of at least 14°C could be achieved, because these warmer temperatures could favor higher growth rates of humpback chub.

Finally, as described in Section 3.6.7 the potential for increased occurrence of new warmwater nonnative species' introductions may increase in the future as the likelihood of low Lake Powell levels increases with drought and expanded water use, or during LSF experiments. For example, it is likely that the establishment of green sunfish in a backwater slough in Glen Canyon was the result of fish passing through the Glen Canyon Dam (Ward 2015). There is a chance that over the life of the LTEMP, under extreme drought and low Lake Powell levels, dam release temperatures could reach temperatures suitable for reproduction of high-risk nonnative predatory species such as smallmouth bass (15°C). However, current temperatures are already suitable for many warmwater species in the lower river. The river temperature at the Lees Ferry gauge approached 15°C during the fall of 2015 (GCMRC 2016), and reached 20°C below Diamond Creek. Increases in smallmouth bass in the Yampa River have coincided with the decline of the humpback chub population; the threat smallmouth bass pose to humpback chub is thought to be 10 times greater than the threats posed by channel catfish and northern pike (Johnson et al. 2008).

4.3 RAZORBACK SUCKER

Reclamation has also determined that the proposed action **may affect and is likely to adversely** affect the razorback sucker, and may adversely affect its designated critical habitat. This determination is based on potential adverse effects of TMFs stranding juvenile or larval razorback sucker in nearshore habitats, and long-term, river-wide effects as the result of fluctuating flows under base operations, which will continue to compromise the diversity and abundance of aquatic insect prey and degrade nearshore habitats that are important for rearing. Spawning habitat (cobble bars and riffles) is also expected to be negatively affected by base flow fluctuations (including increased downramp rates) and TMFs. TMFs will be less likely to beneficially impact razorback sucker in the western Grand Canyon by reducing trout abundance in Glen and Marble Canyons, and may result in stranding of larval or young-of-year razorback sucker during the summer months. The impacts of TMFs on razorback sucker will be investigated in the LTEMP, and ongoing razorback sucker monitoring in the western Grand Canyon will assist in this investigation. In addition, TMFs could impact spawning habitat and incubating eggs in shallow cobble areas that are most susceptible to changes in flow. Increased downramp rates could also impact razorback sucker young-of-year.

The increased frequency of HFEs could lead to improved sediment conservation and backwater habitat maintenance, benefitting razorback sucker habitat. Increases in sediment load will temporarily increase turbidity, which larvae use as cover from predators (Kegerries et al. 2009). In addition, modeling the hydrology and temperature regime expected during the life of the LTEMP indicated an improvement in temperature suitability compared to the baseline condition at areas inhabited by razorback sucker (i.e., Diamond Creek). Improved backwater habitats, in addition to stability during low summer flows and low steady weekend flows for macroinvertebrate production, could benefit young-of-year as well; however, low summer flows would be implemented only rarely, and invertebrate flows would only be in place for a total of 34 days per summer.

4.4 KANAB AMBERSNAIL

Reclamation has also determined that the proposed action **may affect and is likely to adversely affect the Kanab ambersnail**. Although impacts from the proposed action related to habitat scouring during HFEs will be limited to the habitat near the river, the impact would occur almost annually, which would exceed the rate of habitat recovery (2.5 years). This impact will be limited to one of two populations of Kanab ambersnail. Nevertheless, habitat quality or quantity may decline as a result of the proposed action, in the context of climate change.

There is no designated critical habitat for this species, and this analysis did not evaluate primary constituent elements. This determination is based on short-term adverse effects on habitat and snails located in the inundation zone at Vasey's Paradise. Habitat and snails below the high-water line are expected to be scoured and transported downstream with little or no survival of snails. The proportion of habitat and the number of snails affected would vary with the magnitude of the high release. For the past HFEs, Reclamation has removed habitat and snails from the projected inundation zone. When the habitat was relocated, the vegetation recovered within about 6 months, but when the habitat was not relocated, recovery was delayed about 2.5 years.

4.5 SOUTHWESTERN WILLOW FLYCATCHER

Reclamation has determines the proposed LTEMP **may affect, but is not likely to adversely affect** the southwestern willow flycatcher and southwestern willow flycatcher habitat. This determination is based on the fact that nesting activity, nests, or young are not expected to be in the action area during any of the HFEs except the two proactive spring HFEs. In addition, high flows of 45,000 cfs are not likely to adversely affect the species nesting and foraging habitat. Designated critical habitat for the southwestern willow flycatcher does not occur in the area of the proposed action.

4.6 YUMA RIDGWAY'S RAIL

Reclamation has determined the proposed LTEMP **may affect, but is not likely to adversely affect** the Yuma Ridgway's rail and habitat. Designated critical habitat for the Yuma Ridgway's rail does not occur in the area of the proposed action.

The volume and duration of HFEs is determined by the amount of Paria River sediment that is available. Modeling indicates that the amount of sediment required to trigger spring HFEs will occur in about 26% (5 years) of the 20 years of the LTEMP period. Spring HFEs would occur in April, May, or June and may coincide with the nesting period of the Yuma Ridgway's rail. The Grand Canyon has very little true cattail/marsh habitat and it is unlikely that the nests or habitat would be close enough to the river to be impacted by HFEs because HFEs have minimal stage change in this broad floodplain habitat. In addition, due to dropping levels of Lake Mead, most potential habitat in the lowest portion of Grand Canyon where Yuma Ridgway's rails have been detected is now raised 10 ft or more above the flowing river level, and therefore is out of

reach of fluctuating flows, including HFEs. Any implementation of sediment-triggered spring HFEs will consider resource condition assessments and resource concerns using the interagency process described in Section 1.2.8.

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APPENDIX A:

SOUTHWESTERN WILLOW FLYCATCHER DETECTIONS AND NEST SITES, GRAND CANYON NATIONAL PARK, ARIZONA, 1982–2012

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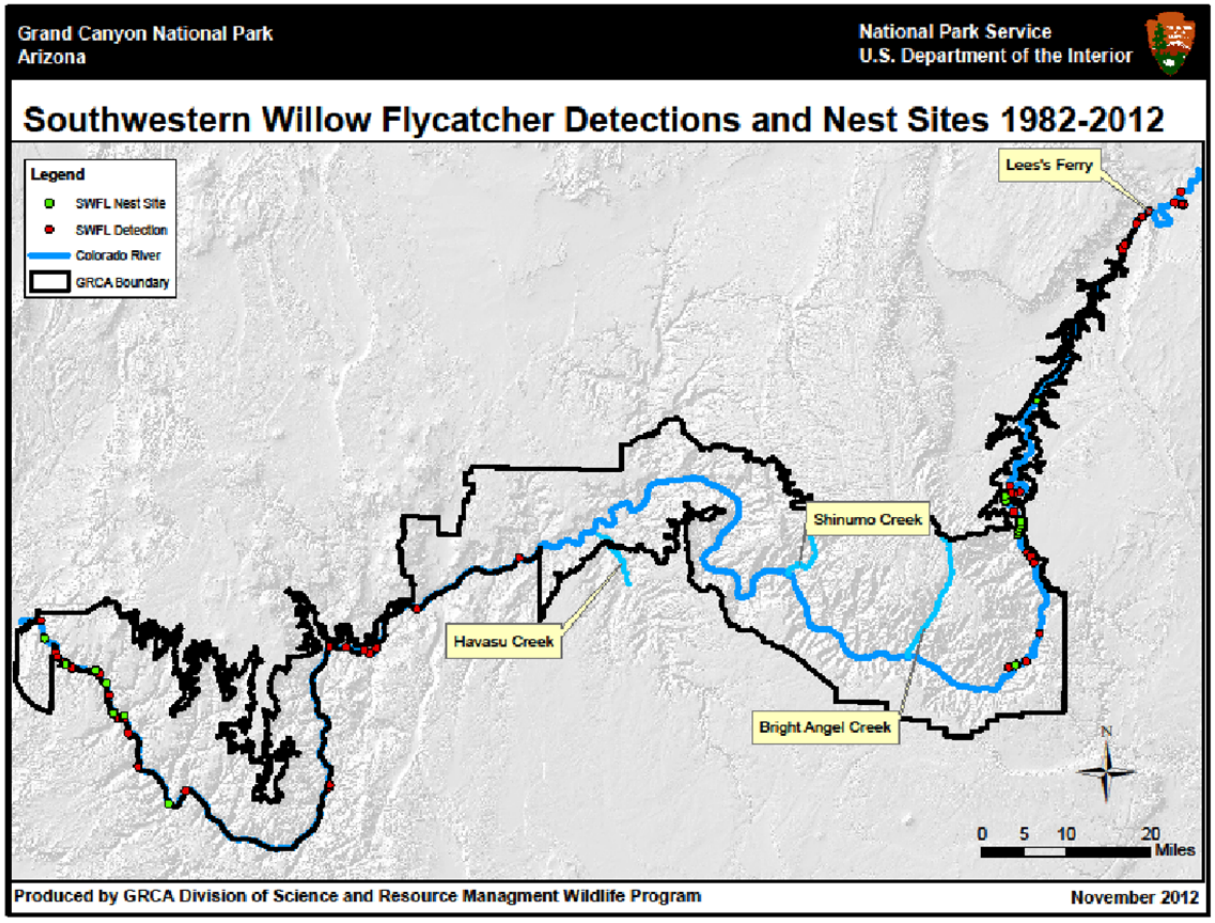
SOUTHWESTERN WILLOW FLYCATCHER DETECTIONS AND NEST SITES, GRAND CANYON NATIONAL PARK, ARIZONA, 1982–2012



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APPENDIX B:

SOUTHWESTERN WILLOW FLYCATCHER HISTORIC AND RECENT TERRITORIES AND NESTING SITES, GRAND CANYON NATIONAL PARK, ARIZONA

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APPENDIX B:

SOUTHWESTERN WILLOW FLYCATCHER HISTORIC AND RECENT TERRITORIES AND NESTING SITES, GRAND CANYON NATIONAL PARK, ARIZONA

River Mile/Location	Year	Notes
0 (Lees Ferry)	1909	Single male collected
0	1933	Specimen collected
0	1935	Used nest collected
0	1961	2 male, 1 female, 1 unknown sex collected
Lava Canyon	1931	
Little Colorado	1953	
RM 0	1987	
RM 46	1987	
RM 51.5–50.5	1993	1 territory
RM 71.3–71	1993	1 territory
RM 277–274	1993	1 territory
RM 51.5–50.5	1994	4 territories
RM 65.3	1994	1 territory
RM 71	1994	
RM 51.5–50.5	1995	1 territory
RM 65.3	1995	1 territory
Lake Mead Delta	1995	1 territory
RM 51.5–50.5	1996	3 territories
Lake Mead Delta	1996	6 territories
RM 51.5–50.5	1997	2 territories
RM 270–168	1997	2 territories (1 presumed nesting at RM 252.9)
Lake Mead Delta	1997	6 territories/3 nesting pairs
RM 51.5–50.5	1998	1 territory
RM 246	1998	2 territories
RM 254 (Spencer Cany.)	1998	2 territories
RM 265–263.5	1998	1 territory
RM 268–264	1998	1 territory
RM 268–265	1998	5 territories
RM 270–268	1998	1 territory
RM 272–268	1998	2 territories
RM 273–270	1998	2 territories
RM 277–273	1998	1 territory
RM 51.5–50.5	1999	1 territory
RM 246	1999	3 territories
RM 254 (Spencer Cany.)	1999	2 territories, 3 yg. fledged
RM 259.5	1999	1 territory (McKernan and Braden report 2)
RM 266–262.5	1999	1 territory
RM 268–265	1999	5 territories
RM 272–268	1999	1 territory
RM 276	1999	1 territory
RM 51.5–50.5	2000	1 territory
RM 246	2000	2 territories
RM 257.5–257	2000	1 territory

River Mile/Location	Year	Notes
RM 259.5	2000	1 territory
RM 266–262.5	2000	1 territory
RM 268–265	2000	1 territory
RM 51.5–50.5	2001	1 territory
RM 246	2001	3 territories
RM 254	2001	3 pairs
RM 257.5	2001	1 pair
RM 259.5	2001	2 territories
RM 262.5–259.5	2001	1 territory/2 nests
RM 263.5–262.5	2001	1 territory
RM 268–265	2001	3 territories
RM 272–268	2001	2 territories
RM 276	2001	2 individuals, no nest confirmed
RM 51.5–50.5	2002	1 territory
RM 28–29	2003	1 pair
RM 50.5-51.5	2003	1 pair
RM 28.3	2004	1 pair
RM 50.4	2004	1 female (June)
RM 274.5	2004	1 pair nesting (+1 lone male)
RM 274.5	2005	1 unpaired male
RM 274.5	2006	1 pair nesting (+1 lone male)
RM 259.5	2007	1 pair nesting
RM 274.5	2007	3 unpaired males
RM 47	2009	1 individual
RM 49	2009	1 individual
RM 50.4–50.7	2009	1 individual
RM 28.5	2010	1 individual
RM 196.4	2010	1 individual
RM 218	2010	1 pair
RM 275	2010	2 territories
RM 51.8	2011	1 individual
RM 183.5	2011	1 individual

APPENDIX C:

RIDGWAY'S RAIL HISTORIC RECORDS AT GRAND CANYON NATIONAL PARK, ARIZONA

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APPENDIX C:

RIDGWAY'S RAIL HISTORIC RECORDS AT GRAND CANYON NATIONAL PARK, ARIZONA

TABLE C.1 Ridgway's Rail Historic Records at Grand Canyon National Park, Arizona

River Mile/Location	Year	Notes
RM 246–RM 277	1996	1 rail; nesting confirmed
RM 246–RM 277	1997	1 rail; nesting not confirmed
RM 275	1999	1 male observed
RM 276	2000	1 female observed
Burnt Springs (~RM 259.8)	2001	3 individuals detected

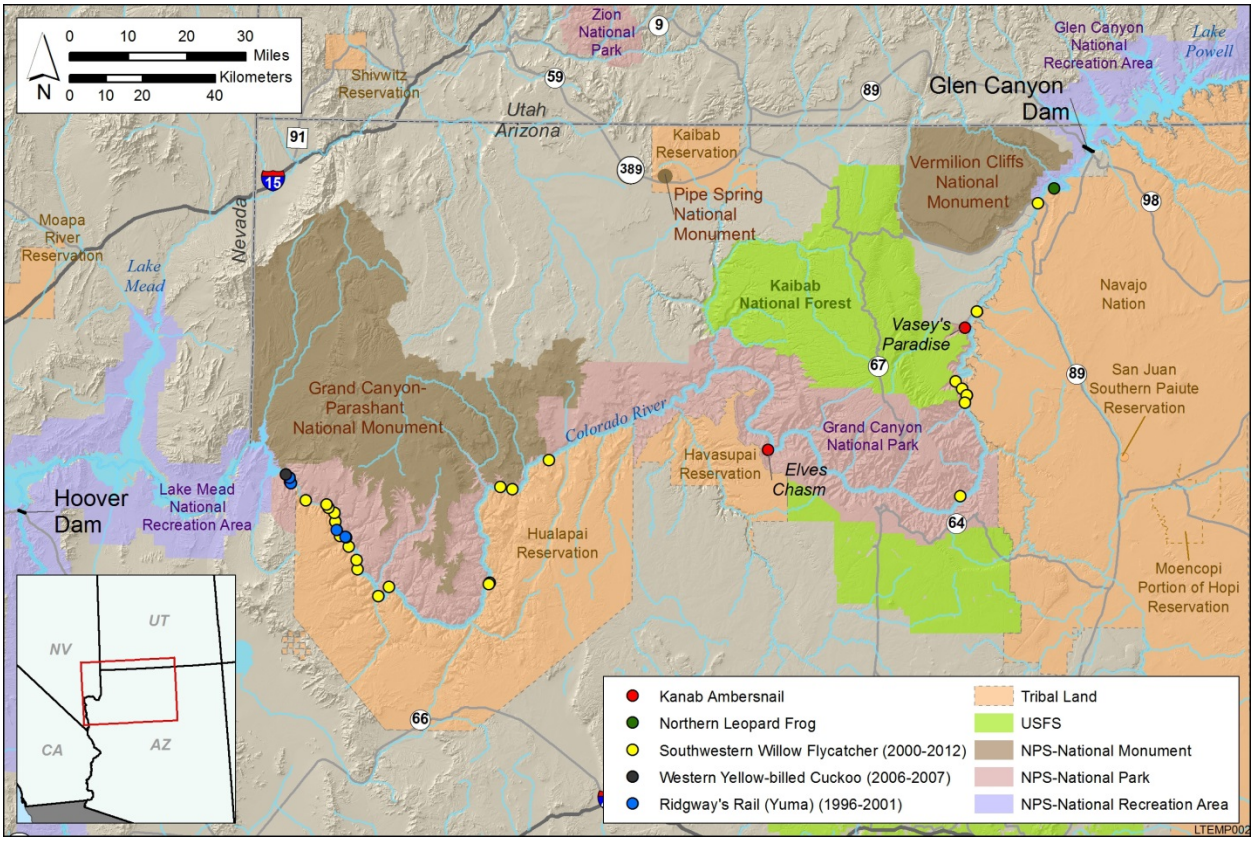

FIGURE C.1 Threatened, Endangered, and Sensitive Species Observed along the Colorado River Corridor (Sources: Drost et al. 2011; FWS 2011b; Johnson et al. 2008; NPS 2013; Stroud-Settles 2012)

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APPENDIX D:

PROPOSED ACTION TRIGGERS FOR THE MANAGEMENT OF HUMPBACK CHUB COLORADO RIVER, GRAND CANYON

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APPENDIX D

DRAFT FINAL

Proposed Action Triggers for the Management of Humpback Chub

Colorado River, Grand Canyon

November 2015

Developed by an Ad Hoc group of Grand Canyon Aquatic Biologists from USFWS, USGS-GCMRC, AZGFD, NPS, USBR (Kirk Young, David Van Haverbeke, Scott VanderKooi, David Ward, Charles Yackulic, Mike Yard, Brian Healy, Melissa Trammel, David Rogowski, Marianne Crawford)

PURPOSE

Mechanical removal of nonnative species is a controversial issue in the Colorado River through Glen and Grand Canyons. A spring 2015 meeting of Grand Canyon biologists (NPS, USFWS, AZGFD, GCMRC) to assess current trout removal triggers resulted in a concept of early conservation measure intervention to maximize conservation benefit to humpback chub (HBC) and minimize the likelihood of mechanical predator removal.

Many factors affect HBC population dynamics such as water temperature, turbidity, and water volume in the Little Colorado River (LCR). This restrains available conservation actions that can be implemented in the event of a declining population of HBC. We can translocate juveniles and young of the year to other areas within and outside the LCR system, juvenile HBC can be head-started at a hatchery, and we can attempt to remove predators. Other conservation tools may include parasite control (although this is unlikely from a population standpoint), non-native fish control in the LCR, and protect from over-utilization for scientific purposes.

Methods to actively manage temperature releases from Glen Canyon Dam sediment augmentation below the Paria River are not included in the Long-Term Experimental Management Program (LTEMP), for Glen Canyon Dam. Inclusion of infrastructure options including these were eliminated from detailed study in the LTEMP alternatives for a variety of reasons. We mention them here because these methods may still represent the most important potential conservation tools that could be used for the long term conservation of HBC in Grand Canyon and the concepts should not be lost.

While healthy wildlife populations are rarely static, trigger objectives include prescribing actions to reverse/ameliorate impacts in order to maintain the LCR HBC population within an acceptable range; and, secondarily to reduce reliance on mechanical removal of predators. For the purposes of these triggers, it is assumed that the primary drivers of HBC population dynamics are interspecific interactions with non-native species, especially rainbow trout, and low water temperature in the mainstem of the Colorado River (Kaeding and Zimmerman 1983; Douglas and Marsh 1996; USFWS 2002; Coggins et al. 2011; Yard et al. 2011). It is suspected that cold water temperatures suppress growth and thus subject young HBC to predation for extended periods of time. The approach described here puts the emphasis on managing humpback chub as opposed to managing predators. Predator removal will only occur if other conservation measures do not appear to be effective in maintaining targeted HBC population levels.

Two Tier Approach

Two tiers of sequential actions were identified; the first would emphasize conservation actions that would take place early during an adult or sub-adult HBC population decline. The second tier would serve as a backstop prescribing predator removal (Threat Reduction) if conservation measures did not mitigate a decline in HBC abundance.

ACTION TRIGGERS

Tier 1 Trigger – Early Intervention Through Conservation Actions:

1a. If the combined point estimate for adult HBC (adults defined ≥200 mm) in the Colorado River mainstem LCR aggregation; RM 57-65.9) and Little Colorado River (LCR) falls below 9,000 as estimated by the currently accepted HBC population model (e.g., ASMR, multi-state).

-OR-

1b. If recruitment of sub-adult HBC (150-199mm) does not equal or exceed estimated adult mortality such that:

1) Sub-adult abundance falls below a three-year running average of 1,250 fish in the spring LCR population estimates.

-OR-

2) Sub-adult abundance falls below a three-year running average of 810 fish in the mainstem Juvenile Chub Monitoring reach (JCM annual fall population estimate; RM 63.45-65.2).

Tier 1 Trigger Response: Tier 1 conservation actions listed below will be immediately implemented either in the LCR or in the adjacent mainstem. Conservation actions will focus on increasing growth, survival and distribution of HBC in the LCR & LCR mainstem aggregation area.

Tier 2 Trigger - Reduce threat using mechanical removal if conservation actions in Tier 1 are insufficient to arrest a population decline:

Mechanical removal of nonnative aquatic predator will ensue:
If the point abundance estimate of adult HBC decline to <7,000, as estimated by the currently accepted HBC population model.

Mechanical removal will terminate if:

Predator index (described below) is depleted to less than 60 RBT/km for at least two years in the JCM reach and immigration rate is low (the long term feasibility of using immigration rates as a metric still needs to be assessed), or

Adult HBC population estimates exceed 7,500 and recruitment of sub-adult chub exceed adult mortality for at least two years.

If immigration rate of predators into JCM reach is high, mechanical removal may need to continue. These triggers are intended to be adaptive based on ongoing and future research (e.g.,

Lees Ferry recruitment and emigration dynamics, effects of trout suppression flows, effects of Paria River turbidity inputs on predator survival and immigration rates, interactions between humpback chub and rainbow trout, other predation studies).

ACTION TRIGGERS BACKGROUND AND RATIONALE

Tier 1 Trigger Target

Adult Humpback Chub population target: 9,000

Using an age-structured mark-recapture (ASMR) model, Coggins and Walters (2009) estimated the adult population of the LCR aggregation of HBC in 2008 was approximately 7,650 fish (6,000-10,000 fish considering a range of assumed mortality rates and ageing error). Using a multi-state model, Yackulic et al. (2014) obtained point abundance estimates of adult HBC between ~11,000-13,000 from 2009 through 2012. This increase in adult abundances roughly coincides with the significant increase of adult HBC that first appeared in the LCR post-2006 (Van Haverbeke et al. 2013). We suggest a population estimate of 9,000 adult fish as a desired future conditions target. Estimates falling below 9,000 would trigger additional conservation actions to increase recruitment until the HBC population recovered to 9,000 adult fish. A 9,000 adult chub target is below the most recent estimate of ~11,000-13,000 individuals and would preclude conservation measures from being initiated immediately, but also provides a "buffer zone" above 7,000 adult fish, at which point mechanical removal is warranted, as prescribed in the 2011 high flow Biological Opinion (USFWS 2011).

LCR and mainstem (LCR aggregation) population targets: 2,000 and 7,000 adult HBC, respectively

We separate the 9,000 total adult target number into an LCR component (2,000 adults), and a mainstem Colorado River component (7,000 adults). It is estimated that ~82% of adult HBC reside in the mainstem Colorado River during the non-spawning season (Yackulic et al. 2014, p. 1015). This proportion was based on estimates obtained during September/October 2011, so this proportion would be expected to vary, possibly considerably, on an annual basis. Nevertheless, objectives to maintain 2,000 adults in the LCR and 7,000 adults in the mainstem during the non-spawning season (i.e., September/October) are proposed. A desired target of 2,000 adults in the LCR is reasonable because the average fall population estimate for adults was 2,380 (SE = 518) from 2007-2014, compared to the average level of 789 adults (SE = 281) from 2000-2006 (Van Haverbeke et al. 2015).

LCR Humpback Chub recruitment target

To maintain a population of 2,000 adult HBC in the LCR during the non-spawning season, there must be sufficient recruitment of sub-adult chub (150-199 mm size class). We estimate that a sub-adult chub population of 1,250 fish annually, as measured during the annual spring spawning season in the LCR is sufficient to maintain the adult HBC target population. This number is derived from an assumption that the annual adult mortality rate in the LCR is estimated at 0.35 (Yackulic et al. 2014, updates Yackulic pers. com). Hence 2,000 x 0.35 = 700 new adults needed annually to replace adult mortality. To annually recruit 700 adults, we estimate that 1,250 sub-adults are annually needed (i.e., not all sub-adults will survive into adulthood). If annual mortality for sub-adults in the LCR is 0.44 (Yackulic et al. 2014, updates Yackulic pers. com.), then 700/(1-0.44) = 1,250 sub-adults needed to offset adult mortality. Hence, if the three-year

running average point population size of sub-adult chub measured during the spring season in the LCR drops below 1,250 fish, additional conservation measures would be triggered (Figure 1).

A three-year running average is used for sub-adults because production of younger life stages of HBC can be highly variable (Van Haverbeke et al. 2013). For long-lived species such as HBC, reduced recruitment of sub-adults in any one year can be compensated in subsequent years with increased recruitment. Three years is considered a reasonable timeframe from which to trigger actions to minimize large changes in adult HBC numbers.

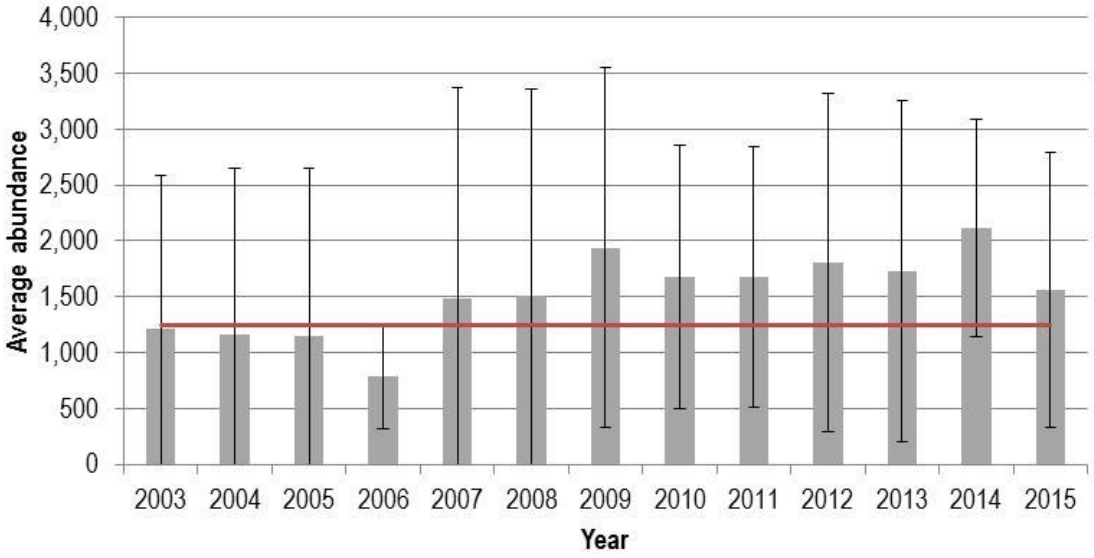

Figure 1. Running three year averages (± 95% CI) of sub-adult humpback chub abundances based on closed spring mark-recapture studies in the Little Colorado River (Van Haverbeke et al. 2013, 2015). For example, the bar for 2003 represents the average abundance of the 150-199 mm size class of humpback chub for 2001, 2002 and 2003 obtained in the Little Colorado River during spring monitoring (note: error bars are large because of typically large annual variability in the abundance of this size class). Additional conservation measures would have been triggered during 2003-2006. The red line represents a trigger value of 1,250 sub-adults, below which conservation measures would be initiated.

Mainstem LCR aggregation recruitment target

To maintain a population of 7,000 adults in the mainstem LCR aggregation reach outside of the spawning season, there must be sufficient recruitment of sub-adult fish (150-199 mm size class). The boundaries of the LCR aggregation in the mainstem traditionally extend from RM 57 (Malagosa Crest) to 65.9 (Lava-Chuar Rapid)(Valdez and Ryel 1995). Since 2009, most mainstem monitoring efforts in the LCR aggregation reach have focused in the JCM (Juvenile Chub Monitoring) reach (RM 63.45-65.2), which is below the LCR and contains ~18% of the adult HBC population found in the mainstem LCR aggregation reach (Yackulic et al. 2014). If ~18% of the population is in the JCM reach, then the desired number of adult chub to maintain in the JCM reach is 7,000 x 0.18 = 1,260 adults. Annual adult mortality in the mainstem LCR aggregation is estimated at 0.15 (Yackulic et al. 2014, updates Yackulic pers. com.). To replace the adults in the JCM reach each year would require 1,250 x 0.15 = 189 adults. Annual mortality of sub-adult chub in the mainstem is estimated at 0.3. Replacing 189 adults annually would require 189/(1-0.3) = 270 sub-adults. Approximately 1/3 of sub-adult chub grow to adult size each year, and accordingly it may take ~3 years1 for a chub in the mainstem to transition from

the sub-adult to the adult size class (Yackulic et al. 2014). Therefore an acceptable target population of sub-adults in the JCM reach each year would be 810 (270 x 3 = 810). As with the LCR component, a running three year average of <810 sub-adults in the JCM reach would trigger conservation actions (Figure 2).

The above scenario assumes that population recruitment dynamics are operating more or less equally throughout the LCR aggregation reach in the mainstem, which is likely not true. Most juvenile chub exiting the LCR are displaced downriver from the confluence (Valdez and Ryel 1995). As such, we might expect that recruitment into adulthood might be more prevalent downstream of the confluence. As such, the proportional number of sub-adults measured in the JCM reach may not reflect the number actually needed to annually replace a total 7,000 adults. In other words, the JCM reach proportional calculation of 810 sub-adults could be low. For example, consider that if the JCM reach harbors a higher than average percent of the mainstem sub-adult chub that recruit into adulthood, then even more than 810 sub-adults in this reach may be needed to maintain a population of 7,000 adults.

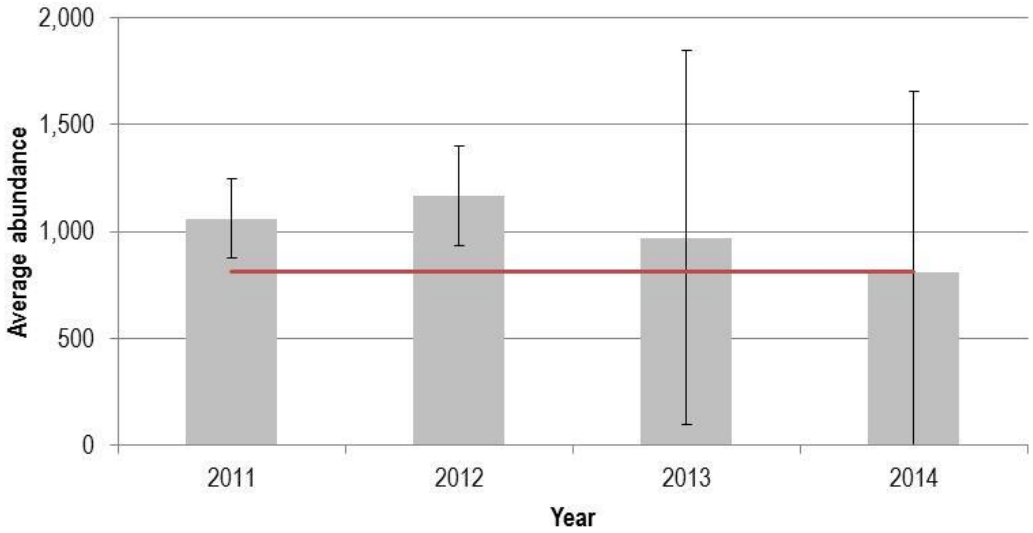

Figure 2. Running three year average abundances (± 95% CI) of sub-adult humpback chub (150-200 mm) abundances based on multi-state model in the mainstem Colorado River in the Juvenile Chub Monitoring reach (data from Yackulic pers. com.). For example, the bar for 2014 represents the average abundance of sub-adult humpback chub in the Juvenile Chub Monitoring reach during 2012, 2013, and 2014. The red line represents the approximate value of a 3-year running average of 810, below which conservation actions would be enacted.

[1]The mainstem LCR population recruitment scenario assumes temperature in the LCR mainstem reach is suitable for growth. If LCR mainstem temperatures are cold (do not exceed 11 oC during the year in the JCM reach), HBC will take longer to reach adulthood, experience greater mortality, and therefore require a larger number of sub-adults targeted to maintain the adult population objective. Target number adjustments will be made prior to implementation of LCR mainstem trigger actions if thought necessary.

Tier 1 Trigger response – HBC Conservation
It is expected that the conservation actions proposed below will assist in ameliorating HBC adult losses or recruitment failures from predation. First, ongoing translocations in the LCR above Chute Falls (~300 fish/year) as well as outside the LCR population (e.g., to Havasu Creek, etc.) will continue, regardless of Tier 1 triggers are met or not. New conservation actions will include expansion of existing activities coupled with experimental actions:

- LCR - Expand translocation actions in the LCR by collecting an additional 300-600 young of the year (YOY) HBC and move to above Chute Falls in October.

- LCR - Assess efficacy of transporting larval HBC (April/May) into Big Canyon and above Blue Springs in the LCR system. Evaluate growth and survival of these transplants;

- Mainstem LCR Aggregation - Larval fish will be removed from LCR (April/May) and head-started at Southwest Native Aquatic Resources and Recovery Center (SNARRC). Once fish reach 150-200 mm they will be translocated to the mainstem LCR reach the following year (currently grow-out space at SNARRC is limited to 750 HBC, use of fish for this purpose would reduce numbers available for other actions, e.g. Havasu, Shinumo.);

- Additional conservation actions as identified and evaluated.

Tier 2 Trigger Targets

Aquatic Predator index
A trout or aquatic predator index is proposed as a means to terminate mechanical removal should it become initiated. Essentially, this is the level (60 predator index fish/km in the JCM reach) at which mechanical removal becomes a futile exercise (i.e., very small return for a high amount of effort). The predator index concept was originally intended to serve as an index whereby mechanical removal would be initiated (e.g., mechanical removal would be initiated once trout levels reached a certain density (~760 index fish/km in the JCM reach). However, because of uncertainty of the actual predation rates of trout on HBC (at differing temperatures, densities, turbidities, etc.), and on its population level effects on HBC, determining an appropriate density of trout at which to initiate mechanical removal is highly uncertain.

A predator index will be developed in the JCM reach to weigh each probable predator by its ability to prey on HBC. The index calculates predator densities by incorporating additional species besides rainbow trout and makes assumptions about their relative predation rates compared to rainbow trout. For example, brown trout are estimated to be about 17 times more predacious on HBC than rainbow trout (Ward and Morton-Starner 2015). Additional predators (e.g., smallmouth bass) could be included through an assignment of their piscivory level relative to rainbow trout. Thus, relative piscivory can be captured in a rainbow trout equivalent predator index (Table 1). For species for which population estimates cannot be estimated with mark/recapture methods, capture probabilities or relative abundance (e.g. catch per unit effort) will be used to estimate the population and incorporate into the density matrix. Also, for certain

species regarded as potentially very piscivorous and dangerous (e.g., small mouth bass, green sunfish), targeted removal efforts for these species may be initiated immediately, regardless of meeting any type of threshold. If initiated, mechanical removal would be terminated once the relative predator index declines to 60 in the JCM reach for two years or HBC recover to a target level. A predator index of 60 in the JCM reach likely represents a point at which there is very diminished return for effort expended, and is roughly equivalent to densities at which mechanical removal was deemed to be not worthwhile as an effective tool to pursue in the past (i.e., mechanical was terminated).

Table 1. Hypothetical predator index. The predator index assigns a relative piscivory rate of 17 to brown trout (Ward and Morton-Starner 2015) and to smallmouth bass (assumed at brown trout rate) and sums the hypothetical numbers of fish. If initiated, mechanical removal would be terminated once the relative predator index declines to 60 in the JCM reach for two years or HBC recover to a target level.

Species	Number	Relative predation factor	RBT equivalent
Brown Trout	21	17	357
Rainbow trout	400	1	400
Smallmouth Bass	1	17	17
Predator index total			774

HBC population level triggers
Continue to use the existing adult HBC population estimate of 7,000, as the trigger for predator removal actions, as stated in the 2011 Biological Opinion (USFWS 2011). Population estimates of sub-adults are not incorporated in Tier 2 triggers, as in Tier 1 triggers.

Tier 2 Trigger response – Threat Reduction.
Mechanical removal of predators from the LCR aggregation reach (& immediate vicinity) will be conducted.

TRIGGER CAVEATS

- If HBC decline and the identified actions are not working, USFWS, in coordination with action agencies and traditionally associated Tribes, will identify future appropriate actions;

- Triggers will be reviewed and modified as necessary (evaluated; new information considered and included; etc.), but no less than every five years;

- Actions and triggers will need to adapt if HBC are found to be impacted by other factors;

- If estimating abundances of small size classes of chub becomes problematic because of population decline (i.e., if numbers get so low capture probability cannot be estimated for

each trip), catch divided by the best estimate of capture probability will be used to estimate abundance.

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APPENDIX P:

HIGH-FLOW EXPERIMENT PROTOCOL FOR THE PREFERRED ALTERNATIVE

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APPENDIX P:

HIGH-FLOW EXPERIMENT PROTOCOL FOR THE PREFERRED ALTERNATIVE

High-volume dam releases for sediment conservation are an experimental action that would be implemented under the preferred alternative (Alternative D) of the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP). Implementation of high-flow experiments (HFEs) under the preferred alternative would follow the HFE protocol described below for the overall process of implementation of HFEs, including implementation considerations and conditions that would result in discontinuing specific experiments.

HFE releases are restricted to limited periods of the year when the highest volumes of sediment are most likely available for building sandbars. Water year releases would follow the pattern identified for the preferred alternative as adopted by the Secretary of the Interior in the LTEMP Record of Decision (ROD) and the Long Range Operating Criteria (LROC) as currently implemented through the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). Sediment-triggered HFEs may be made in spring (March or April) or fall (October or November) (Figure P-1). Fall Extended HFEs duration would range from less than 1 hr to 250 hr. Spring and fall HFEs which are not Extended HFEs, would have a duration range from less than 1 hr to 96 hr. Proactive HFEs may be made in spring or early summer (April, May or June), and would have a duration range up to 24 hr. HFE magnitude would range from 31,500 cfs to 45,000 cfs. Frequency of HFEs would be determined by tributary sediment inputs, annual release volumes, resource conditions, and the decision process carried out by the Department of the Interior (DOI) (Sections 2.2.4.3 and 2.2.4.4 of the EIS). Extended-duration fall HFEs are limited to a frequency of 4 times total in a 20 year period.

The HFE protocol uses a "store and release" approach for sediment-triggered HFEs, in which sediment inputs are tracked over two accounting periods, one for each seasonal HFE: spring (December through June) and fall (July through November) (Figure P-1). In addition, the HFE protocol can trigger proactive spring HFEs that would be tested only in years with high annual water volume (i.e., ≥10 maf) when no sediment-triggered HFE occurs. Implementation of an HFE may require reallocating water from other months in order to maintain flows above the required minimum (i.e., 5,000 to 8,000 cfs). The protocol would implement the maximum possible magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling.

P.1 DECISION-MAKING PROCESS

The HFE protocol is a decision-making process that consists of three components: (1) planning, (2) modeling, and (3) decision and implementation. The following three subsections describe each of these components.

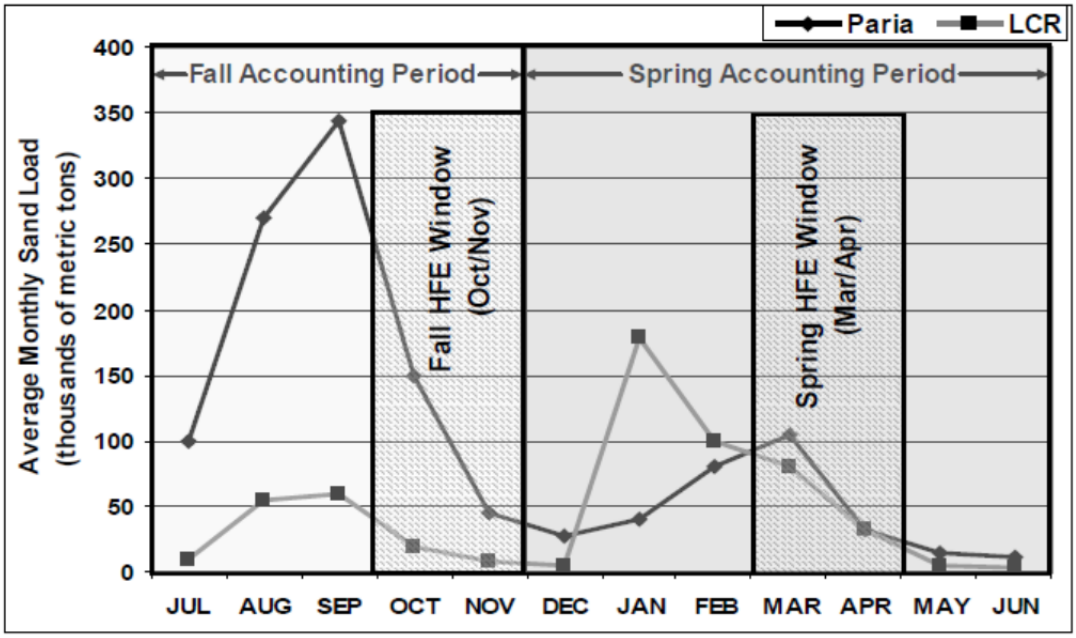

FIGURE P-1 Average Monthly Sand Load from the Paria River and Little Colorado River Showing the Fall and Spring HFE Accounting Periods and Implementation Windows

P.1.1 Planning

The first component of the HFE protocol is planning. An important aspect of planning is the development and implementation of research and monitoring activities appropriate to monitor the effects of the HFEs. The Bureau of Reclamation (Reclamation) would be prepared to conduct an HFE if resource conditions are suitable, there is sufficient sediment input or projected annual release to trigger an HFE, and DOI determines conditions are suitable for proceeding. An annual process prior to a decision on conducting experiments, including an HFE, would evaluate the information on the status and trends of the following resources: (1) water quality and water delivery, (2) humpback chub, (3) sediment, (4) riparian ecosystems, (5) historic properties and traditional cultural properties, (6) Tribal concerns, (7) hydropower production and Western Area Power Administration's (WAPA's) assessment of the status of the Basin Fund, (8) the rainbow trout fishery, (9) recreation, and (10) other resources. Although these resources are listed for consideration on a regular basis, DOI intends to retain sufficient flexibility in implementation of HFEs to allow for response to unforeseen circumstances or events that involve any other resources not listed here. The recent discovery of nonnative green sunfish in the Glen Canyon reach illustrates the need to be responsive to unforeseen conditions.

In implementing HFEs and other experiments, the DOI will exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. As an initial platform to discuss potential future experimental actions, the DOI will hold Glen Canyon Dam Adaptive Management Program (GCDAMP) annual reporting meetings for all interested stakeholders; these meetings

will present the best available scientific information and learning from previously implemented experiments and ongoing monitoring of resources. As a follow up to this process, the DOI will meet with the GCDAMP Technical Work Group (TWG) to discuss the experimental actions being contemplated for the year.

The DOI also will conduct monthly Glen Canyon Dam operational coordination meetings or calls with the DOI bureaus (U.S. Geological Survey [USGS], National Park Service [NPS], Fish and Wildlife Service [FWS], Bureau of Indian Affairs [BIA], and Reclamation), Western Area Power Administration (WAPA), Arizona Game and Fish Department (AZGFD), and representatives from the Basin States and the Upper Colorado River Commission (UCRC). Each DOI bureau will provide updates on the status of resources and dam operations. In addition, WAPA will provide updates on the status of the Basin Fund, projected purchase power prices, and its financial and operational considerations. These meetings or calls are intended to provide an opportunity for participants to share and obtain the most up-to-date information on dam operational considerations and the status of resources (including ecological, cultural, Tribal, recreation, and the Basin Fund). One liaison from each Basin State and from the UCRC will be allowed to participate in the monthly operational coordination meetings or calls.

P.1.2 Modeling

Mathematical models are used to make recommendations for future sediment-triggered HFEs using contemporary sediment data and forecasted hydrologic data to determine whether suitable sediment and hydrology conditions exist for a sediment-triggered HFE.

The two basic inputs for the modeling are the water input or hydrology, which is taken from the Colorado River Simulation System (CRSS) (Reclamation 1988, 2007b) and the sediment input, which in this case is restricted to inputs from the Paria River. A flow routing model (Wiele and Smith 1996) is used to simulate water passing downstream. A sediment budget model (Wright et al. 2010) is used to integrate the flow routing with the sediment inputs and outputs to determine whether or not a sediment mass balance is achieved for sediment-triggered HFEs (Russell and Huang 2010).

The sand budget is the net amount of sand in metric tons that has accumulated in the river channel over some period of time. In the Paria River, the two primary sand input periods are July through October and January through March (Figure P-1). During these two periods, sand is being accumulated at a higher rate than in other months. In order to accommodate the decision process and to address other resource needs or concerns, the sediment-triggered HFE windows are two-months long (October–November and March–April).

The sand budget model would use the sediment inputs and estimates the outputs for three river reaches where sand is tracked: (1) Lees Ferry/Paria River (RM 0) to RM 30, (2) RM 30 to Little Colorado River (RM 61), and (3) Little Colorado River to RM 87. The first two reaches would be used to estimate the maximum possible magnitude and duration of an HFE that will not create a negative sand mass balance in Marble Canyon (RM 0 to RM 61).

Hydrologic data for implementation would be based on forecasted monthly inflow volumes from the National Weather Service's Colorado Basin River Forecast Center and Reclamation's 24-month study projected storage conditions. The 24-month study computer model projects future reservoir conditions and potential dam operations for the system reservoirs given existing reservoir conditions; inflow forecasts and projections; and a variety of operational policies and guidelines. Monthly volumes would be apportioned to daily dam releases by WAPA. Water supply forecasts and models would be needed to make these projections and uncertainty associated with these projects would need to be considered in the decision-making process (Grantz and Patno 2010). The sediment data used would be real-time accumulated inputs estimated from the Paria River streamflow gages.

Sand availability at the onset of each release window is determined by the amount of sand received from the Paria River during the accumulation period less the amount transported downstream to the Little Colorado River as estimated by the sand routing model. Sand in Grand Canyon received from the Little Colorado River is viewed as an added benefit to the amount received from the Paria River. The Little Colorado River input cycle largely follows the same accrual periods as the Paria River; however, only sand inputs from the Paria River would be used in HFE modeling recommendations.

Each run is evaluated against 16 different HFE magnitudes and durations to determine their possible occurrence in the sediment-triggered HFE window months (Table P-1). The magnitude and duration of an HFE would be determined from the stored sand mass available on October 1 and March 1 of each water year, and the forecasted hydrology. The model evaluates each of the 16 sediment-triggered HFE types sequentially starting with the highest magnitude and duration of release. For example, the initial run determines if there is enough sediment available to achieve a positive sand mass balance in Marble Canyon for a release of 45,000 cfs for 250 hours. A positive sand mass balance is defined as a condition in which the amount of sediment being delivered by tributaries into the system exceeds the amount being exported from the system by ongoing dam operations and HFEs in the accounting period under consideration.

If the model run concludes that enough sediment is not available to achieve a positive sand mass balance, the next lower magnitude or duration sediment-triggered HFE is evaluated by the model. This is repeated until a sediment-triggered HFE scenario is reached that can be implemented with the available sediment or it is determined that a sediment-triggered HFE cannot be implemented. If it is determined that a sediment-triggered HFE cannot be implemented and the projected annual volume is greater than or equal to 10 maf, a proactive spring HFE would be triggered.

TABLE P-1 List of HFEs Available for Sediment-Triggered Experiments (fall, extended-duration fall and spring) under the Preferred Alternative

HFE ID	Peak Discharge (cfs)	Duration at Peak (hours)
1	45,000	250
2	45,000	192
3	45,000	144
4	45,000	96
5	45,000	72
6	45,000	60
7	45,000	48
8	45,000	36
9	45,000	24
10	45,000	12
11	45,000	1
12	41,500	1
13	39,000	1
14	36,500	1
15	34,000	1
16	31,500	1

The modeling component is based on four key analysis phases associated with the two sand budget accounting periods and the two sediment-triggered HFE windows:

- Phase 1: Fall Accounting Period. The fall accounting period is from July 1 to November 30. Beginning on July 1 of each year, monitoring data would be used to track the sand storage from Paria River inputs in Marble Canyon.

- Phase 2: October-November HFE Window. Beginning October 1, sand storage and forecast hydrology would be evaluated using the sediment budget model to determine whether conditions are suitable for an HFE. The model determines what magnitude and duration of the HFE, if any, would produce a positive sand mass balance at the end of the accounting period. If the model produces a positive result, the largest HFE that would result in a positive sand mass balance is forwarded to the decision and implementation component (see below), which also allows for other factors to be considered in the planning process (see Section P.1.1). During the decision process, sediment input would continue to be measured, the model would continue to be run and results or output would be forwarded to decision-makers to allow for refinement of the previously recommended magnitude and duration of the HFE. If the model produces a negative result, the model would be rerun using more recent sediment input to determine whether a positive sand mass balance would be reached in time to have an HFE in the release window.

- Phase 3: Spring Accounting Period. The spring accounting period is December 1 to June 30. As with the fall accounting period, monitoring data would be used to track the sand storage conditions in Marble Canyon during this time period. This accounting would be conducted regardless of whether or not a previous October or November HFE was conducted such that two HFEs could theoretically occur in the same year. The exception to this would be following an extended-duration fall HFE, as there would be no spring HFE following an extended-duration fall HFE. The accounting would continue to consider sand storage conditions present at the end of Phase 2, whether or not an HFE has occurred.

- Phase 4: March-April sediment-triggered HFE Window. The evaluation in this phase is the same for the October-November HFE window (see Phase 2) with the model output being forwarded to the decision and implementation component. The model output would be used in the same way as for the October-November determination. Whether or not a spring HFE is scheduled, sediment inputs would continue to be monitored through the end of the spring accounting period for use in the next accounting period. Note that proactive spring HFEs (see Section P.3.2), which are triggered by water volume and not sediment inputs, could occur in April, May, or June. In addition, spring HFEs would not be tested in years when there had been an extended-duration fall HFE earlier in the same water year.

P.1.3 Decision and Implementation

The third component of the HFE protocol is decision and implementation. This component could span a portion or most of the HFE window, depending on when conditions are deemed suitable for an HFE. The output from the model runs described above is used to determine if sediment and hydrology conditions are suitable for an HFE of a given magnitude and duration. For example, if the scenario that is identified by the model cannot be implemented because of facility limitation (e.g., if one or more turbines are out of service), managers would assess the need to modify the range of magnitude and duration of the HFE. Because this EIS has considered the effects of 45,000 cfs HFEs for 1 to 250 hours, it also serves to analyze the effects of HFEs at lower magnitudes and equivalent durations.

Because the model only considers water and sediment, an added purpose of the decision and implementation component is to consider potential effects on other resources. To determine whether conditions are suitable for implementing or discontinuing HFEs, the DOI will schedule implementation meetings or calls with the DOI bureaus (USGS, NPS, FWS, BIA, and Reclamation), WAPA, AZGFD, and one liaison from each Basin State and from the UCRC, as needed or requested by the participants. The implementation group will strive to develop a consensus recommendation to bring forth to the DOI regarding resource issues as detailed at the beginning of this section as well as including WAPA's assessment of the status of the Basin Fund. The Secretary of the Interior will consider the consensus recommendations of the

implementation/planning group, but retains sole discretion to decide how best to accomplish operations and experiments in any given year pursuant to the ROD and other binding obligations.

DOI also will continue separate consultation meetings with the Tribes, AZGFD, the Basin States, and UCRC upon request, or as required under existing RODs.

If the decision is made to conduct an HFE, staff of the USGS's Grand Canyon Monitoring and Research Center (GCMRC) would prepare to conduct monitoring and research in cooperation with other agencies. If not, the process would be repeated during the next accounting window. For each HFE, GCMRC staff would analyze results and integrate information from other HFEs for use in future HFE decisions.

The decision process could result in a sediment triggered HFE being considered whether or not a positive sand mass balance is projected for that release, since the decision must be made in advance of the actual sediment-triggered HFE release and there is an admitted uncertainty in the modeled forecast for both sediment input and dam releases. Caution would be exercised; however, because the sand mass balance only accounts for the difference between inputs and outputs, and does not adequately portray the erosion of sand in the river channel. Successive HFEs or intervening periods of erosion without HFEs could negatively affect the ability of future HFEs to form sandbars and beaches. Furthermore, this erosion could impact other resources and it is advisable to ensure that the net amount of sand in the river channel not be depleted so as to compromise other ecosystem components and functions. The output of the model would be integrated with an assessment of the status and trend of other resources, as an acknowledgement that the decision cannot be focused solely on the condition of the sediment to ensure that the decision encompasses the impacts on the resources identified above in P-1.1.

P.2 OPERATION OF GLEN CANYON DAM UNDER THE HFE PROTOCOL

The scenarios considered below describe how Reclamation would modify the operation of Glen Canyon Dam to reallocate monthly volumes when necessary to achieve HFEs as called for under this protocol. Implementation of the protocol will be done in concert with coordinated river operations. Since 1970, the annual volume of water released from Glen Canyon Dam has been made according to the provision of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (LROC) that includes a minimum objective release of 8.23 maf.

The 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Power and Lake Mead (Reclamation 2007a) for lower basin shortages and the coordinated reservoir operations (Reclamation 2007b) implements relevant provisions of the LROC for an interim period through 2026. This allows Reclamation to modify these operations by allowing for potential annual releases both greater than and less than the minimum objective release under certain conditions. A more thorough description of Reclamation's process for determining and implementing annual release volumes is available in the 2007 EIS and Record of Decision (Reclamation 2007a and 2007b).

Pursuant to the 2007 Colorado River Interim Guidelines, the annual release volume from Lake Powell is projected and updated each month in response to the monthly 24-month study model run. This projected annual release volume is allocated to produce projected monthly release volumes and becomes the basis for scheduled monthly releases from Glen Canyon Dam. It is important to note that, regardless of the timing of releases, implementation of the HFE protocol would not affect annual release volumes.

HFEs could require more water than what is scheduled for release through the coordinated operation process described above. In order to perform these HFEs, reallocation of monthly releases from Glen Canyon Dam may be necessary. Monthly reallocations for an HFE would not affect annual release volumes.

P.2.1 Potential Operation of Glen Canyon Dam during the Fall HFE Implementation Window

Reclamation would attempt to implement fall HFEs by lowering the remaining days within the fall HFE period to the degree practicable up to as low as allowed under the LROC and LTEMP ROD in order to release the projected October and November volumes in the 24-month study. If a fall high-HFE could be achieved within the release volumes projected for October and November, no reallocation of the monthly volumes from other months would need to be performed.

If, however, a fall HFE could not be achieved within the release volumes projected for October and November, Reclamation would reduce the projected monthly release volumes as necessary through the remainder of the water year. The reallocation would be determined in consultation with WAPA to minimize adverse impacts on hydropower. Reallocation would only be conducted up to the amount necessary to result in the projected monthly volume for October and November being sufficient to conduct the HFE.

P.2.2 Potential Operation of Glen Canyon Dam during the Spring HFE Implementation Window

Reclamation would attempt to achieve spring HFEs by lowering the remaining days within the spring HFE period to the degree practicable up to as low as allowed under the LROC and LTEMP ROD in order to release the projected March and April volumes in the 24-month study. If the sediment-triggered spring HFE could be achieved within the release volumes projected for March and April, no reallocation of the monthly volumes from other months would need to be performed. Note that proactive spring HFEs (see Section P.3.2) would not require reallocation of water outside of the month in which they occurred because they would be 24 hours or less in duration.

If, however, Reclamation determined that it would not be possible to achieve the sediment-triggered HFE within the monthly release volumes projected for March and April, Reclamation would reduce the projected monthly release volumes as necessary through the

remainder of the water year. The reallocation would be determined in consultation with WAPA to minimize adverse impacts on hydropower. The reallocation process would only be conducted up to the amount necessary to result in the projected monthly volume for March and April being sufficient to conduct the sediment-triggered HFE. If additional reallocation of the monthly volumes is required to achieve the sediment-triggered HFE, Reclamation would attempt to do so while maintaining the projected July and August release volumes in the 24-month study.

P.3 HIGH FLOW EXPERIMENTS TO BE EVALUATED UNDER THE PREFERRED ALTERNATIVE

Sediment-related experiments under the preferred alternative include (1) sediment-triggered spring and fall HFEs up to 96-hr duration; (2) short-duration (24-hr) proactive spring HFEs in high-volume equalization years (>=10 maf) prior to equalization releases; and (3) implementation of up to four extended-duration (>96 hr) HFEs, up to 250 hr long, depending on sediment conditions. The pattern of transferring water volumes from other months to make up the HFE volume would be discussed in the monthly Glen Canyon Dam operational coordination meetings described in Section P.1.

If sediment resources are stable or improving, the combination of base operations, HFEs, and other treatments would continue as prescribed for the preferred alternative. If sediment resource conditions decrease to unacceptable levels during the LTEMP period, operations may be modified to the extent allowable under the LTEMP ROD or would be evaluated and considered under a separate NEPA process, potentially including additional studies of sediment augmentation or other actions.

For all sediment experiments, testing would be modified or temporarily or permanently suspended if (1) experimental treatments were ineffective at accomplishing their objectives, or (2) there were unacceptable adverse impacts on resources. Monitoring results would be evaluated to determine whether additional tests, modification of experimental treatments, or discontinuation of experimental treatments were warranted.

Implementation of HFEs would consider resource condition assessments and resource concerns using the annual processes described in Sections P.1. HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section P.1. In addition, there is uncertainty associated with cumulative impacts from sequential HFEs. These cumulative impacts would be considered before implementing an HFE.

P.3.1 Sediment-Triggered Spring HFEs

Under the preferred alternative, sediment-triggered spring HFEs would be implemented after an initial 2-year delay in order to enable testing of the effectiveness of trout management flows and address concerns raised by the apparent positive response of trout to the 2008 spring HFE (Korman et al. 2011; Melis et al. 2011). After the first 2 years of the LTEMP period, spring HFEs would be implemented when triggered by sediment conditions, except in water years when

an extended-duration fall HFE (see description in Section P.3.4) was conducted. Modeling indicates that there may be sufficient sediment input for spring HFEs in about 26% of the years in the LTEMP period. Sediment-triggered spring HFEs would be implemented when triggered during the entire LTEMP period unless new information indicated they were not effective in building sandbars, or there were unacceptable adverse effects on resources (Section P.1).

Implementation of sediment-triggered spring HFEs would consider resource condition assessments and resource concerns using the processes described in Section P.1. Spring HFEs may not be tested when there appears to be the potential for unacceptable adverse impacts on the resources listed in Section P.1. In addition, there is uncertainty associated with the cumulative impacts of sequential HFEs on sediment, aquatic, and potentially other resources. These cumulative impacts would be considered before implementing a spring HFE particularly if a fall HFE had been implemented in the same water year.

P.3.2 Proactive Spring HFEs

GCMRC scientists identified proactive spring HFEs as a potential experimental treatment to transport and deposit in-channel sand at elevations above those of equalization flows. Proactive spring HFEs would be tested only in years with high annual release volume (i.e., ≥10 maf). A first test would be a 24-hr 45,000-cfs release conducted in April, May, or June. Duration in subsequent tests could be shortened depending on the observed effects during the first tests. It would be preferable to test proactive spring HFEs at least two to three times in the 20 year LTEMP period, but being able to do so will be dependent upon annual hydrology. Modeling indicates that proactive spring HFEs would be triggered in about 10% of the years in the LTEMP period.

Proactive spring HFEs would not be tested in the first 2 years of the LTEMP. In addition, proactive spring HFEs would not be tested in years when there had been a sediment-triggered spring HFE or an extended-duration fall HFE earlier in the same water year. Proactive spring HFEs could be performed in the same water year as a 96-hr or shorter sediment-triggered fall HFE, although prior to implementation, the potential effects of these HFEs would be carefully evaluated using the processes described in Section P.1. The first test would be carefully evaluated to determine whether additional tests were warranted based on the efficacy of building and maintaining sandbars. If initial tests show positive results without unacceptable adverse effects on the resources listed in Section P.1, proactive spring HFEs would be implemented when triggered during the entire LTEMP period.

Implementation of proactive spring HFEs would consider resource condition assessments and resource concerns using the processes described in Section P.1. Proactive spring HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources identified in Section P.1. The cumulative impacts of sequential HFEs would be considered before implementing a proactive spring HFE.

P.3.3 Sediment-Triggered Fall HFEs

Under the preferred alternative, sediment-triggered fall HFEs could be implemented throughout the 20-year LTEMP period unless new information indicated fall HFEs were not effective in building sandbars, or there were unacceptable adverse effects. Modeling indicates fall HFEs would be triggered in about 77% of the years in the LTEMP period.

Implementation of sediment-triggered fall HFEs would consider resource condition assessments and resource concerns using the processes described in Section P.1. Fall HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section P.1. The cumulative impacts of sequential HFEs would be considered before implementing a sediment-triggered fall HFE.

P.3.4 Extended-Duration Fall HFEs

The HFE EA (Reclamation 2011) had a limit of 96-hr duration HFEs at various release levels. Under the preferred alternative, sediment-triggered fall HFEs with durations longer than 96 hr (up to 250 hr) would be tested. The duration of these extended-duration fall HFEs would be based on the amount of sediment delivered from the Paria River during the fall accounting period and would be no more than the maximum magnitude and duration of HFE that would achieve a positive sand mass balance in Marble Canyon, as determined by modeling. Based on examination of the observed historical sediment input from the Paria River, it was determined that HFEs up to 10.4 days in length (250 hr) could be supported before exhausting seasonal sediment inputs and affecting water delivery requirements. GCMRC scientists have suggested that increasing the duration of HFEs when sediment supply can support a longer duration may lead to more sand being deposited at higher elevations, resulting in bigger sandbars. Modeling indicates the sediment trigger for this treatment may be reached in 25% of the years in the LTEMP period. There would be no more than four extended-duration fall HFEs allowed over the 20-year LTEMP period.

The duration of the first implementation of an extended-duration HFE would be limited to no more than 192 hr (twice as long as the 96-hr limit). This duration is considered long enough to produce a measurable result if the treatment represents an effective approach to building sandbars under enriched sediment conditions. The duration of all tests would be based on available sediment, current hydrology, reviews of available information, the expert opinion of GCMRC and other Grand Canyon scientists, and consideration of potential effects on other resources listed in Section P.1. If feasible, monitoring would include real-time observations of sediment concentrations to determine if sediment deposition continues throughout the duration of the extended HFEs.

Implementation of extended-duration fall HFEs would consider resource condition assessments and resource concerns using the processes described in Section P.1. Extended-duration fall HFEs may not be tested when there appears to be the potential for unacceptable impacts on the resources listed in Section P.1. Because the effects of extended-duration HFEs on Lake Mead water quality are a concern, DOI will coordinate with relevant water quality

monitoring programs or affected agencies prior to implementing any test of extended-duration HFEs. The cumulative impacts of sequential HFEs would be considered before implementing an extended-duration fall HFE.

Another important concern that results from the large volume of water bypassed during an extended-duration HFE is water delivery. Water delivery issues would be considered before deciding to implement an extended-duration fall HFE. An extended-duration HFE would not be implemented if annual release volume would be affected. It is possible that in lower volume years there would not be sufficient water available to support an extended-duration HFE. A 250-hr extended-duration HFE would result in a monthly total release of approximately 1.2 maf. In lower volume release years (e.g., 7.0 maf or 7.48 maf), the maximum duration may be less than 250 hr. In addition, a sediment-triggered spring HFE or proactive spring HFE would not be conducted in the same water year as an extended-duration fall HFE. If an extended-duration fall HFE was triggered but not implemented for any of the reasons described above, a fall HFE 96 hr or less in duration could be implemented instead. Implementation would necessitate reducing water volume in other months of the same water year.

In order to fully test the efficacy of these longer HFEs, several replicates would be desirable in the 20 year LTEMP period. Extended-duration HFEs would be considered successful and would be continued up to a total of four times in the 20-year LTEMP period as part of an adaptive experimental treatment if there was a widespread increase in bar size relative to ≤96-hr HFEs, and if sand mass balance was not significantly compromised relative to the ability to maintain a long-term equilibrium. Extended-duration HFEs would not continue to be tested if they were not effective in building sandbars, if resulting total sandbar volumes were no bigger than those created by shorter-duration HFEs, or if unacceptable adverse impacts on resources listed in Section P.1 were observed.

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APPENDIX Q:

RESPONSES TO PUBLIC COMMENTS ON THE GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN DRAFT ENVIRONMENTAL IMPACT STATEMENT

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APPENDIX Q:

RESPONSES TO PUBLIC COMMENTS ON THE GLEN CANYON DAM LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN DRAFT ENVIRONMENTAL IMPACT STATEMENT

The U.S. Department of the Interior (DOI), through the Bureau of Reclamation (Reclamation) and National Park Service (NPS), proposes to develop and implement a Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam. The LTEMP would provide a framework for adaptively managing Glen Canyon Dam operations over the next 20 years, consistent with the Grand Canyon Protection Act of 1992 (GCPA) and other provisions of applicable federal law. The LTEMP would determine specific options for dam operations, non-flow actions, and appropriate experimental and management actions that will meet the GCPA's requirements and minimize impacts on resources within the area impacted by dam operations, including those of importance to American Indian Tribes.

On January 8, 2016, the LTEMP DEIS was filed with Region 9 of the U.S. Environmental Protection Agency (EPA); a Notice of Availability and Notice of Public Meetings were published in the *Federal Register* (81 FR 963); and an email notification of the availability of the DEIS for download from the project website (www.ltempeis.gov) was sent to approximately 600 members of the public who had signed up for notification during the scoping period. Prior to this date, the DEIS was sent to each of the Governors, Senators, and Representatives from relevant congressional districts of the seven Colorado River Basin States (Arizona, California, Colorado, Utah, Nevada, New Mexico, and Wyoming).

In addition to making the DEIS available on the public website, 84 compact disc copies of the DEIS were mailed to individuals at their request; 46 copies were picked up at public meetings held for the DEIS; and copies were made available for public review after the DEIS was published at the following locations:

- J. Willard Marriott Library, University of Utah, 295 South 1500 East, Salt Lake City, Utah 84112.
- Cline Library, Northern Arizona University, 1001 S. Knoles Drive, Flagstaff, Arizona 86011-6022.
- Burton Barr Central Library, 1221 North Central Avenue, Phoenix, Arizona 85004.
- Page Public Library, 479 South Lake Powell Boulevard, Page, Arizona 86040.
- Grand County Library, Moab Branch, 257 East Center Street, Moab, Utah 84532.
- Sunrise Library, 5400 East Harris Avenue, Las Vegas, Nevada 89110.

- Denver Public Library, 10 West 14th Avenue Parkway, Denver, Colorado 80204.

- Natural Resources Library, U.S. Department of the Interior, 1849 C Street NW, Main Interior Building, Washington, D.C. 20240-0001.

The original 90-day public comment period was extended an additional 32 days (122-day total) to May 9, 2016, after several requests were received from the public and Cooperating Agencies. During the comment period, two in-person meetings and two Internet-based webinars were held to provide the public with information about the content and findings of the DEIS and to receive written comments on the DEIS. The meetings and webinars were held on the following dates:

- Webinar—Tuesday, February 16, 2016, at 6:30 p.m. Mountain Standard Time (MST);

- Meeting—Monday, February 22, 2016, at 6:00 p.m. MST, Flagstaff, Arizona;

- Meeting—Thursday, February 25, 2016, at 6:00 p.m. MST, Phoenix, Arizona; and

- Webinar—Tuesday, March 1, 2016, at 1:00 p.m. MST.

At these meetings, LTEMP staff were available to take comments and answer questions before and after presentations were made on the DEIS.

During the public comment period, the public was encouraged to submit comments electronically through the NPS Public, Environment, and Public Comment (PEPC) website. Comments were also received, however, through the mail or using a public comment form provided at the public meetings. More than 3,000 individual comment documents were received on the DEIS.

Comments were determined to be substantive or nonsubstantive in nature. NEPA regulations require that responses be provided to substantive comments. Comments are considered substantive if they:

- Challenge accuracy of analysis

- Dispute information accuracy

- Suggest different viable alternatives

- Provide new information that makes a change in the proposal In other words, they raise, debate, or question a point of fact or policy.

Comments in favor of or against the proposed action or alternatives, or comments that only agree or disagree with co-lead agency policies, are not considered substantive. Substantive comments were summarized and are presented, along with a response, per issue or impact topic in this appendix. Substantive comments were used to make changes to the DEIS when deemed appropriate and justified. Comment issues and the pages on which responses are located are presented in Table Q-1.Commenters, their affiliation (if any), and the section(s) where responses to their substantive comments are located are presented in Table Q-3, in Section 15.

Nonsubstantive comments are comments that offer opinions or provide information not directly related to issues or impact analyses. Nonsubstantive comments have been considered by the joint leads, but do not require a formal response.

PUBLIC COMMENT SUBMITTAL METRICS

Comment documents were received from 3,035 individuals; organizations (including environmental groups and other special interest groups); Tribes, private businesses (including recreational companies) and industry; and local, state, and federal agencies. Submissions were received from all 50 states plus the District of Columbia. About 12% of the submissions were from Arizona. Most submissions were received from California, at 19%. Table Q-2 shows the percentages for the five states with the most comments. Additional states that submitted more than 100 comments included Illinois, Pennsylvania, Texas, and Washington. Over 2,900 submissions were received via the LTEMP public website, and about 30 were received via postal mail. Another 20 were submitted using a comment form distributed at the Public Meetings. One petition included approximately 400 signatures.

FORM LETTERS

Over 1,400 of the 3,035 comment letters received were submitted as form letters that included the same comment language. Ten form letters were received, with submittals numbering: 15, 17, 21, 21, 24, 24, 29, 100, 166 and >1,000. Also, as noted above, one letter, a petition to enhance the Lees Ferry rainbow trout fishery, was signed by 404 individuals. The vast majority of the form letters expressed support for the preferred alternative. The form letter with over 1,000 submittals read as follows:

"Thank you for the opportunity to provide comments on the future of the Colorado River below Glen Canyon Dam. I support the preferred management plan (Alternative D) for Glen Canyon Dam, including experimental high flow releases, for the next 20 years. The Grand Canyon's native fish, recreational experiences, and other natural and cultural resources deserve this best option. It is especially important to keep daily water release fluctuations capped at 8,000 cfs. This will help preserve natural resources that provide habitat for endangered fish and the re-building of beaches along the Colorado River. Thank you for including efforts to restore riparian vegetation, which would otherwise degrade under any of the other alternatives."

TABLE Q-1 Comment Issues and Location in the Report

1 AIR QUALITY AND CLIMATE CHANGE Q-13

1.1 Delete "negligible" because it is Subjective Q-13
1.2 Minimize Potential Impacts by Comparing Project-Related GHG Emissions with Regional Total and US Total Q-13
1.3 Consider Effects of HFE on GHG Emissions Q-13
1.4 Display Greenhouse Gas (GHG) Emissions Increase in Everyday Terms Q-13
1.5 Alternative D increases GHG Emissions, Nearly Four Times the Level Associated with Alternative A Q-14
1.6 Methane Emissions from Lake Powell that Contribute to Climate Change Q-14

2 ALTERNATIVES Q-15

2.1 EIS Does Not Comply with NEPA Q-15
2.1.1 The DEIS Did Not Evaluate All Reasonable Alternatives Q-15
2.1.2 No Alternative Featured Greatly Increased Hydropower Q-16
2.1.3 Experiments are not Adequately Defined or Analyzed Q-16
2.2 EIS Does Not Comply with ESA Q-17
2.3 EIS Does Not Comply with CRSPA Q-20
2.4 Support Alternative D Q-22
2.5 Support Alternative D with Caveats Q-22
2.6 Support Alternative B Q-25
2.7 Support Alternative A Q-27
2.8 Support Alternatives Considered but Rejected (Fill Mead First, Decommission Dam) Q-28
2.9 EIS Should Have Considered Infrastructure Additions/Modifications Q-30
2.10 Alternative D ignores (or does not meet) Hydropower Objective Q-31
2.11 EIS Did Not Consider a Full Range of Alternatives Q-32
2.12 Flows Should Not Drop Below 8,000 cfs Q-33
2.13 8,000 CFS Fluctuation Limit Q-34
2.14 EIS Did Not Adequately Consider the Effects of Climate Change Q-35
2.15 Geographic Scope of the EIS Q-36
2.16 Monitoring to Support Adaptive Management Q-37
2.17 Include a Summary of Experimental and Management Actions for the Rainbow Trout Fishery Q-37
2.18 Glen Canyon Dam Safety and Security Q-37
2.19 Experimental Uncertainty Q-37
2.20 Impacts on Basin Fund Q-38
2.21 Due Consideration of Hydropower Q-39
2.22 Support Alternative F Q-39

3 AQUATIC ECOLOGY Q-40

3.1 Alternatives Adequate Will Not Protect Colorado River Ecosystem Q-40
3.2 Impacts of Fall HFEs on Fish and Aquatic Food Base Q-40

TABLE Q-1 (Cont.)

3.1 None of the Alternatives Adequate to Change and Protect Colorado River Ecosystem ... Q-40
3.2 Impacts of Fall HFEs on Fish and Aquatic Food Base ... Q-40
3.3 Reduce Number of HFEs to Improve the Aquatic Food Base ... Q-41
3.4 Impacts of Minimum Flows Before and After HFEs ... Q-41
3.5 Provide Additional Information on Most Recent Fall HFEs ... Q-42
3.6 Support Careful Testing of TMFs ... Q-42
3.7 Quagga Mussels ... Q-43
3.8 Provide Additional/Updated Information on Aquatic Resources and Species ... Q-43
3.9 AZGFD Management Plan ... Q-44

4 CULTURAL RESOURCES ... Q-45

4.1 Applicability and Composition of Cultural Resource Metrics ... Q-45
4.1.1 Wind Transport ... Q-45
4.1.2 Time Off River ... Q-45
4.1.3 Glen Canyon Flow Effect Metric ... Q-46
4.2 Area of Potential Effects ... Q-46
4.3 Landmark Status for Grand Canyon and its Resources ... Q-46

5 CUMULATIVE IMPACTS ... Q-47

5.1 Additional Foreseeable Actions (Including Management Plans) to be Included ... Q-47
5.2 Refinement of Description and/or Impact Assessment for Foreseeable Actions Considered ... Q-47

6 HYDROPOWER ... Q-48

6.1 Scope of Analysis and Study Elements ... Q-48
6.1.1 Hydropower Goals and Objectives ... Q-48
6.1.2 Generation at Hoover Dam ... Q-48
6.1.3 Cumulative Impacts on Power Systems ... Q-48
6.1.4 Analysis of Impacts on Basin Fund ... Q-48
6.1.5 Consideration of Impacts on Basin Fund ... Q-49
6.1.6 Power System Impacts on Climate Change ... Q-49
6.1.7 Sensitivity Analysis of Fuel Prices ... Q-49
6.1.8 Clean Powerplant Legislation ... Q-49
6.2 General Overarching Comments on the Power Systems Analysis ... Q-50
6.2.1 Adequacy of Power Systems Analysis ... Q-50
6.2.2 Ratepayer Analysis Flawed ... Q-50
6.2.3 Inputs to Capital Costs Analysis ... Q-51
6.3 Legal Issues ... Q-52
6.3.1 HFEs as Part of Long-Term Operations ... Q-52
6.3.2 Irretrievable Loss of Hydropower ... Q-52
6.4 Technical Power System Issues ... Q-52
6.4.1 Discount Rate ... Q-52
6.4.2 Capital Costs ... Q-52
6.4.3 Exceedance Level ... Q-53
6.4.4 Ancillary Service Assumptions ... Q-53
6.4.5 Modeling Assumptions ... Q-54

TABLE Q-1 (Cont.)

6.4.6 Small Customer Representation Q-54
6.4.7 Small Customer Loads and Load Growth Q-54
6.4.8 System Expansion Plan Q-54
6.4.9 Transmission Constraints Q-55
6.4.10 Renewable Portfolio Standards Q-55
6.4.11 Costs of HFEs Q-56
6.4.12 Costs of Experiments Q-56
6.4.13 Impacts of Macroinvertebrate Production Flows on Hydropower Q-56
6.4.14 Effects at Hoover Dam and Glen Canyon Dam Q-56
6.5 Retail Rate Analysis Q-57
6.5.1 Consideration of Wholesale Rate Input Q-57
6.6 Wholesale Rate Analysis Q-57
6.6.1 Assumptions Q-57
6.7 Editorial Comments Q-57

7 NATURAL PROCESSES Q-58

7.1 Naturally Patterned Flow and Run-of-the-River Flow Alternatives Q-58
7.2 Remove Natural Processes from the EIS Q-58
7.3 Natural Resource Performance Goal Q-58
7.3.1 Quantitative Performance Metric Q-58
7.3.2 Goal to Restore Is Not Achievable Q-58
7.3.3 National Park Service Natural Processes Management Policy and Goals Q-59
7.4 Opportunity to Expand Non-Flow Management Options to Improve Aquatic and Riparian Habitat Q-59
7.5 HFEs Should be Included in the Evaluation of Effects to Natural Processes Q-60

8 PROCESS AND POLICY Q-61

8.1 Include THPOs in Contact List Q-61
8.2 Tribes Involvement in Alternatives Development Q-61
8.3 Sierra Club's Scoping Comments Q-61
8.4 Involvement of Cooperating Agencies and SME Teams Q-68
8.5 LTEMP Effects on Reservoir Operations Q-69
8.6 List Relevant Laws and Management Documents Q-69
8.7 Application of Structured Decision Analysis (SDA) Q-69
8.8 DOI Disclaimer Q-71
8.9 DOI Response to Comments Q-71
8.10 Comment Period Deadline Q-71
8.11 Language Regarding LROC Q-71
8.12 Description of HFE Protocol and Nonnative Fish Control Protocol for the Preferred Alternative Q-72
8.13 Conservation measures to Be Applied Under Alternative D Q-72

9 RECREATION Q-73

9.1 Note Economic Benefits of the Recreation Industry Q-73
9.2 Recreation Resource Goals Incomplete Q-73
9.3 Adopt the Goals and Objectives of the AZGFD Fisheries Management Plan Q-73

TABLE Q-1 (Cont.)

9.4 Adoption of MLFF Flows Corresponded with Degradation of the Lees Ferry Fishery Drop in Visitations Q-74

10 TRIBAL RESOURCES Q-75

10.1 Opposition to Mechanical Removal of Trout and Trout Management Flows Q-75
10.2 Lack of Tribal Representation in Development of EIS Q-75
10.3 Metric Should Not Be Used to Analyze Impacts to Cultural and Tribal Resources Q-76
10.4 Cultural Landscapes and Traditional Cultural Properties not Thoroughly Discussed Q-76
10.5 Tribal Lands and Resources on Tribal Lands Not Taken Into Consideration Q-77
10.6 Impacts to Hualapai Tourism Operations Not Thoroughly Analyzed Q-77
10.7 Tribal Perspectives on Components of the Colorado River Ecosystem Q-77
10.8 Editorial Comments Q-78

11 SEDIMENT Q-79

11.1 Concern Over Erosion of Sandbars and Beaches following High Flows (i.e., HFEs) Q-79
11.2 Spring HFEs—Uncertainty and Concern Over Impacts; More Testing Is Needed Q-79
11.3 Equalization Flows—Concern Over Increased Erosion and Higher Rate of seDiment Transport Q-79
11.4 Sediment Should Be Considered a "secondary" Resource Q-80
11.5 Concern Over Sediment Accumulation in Lake Powell and Behind the Dam Q-80

12 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE Q-81

12.1 Regional Economic Impacts Associated with Boating Visitor Expenditures Q-81
12.2 Regional Economic Impacts Associated with Angler Visitor Expenditures, in Particular Impacts of HFEs Q-81
12.3 Use Values Associated with Angling and Boating Trips Q-81
12.4 Non-Use Values Associated with Fishing Resources Q-81
12.5 Economic Impacts on Tribes Q-82
12.6 Impact on Water Provision Q-82
12.7 Regional Electric Power Economic Impacts Q-82
12.8 Economic Impacts of Activities of Confluence Partners Out of Scope of EIS Q-82
12.9 Depth of Literature review on Use Valuation in Appendix I Q-83
12.10 Mechanical Removal and Trout Management Flows Q-83

13 WATER Q-84

13.1 Consideration of Climate Change Effects Related to Water Supply Reductions, Evaporation, and Operational Levels of Lake Powell Q-84
13.2 Consideration of Climate Change Impacts on Water Availability, Increased Demand, and Greater Depletion Q-84
13.3 Influence of Tributaries and Lake Powell on Main Stem and Lake Mead Salinity Levels Q-84
13.4 Editorial Comments Q-85

14 WILDLIFE Q-86

14.1 Averting the Responsibility to Protect Native Species Q-86
14.2 HFE IMPACTS on Kanab Ambersnail Q-86

TABLE Q-1 (Cont.)

14.3 Operate Glen Canyon Dam in a Way that Protects All Wildlife (Including Listed Species) Q-87

TABLE Q-2 Commenter Distribution by State

State	Percentage
AZ	12
CA	19
CO	5
FL	5
NY	5
All others	53

The form letter with 166 submittals and the petition with 404 signatures had nearly identical language, which recommended that the LTEMP should:

- Explicitly recognize that the Lees Ferry tailwater trout fishery as priority resource "value" for which Glen Canyon Dam should be operated as provided for in the Grand Canyon Protection Act.

- Incorporate the goals and objectives of the Arizona Game and Fish Department's Fishery Management Plan for the Lee Ferry Trout Fishery as stated goals and objectives of the LTEMP.

- Fully consider the impacts of repeated fall high flow experiments on the aquatic food base, rainbow trout, and invasive species in Glen and Marble Canyons.

- Place more emphasis on conducting high flow experiments in the spring to benefit a variety of resources besides sediment/sandbars including the aquatic food base, native fish, rainbow trout and riparian vegetation.

- Test the use of sustained low steady flows (also known as "macroinvertebrate production flows") to increase the production and diversity of the aquatic insects in the Colorado River below Glen Canyon Dam.

- Carefully test the use of Trout Management Flows (TMF), but only when there is an identified need to reduce the number of young of the year rainbow trout in Lee Ferry.

The form letter with 100 submittals simply endorsed "DOI's plan to operate the Glen Canyon Dam in a way that will best protect Grand Canyon National Park." Conversely, the form letter with 29 submittals stated that the "DEIS fails to adequately analyze the impacts of climate change on the entire Colorado River water supply system" and "should have considered a wider range of reasonable alternatives that fully take climate change into account." The remaining form letters were variations on the themes of protecting the Lees Ferry trout fishery or endorsing DOI's plan. Substantive issues raised in the form letters and in individual letters submitted are addressed in the following sections.

SUMMARY OF ISSUES RAISED IN COMMENTS ON THE DEIS AND DOI'S RESPONSES

Comment letters received on the public draft of the LTEMP EIS raised substantive issues in a number of technical areas related to the analyses presented in the EIS and in non-technical areas related to the requirements of preparing the EIS under NEPA. Comments ranged from support of the preferred alternative as is, to support with qualifications, to support of other alternatives. Some commenters disagreed with the exclusion of some proposed alternatives as not meeting the purpose and need of the proposed action, including decommissioning of the dam. Other comments questioned the adequacy of the EIS under NEPA and ESA and in addressing the effects of climate change. Many comments addressed the proposed experiments that are a part of the preferred alternative and other alternatives, their triggers, their potential effectiveness, and their potential effects on other resources not targeted by the experiments. Other comments addressed the modeling conducted to analyze effects of dam operations on resources and on the metrics produced by the models to assess impacts. A number of comments concerned the effects of daily fluctuations and minimum river flows downstream of the dam resulting from dam operations under the various alternatives. Many comments addressed the use of HFEs, their timing, potential benefits and effects on hydropower generation. These and other substantive issues are outlined in the following section. Following the outline is a section that presents a summary of each issue as raised in comments and DOI's response. Finally, an index of all comment letters submitted, the names of the commenters, and their affiliation is presented following the issues and responses section.

Comment Categories, Comment Issues, and Location Where Responses are Found

Comments issues were categorized according to a number of technical and non-technical areas based on the substantive content of the letters submitted. In addition, a large number of editorial comments were received, and we have updated the text where appropriate in response to these comments. These comments refer to specific page numbers and line numbers in the DEIS. Because the overall document pagination has changed from the DEIS to the FEIS, including the specific location of each change would have limited utility and be cumbersome. Accordingly, we have not included the specific locations of each change in this Appendix. The EIS was revised appropriately to address all substantive editorial comments, to correct typographical errors, and to add specific language submitted by Tribes.

The following outline presents the comment categories, a brief description of the issues raised, and the location in the following section where each issue is summarized and DOI's response is presented.

LTEMP CONSOLIDATED ISSUES AND RESPONSES

1 AIR QUALITY AND CLIMATE CHANGE

1.1 DELETE "NEGLIGIBLE" BECAUSE IT IS SUBJECTIVE.

Summary Comment: Commenters expressed that the term "negligible" is a biased, subjective term.

Response: For emissions of SO2 and NOx presented in Section 4.15, the term "negligible" was used to describe impacts, but the actual projected emissions (in tons/yr) and percentage change relative to Alternative A also were provided. No change was made to the text. In Section 4.16, the text was edited to remove the term negligible and only the actual projected emissions of greenhouse gases (in tons/yr) and percentage change relative to Alternative A, and current conditions in the 11-state region and the United States were provided.

1.2 MINIMIZE POTENTIAL IMPACTS BY COMPARING PROJECT-RELATED GHG EMISSIONS WITH REGIONAL TOTAL AND US TOTAL

Summary Comment: Commenters expressed that the effects of increases in GHG emissions for the alternatives should be presented on a local or regional basis, and not at a national level.

Response: Text was updated to show project-related GHG emissions compared to total regional (11 states) while still retaining U.S. GHG emissions as that level is a conventional way of assessing their impacts.

1.3 CONSIDER EFFECTS OF HFE ON GHG EMISSIONS

Summary Comment: Commenters suggested that strong consideration should be given to the air emission impacts resulting from HFEs.

Response: The analysis considered the effects of HFEs on air quality in Section 4.15 and on greenhouse gas emissions in Section 4.16. The modeling results presented in these sections included HFEs in all of the alternatives.

1.4 DISPLAY GREENHOUSE GAS (GHG) EMISSIONS INCREASE IN EVERYDAY TERMS

Summary Comment: Commenters recommended that increases in GHG emissions be expressed as an equivalent mass of coal burned using the EPA's "Greenhouse Gas Equivalencies Calculator," rather than just presenting GHG emissions in metric tons.

Response: In Table 4.16-1, we added a footnote which states, "Using an online tool from the EPA (https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator), one can express a given amount of GHG emissions in MT in everyday terms. For example, 1 million MT/yr is estimated to be equivalent to the amount of CO_2 that is emitted as a result of the electricity use of 148,000 households. However, because the EPA cautions that these estimates are approximate and should not be used for emission inventory or formal carbon footprinting exercises" the authors felt it was not appropriate to report the results in this document using that conversion.

1.5 ALTERNATIVE D INCREASES GHG EMISSIONS, NEARLY FOUR TIMES THE LEVEL ASSOCIATED WITH ALTERNATIVE A

Summary Comment: Commenters noted that Alternative D, which averages more than 1 HFE per year for the 20-year DEIS period, increases GHG emissions by 22,908 metric tons per year, nearly four times the level associated with Alternative A, which is the lowest GHG-producing Alternative due to the lowest frequency of HFEs.

Response: While the commenter is correct that Alternative D increases GHG by 22,908 metric tons per year (MT/yr), the EIS analysis found that the level of emissions for Alternative A was 55,177,668 MT/yr and the level of emissions for Alternative D was 55,200,576 Mt/yr and so the difference from Alternative A would be only 0.042%.

1.6 METHANE EMISSIONS FROM LAKE POWELL THAT CONTRIBUTE TO CLIMATE CHANGE

Summary Comment: Commenters state that preliminary estimates of methane emissions from the operation of Glen Canyon Dam and Lake Powell indicate that the combined life cycle GHG equivalents may be as high as one-third of a natural gas power plant.

Response: Because no studies on GHG emissions from Lake Powell and Grand Canyon Dam have been made, GHG emissions, such as CO_2, CH_4, and N_2O, from the reservoirs were discussed qualitatively in Section 4.16.2.1. Reservoirs such as Lake Powell would be expected to produce some amount of GHG emissions consistent with levels reported for reservoirs in the semiarid Western U.S. (Tremblay et al. 2004 and http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_p_Ap3_WetlandsCH4.pdf). However, GHG emissions from these sources and associated climate change are not anticipated to be different among the alternatives.

2 ALTERNATIVES

2.1 EIS DOES NOT COMPLY WITH NEPA

2.1.1 The DEIS Did Not Evaluate All Reasonable Alternatives

Summary Comment: Citing 40 CFR 1502.14 requiring agencies to "[r]igorously explore and objectively evaluate all reasonable alternatives, and for alternatives which were eliminated from detailed study briefly discuss the reasons for their having been eliminated." Commenters stated that the LTEMP EIS process does not appear to comply with NEPA because Reclamation and NPS (i) did not objectively evaluate all reasonable alternatives, (ii) failed to assess mitigation measures regarding sediment issues, and (iii) appeared to utilize a partial decision making process.

Response: The LTEMP EIS carried forward a range of reasonable alternatives that were developed based on the input of DOI experts, Cooperating Agencies, stakeholders, Tribes and the public. Early alternative concepts were provided to cooperators and stakeholders for input and a public meeting was held on in April of 2012 to further explore and characterize those concepts. Mitigation measures within the scope of this EIS that fit the purpose and need were considered. The decision making process for this EIS conforms with the established NEPA process and considered input from the public, cooperators, stakeholders and Tribes. This NEPA document provides detailed analysis for a broad range of alternatives ranging from those proposed for ecological purposes, and those proposed by hydropower interests and focused on hydropower generation to, and those proposed to strike different a balances among all resource areas.

Alternatives F and G, the seasonally adjusted steady flow and year round steady flow alternatives were proposed by members of the public and interest groups during scoping. These alternatives were similar to ones considered in the 1996 EIS as well. These alternatives considered as part of a range of reasonable alternatives and these showed many positive and negative impacts on a variety of resources as were disclosed in the draft impact statement. The preferred alternative showed a better balance between resources to achieve the purpose and need.

Full powerplant capacity operations were considered and eliminated as an alternative as discussed in Section 2.3.10 because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose and need for this EIS. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the DEIS. The preferred alternative showed a better balance among resources to achieve the purpose and need. [519951]

DOI believes the EIS is in full compliance with NEPA regulations. The USEPA reviewed the DEIS and determined that, based on their review, rated the preferred alternative as "Lack of Objections-Adequate," the highest rating possible.

2.1.2 No Alternative Featured Greatly Increased Hydropower

Summary Comment: Commenters stated that, none of the alternatives feature greatly increased (hydropower) flexibility and that the Agencies should provide more explanation regarding why an alternative with even more daily flexibility was not considered. Others stated that the LTEMP EIS preferred alternative does not meet the renewable resource goal of NEPA Section 101 (b) 6 or the hydropower resource goal established by the DOI for the LTEMP EIS process due to restrictions on the utilization of Glen Canyon Dam for hydropower production under the preferred alternative

Response: Full powerplant capacity operations were considered and eliminated as an alternative as discussed in Section 2.3.10 because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose and need for this EIS. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the DEIS. The preferred alternative showed a better balance between resources to achieve the purpose and need.

The analysis performed in this EIS is fully consistent with both the hydropower resource goal in Section 1.4 and the goal set forth in the "policies and goals" subchapter of NEPA, including the cited goal in Section 101(b)(6). Hydropower impacts and consistency with the hydropower resource goal are discussed in Section 4.13. Regarding Section 101(b)(6) of NEPA, this is a general statutory statement that Congress that cannot be read in isolation. Instead, it must be read in connection with the Law of the River, the GCPA, and other statutory provisions specific to operations of Glen Canyon Dam. When these authorities are read together, Congress has established specific requirements for the operation of Glen Canyon Dam. This EIS considers those specific requirements and identifies a preferred alternative that meets the purpose and need and achieves an appropriate balance for meeting the objectives

2.1.3 Experiments are not Adequately Defined or Analyzed

Summary Comment: One commenter stated that Alternative D violates the requirements of NEPA because it contains experiments or other proposed actions that are not adequately defined or analyzed. Another commenter stated that "poorly defined experimental conditions, coupled with the unquantified discretion of the DOI to determine whether there are "adverse effects" on "other resources" renders the EIS legally inadequate because it does not contain the required "hard look" at the environmental and other impacts of the proposed action."

Response: The co-lead agencies feel that this NEPA process takes a comprehensive "hard look" at the proposed action and alternatives to determine whether there are "adverse effects" on "other resources" and is fully consistent with NEPA. As stated in Section 2.2.4.3, This EIS analyzed a wide range of conditions that could occur and states the potential effects in the document.

DOI disagrees with the statement that experiments or other proposed actions are not adequately defined or analyzed. Extensive detail on the costs of experiments appears in Appendix K and text was added to Section 4.13.2.3 to more fully describe effects to hydropower from all experiments. The LTEMP EIS describes experiments to be conducted under different alternatives in sufficient detail to allow for a full analysis of their effects. Extensive modeling of the effects of these alternatives on a full set of resources was conducted and formed the basis of the assessment presented in the EIS. These modeling results were supplemented with qualitative assessments of effects based on existing literature and observations. An assessment of the cumulative impacts of LTEMP alternatives in combination with other past, present, and reasonably foreseeable future impacts is presented in Section 4.17 of the EIS. GCMRC has developed a science plan that describes the information that will be gathered during implementation of the LTEMP, and how that information would be used in an adaptive management context.

The adaptive management process and triggers are adequately addressed in this NEPA document. Section 4.1 and Appendices C and K of the LTEMP DEIS have detailed information on the extensive modeling that was performed with a variety of long term strategies and referring to uncertainties explicitly. The range of adaptations are also well defined and analyzed in the EIS. Text was added between the DEIS and the FEIS to further define this and state specifically under each experiment how magnitudes, duration or frequencies of components of the experiments may change. The long term strategies were variations of the alternatives that turned various experiments "off" or "on" to model different combinations and frequencies of experiments under a variety of hydrologic inflow conditions. This extensive modeling was coupled with extensive literature review and subject matter expert input to provide thorough analysis. This is sufficient for a NEPA analysis. Additional details of experiments and monitoring will be developed through the AMP annual work plans.

DOI believes the EIS is in full compliance with NEPA regulations. The USEPA reviewed the DEIS and determined that, based on their review, rated the preferred alternative as "Lack of Objections-Adequate," the highest rating possible

2.2 EIS DOES NOT COMPLY WITH ESA

Summary Comment: Commenters stated that the LTEMP EIS does not comply with the Endangered Species Act because considered experiments, operations or management actions are quite likely to result in negative impacts to an endangered species.

(1) In addition, DOI should seek input from AMWG and TWG representatives on the draft Biological Assessment under the ongoing Species Status Assessment for HBC, which could improve and refine experimental treatments in the Preferred Alternative and clarify triggers, off ramps, monitoring and definitions of success.

(2) Further, Alternative D is incompatible with the ESA, in part because there are no binding obligations or criteria or required mitigation that protect the endangered HBC.

(3) Because the DEIS fails to define "annual implementation considerations" and "off-ramps," so nearly every experimental treatment will be undertaken unless there are "potential unacceptable impacts" on certain defined and undefined resources.

(4) A commenter stated that the failure of the DEIS to include and consider the cumulative impacts all of the HFEs, including the effects on rainbow trout recruitment and humpback chub from the 2013 and 2014 HFEs, represents a significant analytical flaw, and that it is inappropriate to consider 250 hour long HFEs due to erosion concerns.

(5) A number of people commented that the EIS did not consider or should have considered more the restoration of extirpated species and recovery implementation plans for all species known to be native to Grand Canyon prior to the operation of Glen Canyon Dam.

(6) With respect to proposed low summer flows, one commenter supports convening a panel of experts to analyze existing science on low summer flows within the first 5 years of the LTEMP period.

(7) With respect to sustained low flows for benthic invertebrate production, a commenter requested a comprehensive review of these flows by a scientific panel during the first several years of the LTEMP period to determine their cost, efficacy, and impact on native and nonnative fish.

Response: DOI has consulted with the U.S. Fish and Wildlife Service and developed conservation measures and alternative-specific experimental actions to avoid, minimize, and mitigate adverse impacts on endangered species and critical habitat potentially affected by the proposed action. The Biological Assessment is found in Appendix O in the final EIS. [519929] DOI has been consulting with FWS throughout the 5-year EIS process. The LTEMP EIS used the best available science and peer-reviewed modeling in its analysis of the effects of the proposed action and alternatives on endangered species and critical habitat.

(1) In developing the Biological Assessment for LTEMP, Reclamation convened an ad hoc group of Grand Canyon aquatic biologists from FWS, GCMRC, AZGFD, NPS, and Reclamation to develop the conservation measures, experimental actions, and trigger levels for those actions to be included in the EIS. GCMRC scientists have been involved since scoping with development of LTEMP alternatives and have provided information, research results, and expert opinions regarding the effects of the proposed action on endangered species and critical habitat throughout the EIS process. Also several Cooperating Agencies, including Tribes and Western Area Power Administration were given a chance to review the Biological Assessment and the proposed conservation measures were presented to the AMWG members at the August 2016 AMWG meeting. The Biological Assessment was updated to incorporate feedback and input resulting from these reviews.

The FWS humpback chub species status assessment that the commenter refers to is in process and will not be completed until well after the publication of the LTEMP FEIS. It is

not required to be complete for the FEIS or the record of decision, and is therefore independent of this NEPA process.

Greater specificity regarding triggers for HFE implementation and humpback chub actions have been added to the EIS (Appendices O and P).

(2) Formal consultation with FWS has resulted in a Biological Assessment and Biological Opinion on the effects of the proposed action on listed species and designated critical habitat, as presented in Appendix O of the EIS. DOI has worked closely with FWS throughout the 5-year EIS process to ensure that the appropriate experiments, dam operations, and non-flow actions were identified in the proposed action or as conservation measures. LTEMP EIS alternatives include experiments that are intended to improve conditions for ESA-listed species and other special status species. The LTEMP EIS team used the best available science and peer-reviewed modeling to determine the potential effects of these alternatives on these species.

Throughout the LTEMP DEIS drafting process, the parties to the DEIS have consistently prioritized the conservation of humpback chub and its habitat. FWS, the expert agency on endangered species issues, has been involved in the DEIS process from its inception. GCMRC scientists, who specialize in studying HBC and its habitat, have also provided valuable input regarding HBC during this process.

(3) The LTEMP EIS did consider and define "annual implementation considerations" and "off-ramps" for experiments. The implementation framework for Alternative D (Section 2.2.4.3 of the EIS) explicitly calls for the consideration of key resources (including endangered and threatened species and their designated critical habitat) when determining which experiments to conduct in any given year. The framework also establishes off-ramps that would identify when experiments should no longer be conducted if it was established there were potential unacceptable adverse impacts to endangered species and critical habitat. As described in Section 2.2.4.4, DOI will also exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. GCMRC has developed a science plan that describes the information that will be gathered during implementation of the LTEMP, and how that information would be used in an adaptive management context in order to promote the conservation of humpback chub and other species of concern.

(4) The LTEMP EIS did fully consider direct, indirect and cumulative effects of HFEs. Descriptions of the observed effects of HFEs conducted in 2012, 2013, and 2014 have been added to the EIS. The impacts of HFEs on other resources, including endangered species and hydropower, were fully analyzed in the EIS. The EIS acknowledges that experimental testing may provide new information about the effects of extended-duration fall HFEs on endangered species and their habitat. If that experimentation results in significant new information about potentially adverse impacts, outside of what was analyzed in this NEPA process then additional NEPA reviews would be completed as appropriate. These HFEs would only be conducted in years of very large sand input from the Paria River during the fall accounting period and the duration would be adjusted to be compatible with the magnitude of the sand input. Extended-duration fall HFEs would only be allowed in 4 of the

20 years of the LTEMP period and spring HFEs would not be allowed in the same water year to mitigate the cumulative impact of sequential HFEs. In addition, consideration would be given to their effects on key resources including water delivery, the Basin Fund, endangered species, and sediment.

(5) The reintroduction of extirpated species was outside the scope of this EIS and is discussed in Section 1.5.3.

LTEMP EIS alternatives include experiments that are intended to improve conditions for ESA-listed species and other special status species. The LTEMP EIS team used the best available science and peer-reviewed modeling to determine the potential effects of these alternatives on these species. DOI has worked closely with FWS throughout the 5-year EIS process to ensure that the appropriate experiments, dam operations, and non-flow actions were identified as conservation measures. Formal consultation with FWS has resulted in a Biological Assessment and Biological Opinion on the effects of the proposed action on listed species and designated critical habitat, as presented in Appendix O of the EIS.

The original notice of intent to prepare the LTEMP EIS identified the need to determine whether to establish a recovery implementation program for endangered fish species below Glen Canyon Dam. The LTEMP team found that identifying the need to determine whether to establish a recovery implementation program (RIP) for endangered fish species below Glen Canyon Dam did not meet the purpose and need for the action.

(6) Additional description of the implementation process for low summer flows has been added to the EIS (Section 2.2.4.6) including convening a scientific panel that includes independent experts prior to the first potential use of low summer flows to synthesize the best available scientific information related to low summer flows. Based on input from GCMRC, FWS, and joint-lead experts, we feel the additional restriction of only implementing the first test of low summer flows if humpback chub population status is robust is not needed because any test of low summer flows would consider the possibility for unacceptable adverse impacts to endangered species and critical habitat, and implementation of such a test may be delayed until conditions were suitable and unacceptable adverse impacts were minimized.

(7) We acknowledge that testing may be needed to determine the efficacy of macroinvertebrate production flows in this ecosystem, but find there is sufficient evidence for testing this tool experimentally. We acknowledge the potential for macroinvertebrate production flows to lead to increases in trout numbers. As described in Section 2.2.4.6, the "effects of the test would be evaluated…" and "…could be discontinued if there were unacceptable effects on other resources." Furthermore, we have consulted with FWS and GCMRC, and they both regard the experiment as low risk to the humpback chub population.

2.3 EIS DOES NOT COMPLY WITH CRSPA

Summary Comment: Several commenters have stated that the DEIS has improperly excluded hydropower enhancing alternatives and that the preferred alternative runs counter to the Grand Canyon Protection Act, the implementation of which is subject to and must be consistent with

Colorado River Storage Project Act (CRSPA). Under Section 7 of CRSPA, hydroelectric power plants are under CRSP A are to be operated "so as to produce the greatest practicable amount of power and energy that can be sold at firm power and energy rates." Alternative B outperforms Alternative D in this regard, while Alternative D provides no experiments to benefit hydropower, which would benefit HBC. Commenters state that the DEIS considers only the water management aspects of CRSPA and disregards the hydropower enhancement aspects and that the GCPA and CRSPA must be considered together, giving full consideration to each and that hydropower enhancement was disregarded because it did not conform to the agencies preconceived notion of where the program was to go. Finally, one commenter stated that the LTEMP is deficient as a management program because ignores the legal responsibility to explore mitigation strategies that would allow the use of the dam for its hydropower generating purposes as originally intended and that mitigation strategies are available that will benefit the trout fishery, reduce mechanical removals, stabilize sediment, and enhance river running while providing hydropower in a load following context. One commenter stated that environmental studies thus far completed and proposed do not support disruptions to continued dam management for water and power with either only negligible or zero species improvements and in the absence of reliably identifiable cause/effect and resulting benefit correlations, they urged prioritization of CRSP hydroelectric power purposes for the Glen Canyon Dam operations.

Response: Contrary to statements in the comment, the LTEMP EIS did evaluate and present the results for an alternative that increased hydropower generation. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action Alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the EIS. The preferred alternative showed a better balance between resources to achieve the purpose and need of the proposed action.

DOI formulated the characteristics of the preferred alternative based on initial modeling of a set of 6 alternatives. There were several characteristics that were chosen to specifically reduce cost to the hydropower resource including increasing the fluctuation factor from 7 to 10 in high demand months, adjusting the monthly release pattern to match WAPA's Contract Rate of Delivery, increasing the volume of water in the high demand month of August from 750 to 800 kaf in 8.23 maf years, and eliminating steady flows after HFEs. Many objectives and resource goals were considered in the LTEMP EIS. No one alternative was found which met all goals and objectives. Alternative D performed the second best out of the action alternatives on the hydropower metrics while also meeting the purpose and need and providing the best balance of resource impacts to comply with the Grand Canyon Protection Act and protect, mitigation and improve downstream resources. The preferred alternative was identified as the best balance for meeting the purpose and need of the LTEMP EIS.

Full powerplant capacity operations were considered and eliminated as an alternative as discussed in Section 2.3.10 because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose and need for this EIS.

The DEIS is consistent with both Section 7 of CRSPA and the GCPA. The CRSPA and the GCPA are both statutes that concern operation of Glen Canyon Dam, and the GCPA expressly acknowledges that the Secretary shall implement the GCPA "in a manner fully consistent with and subject to the Colorado River Compact, the Upper Colorado River Basin Compact, the Water Treaty of 1944 with Mexico, the decree of the Supreme Court in Arizona v. California, and the provisions of the Colorado River Storage Project Act of 1956 and the Colorado River Basin Project Act of 1968 that govern allocation, appropriation, development, and exportation of the waters of the Colorado River basin." Accordingly, the Secretary has considered both statutes in this NEPA process analyzing the operation of Glen Canyon Dam. Regarding the "Full-Powerplant Capacity Operations Alternative", as explained in the EIS (see Section 2.3.10), this alternative was rejected because it would not meet the purpose, need, and objectives of the LTEMP including compliance with the GCPA. However Alternative B described in Section 2.3.2 and analyzed in Chapter 4 includes a test of "hydropower improvement flows" that featured wide daily fluctuations (up to 20,000 cfs in some years and months).

2.4 SUPPORT ALTERNATIVE D

Summary Comment: Numerous commenters support Alternative D, the preferred alternative, some noting that Modulated flows as set out in Alternative D will better accomplish the stated objective- "...to protect, mitigate adverse impacts on, and improve the values for which GCNP and GCNRA were established, including, but not limited to natural and cultural resources and visitor use.

Response: Alternative D was identified as the preferred alternative because it met the purpose and need of the proposed action while achieving the best balance between downstream resource protection and hydropower production. It was the second best of the action alternatives in terms of hydropower performance.

2.5 SUPPORT ALTERNATIVE D WITH CAVEATS

Summary Comment: A number of commenters support Alternative D with some changes or caveats:

(1) Modify the HFE trigger to allow for more frequent spring HFEs that are aimed at benefitting a variety of priority resources besides sediment/sandbars, including aquatic food base, the endangered humpback chub and razorback sucker, other native fishes, the rainbow trout fishery, and riparian vegetation.

(2) Support and opposition to low summer flows.

(3) Support testing of sustained low steady flows (macroinvertebrate production flows) designed to increase the production and diversity of the aquatic insects in the Colorado River below Glen Canyon Dam and recommend testing of macroinvertebrate production flows very early in the 20-year implementation process.

(4) Prefer fewer HFEs in general, as many fishermen and fishing guides believe that repeated/frequent fall HFEs may be adversely impacting the rainbow trout fishery and the aquatic food base.

(5) Support continued testing of fall HFEs, but noting that extended duration HFEs up to 10 days in length, need to carefully consider potential impacts to the aquatic food base, rainbow trout, and invasive species in both Glen and Marble canyons

(6) The alternative should employ actions to prevent low dissolved oxygen levels that could be harmful to fish. In general, flows below 8000 cfs should be avoided if the condition of trout or food base is poor, water temperatures are above average, and DO levels are below average.

(7) Support careful testing of Trout Management Flows (TMFs) when there is an identified need to reduce the number of young of the year rainbow trout in Lee Ferry agreement is reached with AZGFD that the trout population can withstand a TMF experiment that has the potential to eliminate a recruitment year class.

(1) Response: The implementation framework for Alternative D (Section 2.2.4.3 of the EIS) explicitly calls for the consideration of key resources, including the trout fishery, when determining which experiments to conduct in any given year. The framework also establishes off-ramps that would identify when experiments should no longer be conducted due to unacceptable adverse impacts. As described in Section 2.2.4.4, DOI will also exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources.

The EIS discloses effects related to the frequency of spring HFEs. Based on modeling and analysis, there are potential positive and negative benefits to downstream resources from spring HFEs. DOI has reviewed the parameters under which spring HFEs are conducted and the way in which the accounting periods are applied. Under the preferred alternative, there would be 4-7 spring HFEs on average over the 20 year period, and there would testing and monitoring of impacts. Under the preferred alternative, spring HFE's are triggered based upon sediment or hydrology triggers. GCMRC was consulted on the potential to modify the accounting periods and the scientists most familiar with the protocol did not believe it warranted a change in accounting periods. The DOI feels that the frequency of spring HFEs in the preferred alternative provides the appropriate balance between potential positive and negative impacts.

(2) The EIS discloses effects related to low summer flows. Positive benefits include potential warming that could help with humpback chub spawning in the mainstem, and negatives include hydropower impacts and potential concerns related to trout recruitment, water quality, recreation and other concerns. The FEIS includes additional language regarding the review of scientific information that would occur prior to use of this tool in the second ten years of the LTEMP experimental period. DOI feels that the preferred alternative provides an appropriate balance between those positive and negative impacts.

(3) The preferred alternative would allow for the possibility of testing macroinvertebrate production flows early in the LTEMP period. The decision would be based on the recommendations from GCMRC for the conditions of the year and for good experimental design including avoiding confounding results based on the experiments. The process under the preferred alternative includes communication and input from agencies including AZGFD. The impact of these flows on the aquatic food base, trout, and other species are discussed in the EIS.

(4) The EIS discloses effects related to the frequency of HFEs. The frequency of HFEs varies between alternatives and further modeling and evaluation was performed on long term strategies that has HFEs "turned on" or "turned off" for various modeling runs. Based on evaluation of these modeling results, on analyses of published studies and on input from cooperators and the public, the DOI feels that the preferred alternative provides an appropriate balance between those positive and negative impacts.

(5) The best available science related to the potential effects of extended duration HFEs on trout and other resources were incorporated into the analysis. The experiments include various "off ramps" in order to respond to potential impacts in the basin, including unacceptable adverse impacts outside of what was analyzed in the EIS to the rainbow trout fishery. In addition, impacts to recreation economics and other resources were included in the EIS. Consideration of unacceptable effects of sequential HFEs, including extended-duration fall HFEs, is explicitly identified in the EIS as a concern to be addressed before implementation. DOI feels that the preferred alternative includes an appropriate level of caution and consideration regarding the use of extended duration HFEs.

(6) The preferred alternative does not include flows to address low dissolved oxygen levels in the Lees Ferry area. This concern has only been documented as occurring in one year and the recommendations from GCMRC at this time are to monitor this issue to learn more about those potential conditions prior to considering experimental actions. The joint leads recommended to GCMRC to include this consideration of monitoring in their science plan to accompany the LTEMP.

(7) The use of TMFs has been designed as a tool for managing the trout population with respect to downstream endangered fish concerns but would also be expected to result in a healthier trout fishery with less population oscillation due to density dependence. Regardless of purpose, the trigger for this tool would be a large predicted trout recruitment event. Under these circumstances, TMFs would be expected to have positive benefits for endangered species and the stability and health of the trout fishery. Under the preferred alternative, AZGFD would be involved in annual implementation and planning discussions and Tribes would be consulted regarding the use of this tool. DOI feels that the preferred alternative includes an appropriate level of caution and consideration regarding the use of trout management flows.

2.6 SUPPORT ALTERNATIVE B

Summary Comment: Commenters expressed a preference for Alternative B, stating that Alternative B outperforms all other action alternatives for nearly all resources, and is the only action alternative that addresses the stated hydropower objective of the LTEMP EIS. In addition, DOI should consider eliminating the 8,000 cfs cap on daily fluctuations, eliminate low summer flow experiments, reduce HFE experiments to no more than one every other year, and allow operation at full power plant capacity. In comparison to Alternative D, commenters stated that Alternative B has lower air emissions and performs better than Alternative D across a wide range of resources considered in the LTEMP DEIS - humpback chub, air emissions, archeological resources, recreation value, retail power rates, hydropower value, increase in native vegetation, and water quality among others. In addition, Alternative D proposes a series of treatments which appear to be counterproductive and which would require subsequent treatments that would otherwise be unnecessary, specifically, as noted on p. 4-67, that subsequent HFEs erode the sandbars potentially benefitted by earlier HFEs. Further, Alternative D maintains an artificial intraday fluctuation cap of 8,000 cubic feet per second (cfs), while DOI has failed to show that the same cap under current operations benefits other resources. Finally, the DEIS reveals a bias towards the sediment resource, but is flawed because it considers flows as the only available method for improving the sediment resource.

Response: Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range of water flows compared to the No Action Alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the EIS. The preferred alternative, Alternative D, showed a better balance of effects to resources to achieve the purpose and need of the proposed action. Alternative D performed the second best out of the action alternatives on the hydropower metrics while also meeting the purpose and need and providing the best balance of resource impacts to comply with the Grand Canyon Protection Act and protect, mitigate and improve downstream resources.

As stated in Section 2.4.1, DOI considers sediment augmentation to be outside the scope of the LTEMP EIS because it is currently economically infeasible and would require additional congressional authorizations.

Modeling and NEPA analysis indicates that Alternative B would perform better than other alternatives for hydropower, however the joint leads identified Alternative D as the preferred alternative because it better satisfies the purpose and need of the proposed action and performed better than Alternative B for most other resources.

Note that the wording of the hydropower objective as presented in the EIS is "Maintain ***or*** increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs ***to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources*** [emphasis added]." With this definition, all of the alternatives considered in the EIS satisfy the hydropower objective; however, the performance varies by alternative. It should be noted that Alternative D performed second best for hydropower out of all the action alternatives.

As stated in Section 4.5.2.3, "The average minimum number of adult humpback chub was highest for Alternatives B, D, and E, slightly lower under Alternatives A and C, and lowest under Alternatives F and G (Figure 4.5-8). These results indicate that although there are small differences among the alternatives with regard to the predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all alternatives would maintain the population above at least 1,000 adults throughout the 20-year LTEMP period." It should be noted that the modeling for Alternative D showed improvement for humpback chub abundance; slightly higher abundance than No Action. Alternative D also includes macroinvertebrate production flow experiments which are expected improve the food base for humpback chub.

As stated in Section 4.15.2, "For both SO_2 and NO_x, steam turbine (coal plant) emissions are slightly lower under Alternatives F and G…. even though these two alternatives generate <2% less Glen Canyon Dam energy than the fluctuating flow alternatives…" such as Alternative B. "Net NO_x emissions related to spot market sales and purchases are lowest (greatest negative value) for the steady flow Alternatives F and G, and highest for the fluctuating flow Alternatives B and A. Net SO_2 spot market emissions are essentially the same across alternatives." However, "Given the very small differences in the estimated emissions after considering all of the factors discussed above and in light of the uncertainty of emissions modeling, it may be concluded that emissions would be similar under all of the alternatives."

As stated in Section 4.16.3, "There are expected to be some differences in the emissions of GHGs among the LTEMP alternatives." All differences were less than 0.1% of the total emissions and less than 0.0005% at the 11-state regional scale and less than 0.0001% at the US scale. The minor differences among alternatives are reported in Section 4.16.3.

The 8,000 cfs maximum daily fluctuation cap that is currently in place has been in place since 1996. The cap is present in both No Action and the preferred alternative. It was put in place in 1996 to address safety, recreation and sediment concerns. The LTEMP EIS analysis has found that the same concerns still apply. The 8,000 cfs maximum daily fluctuation is based on the 1995 Bishop study, which was reviewed by DOI experts and found to still be the best available information and appropriate for this EIS. The Bishop study surveyed both the river guides and the general public regarding preferences and the river guides reported a preference for a maximum of 8,000 cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. See Appendix J, where table J-1 has been updated to show the survey responses at a range of flow levels. The 8,000 cfs maximum daily fluctuation in the preferred alternative is consistent with the over 1,000 comment letters received from river guides and members of conservation groups on the DEIS specifically stating the preference for retaining the 8,000 cfs maximum daily fluctuation in the preferred alternative that is currently in place for No Action.

Under Alternative D, low summer flows are only considered in the second ten years as an experiment and would only be performed more than once if the first test was shown to be successful in terms of effects to the humpback chub population. As disclosed in the DEIS, there are potentially negative impacts of lower summer flows to hydropower, bacteria/pathogens, vegetation, and food base/aquatic invertebrates. In terms of positive benefits, the modeling showed potential modest temperature increases which may be beneficial to humpback chub

populations under certain conditions. When considering individual model traces, variations in downstream temperatures were generally greatest in July (nearly 3°C warmer for low summer flows) and least in September (about 1°C warmer for low summer flows), with August falling in the middle (approximately 2°C warmer for low summer flows). In many meetings and consultations, GCMRC and FWS staff have expressed their expert opinions that LSFs are considered a low risk experiment to endangered fish and a potentially useful tool worthy of experimental testing because of the potential improvement to humpback mainstem spawning.

As determined by the modeling conducted for Alternative B, a reduction in HFE frequency to no more than one every other year would reduce sandbar building with potential negative impacts on camping and riparian species. Implementation of full powerplant capacity operations ("hydropower improvement flows" of Alternative B) would have adverse impacts on a number of downstream resources including aquatic food base, native fish, riparian vegetation, wildlife, cultural resources, and recreation.

Full powerplant capacity operations were considered and eliminated as an alternative as discussed in Section 2.3.10 because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose and need for this EIS. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range of water flows compared to the No Action alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the DEIS. The preferred alternative showed more positive than negative effects to resources, as compared to Alternative B, to achieve the purpose and need.

Although Alternative D was projected to increase greenhouse gas emissions relative to Alternatives A and B, this difference was 22,908 "metric" tons not "million" tons. This increase represents a very small percentage (0.042%) of the greenhouse gas emissions that would result from the actions considered in Alternative A. The analysis for the EIS determined that under Alternative D, there would be a 152% increase in the sand load index (a measure of sandbar building potential) and a 47% decrease in the sand mass balance index, the lowest decrease of all the action alternatives. No one alternative was found which performed best for all goals and objectives. The preferred alternative was identified as the best balance for meeting the purpose and need of the LTEMP EIS.

2.7 SUPPORT ALTERNATIVE A

Summary Comment: Commenters expressed support for Alternative A, the no-action alternative, noting that Alternative A outperforms Alternative D with respect to a number of resource interests, and that Alternative A and Alternative B are the only two alternatives that meet the goal to "maintain or improve hydropower production." Some of the commenters acknowledged that the Preferred Alternative (Alternative D) has been changed to improve hydropower compared to how it was originally proposed, with more volume in the peak power month of August and more fluctuation in general, and could conditionally support it with the following changes: (i) increased daily fluctuations to 12 times monthly volume (in kaf) in June-August., and 10 times monthly volume (in kaf) in other months; (ii) removal of the 8,000 cfs fluctuation

cap; (iii) inclusion of hydropower improvement flow experiments; (iv) limitation of HFEs to a maximum of one occurrence per calendar year, and (v) exclusion of low summer flow experiments.

Response: DOI formulated the characteristics of the preferred alternative based on initial modeling of a set of 6 alternatives. There were several characteristics that were chosen to specifically reduce cost to the hydropower resource including increasing the fluctuation factor from 7 to 10 in high demand months, adjusting the monthly release pattern to match WAPA's Contract Rate of Delivery, increasing the volume of water in the high demand month of August from 750 to 800 kaf in 8.23 maf years, and eliminating steady flows after HFEs. Many objectives and resource goals were considered in the LTEMP EIS. No one alternative was found which met all goals and objectives. Alternative D performed the second best out of the action alternatives on the hydropower metrics while also meeting the purpose and need and providing the best balance of resource impacts to comply with the Grand Canyon Protection Act and protect, mitigate and improve downstream resources. The preferred alternative was identified as the best balance for meeting the purpose and need of the LTEMP EIS.

The increases in fluctuation described in the comment were all analyzed in the document in association with other alternatives and showed a number of positive and negative impacts to resources that led to those other alternatives not being identified as the preferred alternative. The preferred alternative performed the best with the fluctuation levels it currently has to address the concerns of endangered species, sediment, hydropower and other related resources.

Note that the wording of the hydropower objective as presented in the EIS is "Maintain or increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources [emphasis added]." With this definition, all of the alternatives considered in the EIS satisfy the hydropower objective; however, the performance varies by alternative. It should be noted that Alternative D performed second best for hydropower out of all the action alternatives.

2.8 SUPPORT ALTERNATIVES CONSIDERED BUT REJECTED

Summary Comment: Commenters expressed support for alternatives that were considered but rejected, specifically for the "Fill Lake Mead First, "Run of the River," and Decommission Glen Canyon Dam" alternatives. None of the retained alternatives, the commenters state, would be viable in the event of catastrophic reductions in Colorado River flows due to climate change, would adequately address the impacts of Glen Canyon Dam in driving the decline of Lake Mead, is capable of curtailing and reversing and the harm caused by to Glen Canyon under Lake Powell reservoir, or alleviates the effects of the dam's holding back sediment. DOI's justification for rejecting the alternatives is obsolete in the context of dramatic climate change impacts, while the current infrastructure for providing municipal water supplies through Glen Canyon Dam in unsustainable. Commenters also requested the analysis of a new alternative employing a historically based hydrograph alternative that attempts to restore hydrological functions that would benefit vegetation and possibly beaches. Other commenters stated that the LTEMP

alternatives would not be viable under catastrophic reductions in Colorado River flows due to climate change, nor adequately address the impacts of Glen Canyon Dam in driving the decline of Lake Mead. DOI's rationale for rejecting the proposed The "Fill Mead First Alternative" and "The Run-of-the-River Alternative" would be obsolete under severe climate change. Further, none of the alternatives analyzed the possibility that continued decline of Lake Mead could trigger a "shortage declaration" under the 2007 Interim Guidelines or an even more extreme "Compact Call," under which lower Colorado River basin states would legally compel the upper basin states to deliver their water allocation under the Law of the River.

Response: The LTEMP team developed a set of alternatives that represented the full range of reasonable experimental and management actions; met the purpose, need, and objectives of the proposed action; and were considered within the constraints of existing laws, regulations, and existing decisions and agreements. Other alternatives such as the "Fill Mead First," "Run-of-the River" and "Decommissioning the Dam" proposals were not included in the EIS because they would not meet the purpose, need, or objectives of the proposed action (see Sections 2.3.9 and 2.3.10). These alternatives would not allow compliance with water delivery requirements including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA.

The EIS presented an analysis of historical hydrographs to determine how the alternatives would perform under the drier conditions of climate change conditions, and found that, although the resource impacts under climate change would be different from those under historic hydrology, the relative performance of alternatives would be consistent relative to each other. This indicated that Alternative D would continue to be the best of the alternatives under a changed climate.

The "Fill Mead First" proposal was not included in the DEIS because it would not meet the purpose, need, or objectives of the proposed action (see Section 2.3.9). The alternative would not allow compliance with water delivery requirements including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA.

Regarding whether the annual volume of water moving from the Upper Colorado River Basin to the Lower Colorado River Basin should be changed for the purpose climate change considerations, annual volume determinations are presently implemented through the LROC as currently implemented through the 2007 Interim Guidelines. Consistent with the GCPA, and the purpose and need for this proposed action, any changes to annual volume determinations are beyond the scope of this NEPA analysis. Accordingly, the Proposed Action in the draft EIS does not require the Federal agencies (NPS and BOR) to either create a plan for providing water to the Colorado River in Grand Canyon during extended drought periods or develop a basin wide plan for the operations of all dams.

In December 2012, Reclamation and agencies representing the seven Colorado River Basin States completed the Colorado River Basin Water Supply and Demand Study (Reclamation 2012e). The purpose of the Study was to define future imbalances in water supply and demand in the Basin through the year 2060, and to develop and analyze options and strategies to resolve those imbalances. The study used several different scenarios for both supply and demand to capture a range in potential future conditions.

The LTEMP EIS includes an analysis of meeting water delivery requirements under historic hydrology (Section 4.2.2.1) and climate change scenarios (Section 4.16.2.2). This analysis demonstrated that, although there were differences in the performance of alternatives under historic and climate change scenarios, the same relative performance of alternatives was observed under the two scenarios. The analysis also demonstrated that all alternatives could continue to meet Compact requirements.

2.9 EIS SHOULD HAVE CONSIDERED INFRASTRUCTURE ADDITIONS/MODIFICATIONS

Summary Comment: Commenters disagree with DOI's decision to exclude some forms of infrastructure additions, or modifications, mainly involving temperature control of dam discharges or sediment augmentation below the dam, or with DOI's definition of sediment augmentation as an infrastructure addition or modification. Commenters stated that the DEIS dismissed any augmentation outright as deeming them economically unfeasible, request that DOI provide additional information as to the decision making process used to eliminate sediment augmentation from consideration because it is "infeasible," and note that no cost evaluation or studies were performed to determine whether the installation of temperature control devices would be an appropriate alternative to analyze. Options are available to deliver trapped sediment upstream of the dam downstream, to reposition bed-load sand to beaches and/or enhance supplies from the Paria, including the use of dredges. Dredging and beach building is not new infrastructure, but a possible alternative to HFEs that should be considered.

Response: As stated in Section 2.4.1, DOI considers any infrastructure modifications or additions to be outside the scope of the LTEMP EIS because they are currently economically infeasible and would require additional congressional authorizations (16 U.S.C. § 460l-19). However, the DOI does not rule out future new infrastructure if resource conditions warrant. Any infrastructure addition or modification would require additional time and study. Future potential infrastructure modifications would need to be evaluated in NEPA assessments (EAs or EISs) that fully considered the environmental impacts of construction and operation. These assessments and the construction of the infrastructure would necessarily result in some delay from the time of the LTEMP ROD and actual start of operation of the infrastructure. It could take as many as 10 years or more to evaluate and construct a TCD or sediment augmentation. Sediment augmentation was also determined to be outside the scope of the 1995 EIS. The EIS has demonstrated how the preferred alternative is designed to meet as many of the environmental conditions as possible as mandated by the GCPA.

The analysis for the EIS determined that under Alternative D, there would be a 152% increase in the sand load index (a measure of sandbar building potential) and a 47% decrease in the sand mass balance index, the lowest decrease of all the action alternatives.

Sediment is an important resource in the Grand Canyon and supports aquatic and riparian ecosystems, cultural resources, and recreation. Options for how to mitigate sediment impacts have been intensively studied for more than 20 years by the Grand Canyon Research and Monitoring Center (GCMRC) as well as by many academics and DOI bureau staff. Many options were considered throughout the LTEMP EIS process to address this problem. Options for

sediment augmentation were considered originally but after evaluation were considered economically infeasible at this time. Without augmentation, HFEs are considered the most feasible and potentially beneficial approach to building sandbars with the limited sand supply available downstream of Glen Canyon Dam.

2.10 ALTERNATIVE D IGNORES (OR DOES NOT MEET) HYDROPOWER OBJECTIVE

Summary Comment: Commenters state that the LTEMP EIS preferred alternative does not meet the renewable resource goal of NEPA Section 101 (b) 6 or the hydropower resource goal established by the DOI for the LTEMP EIS, that power production be "maintain[ed] (or/and) improve[d]," as stated in the Purpose and Need Statement (76 FR 129, July 6, 2011. Alternative D, places restrictions on the utilization of Glen Canyon Dam for hydropower production that are in addition to the restrictions that were established as a result of the 1996 Record of Decision (ROD). As a result, the renewable hydropower resource objectives of NEPA and the LTEMP EIS process will not be met if the preferred alternative is selected. In addition, low steady flow in July, August and September would result in a detrimental impact to hydropower production and would not meet the hydropower DFC objective.

Response: Hydropower production was one of the key resources thoroughly evaluated in the EIS. Many objectives and resource goals were considered in the LTEMP EIS. No one alternative was found which met all goals and objectives. Alternative D was identified as the preferred alternative because it met the purpose and need of the proposed action while achieving the best balance between downstream resource protection and hydropower production. It was the second best of the action alternatives in terms of hydropower performance.

DOI formulated the characteristics of the preferred alternative based on initial modeling of a set of 6 alternatives. There were several characteristics that were chosen to specifically reduce cost to the hydropower resource including increasing the fluctuation factor from 7 to 10 in high demand months, adjusting the monthly release pattern to match WAPA's Contract Rate of Delivery, increasing the volume of water in the high demand month of August from 750 to 800 kaf in 8.23 maf years, and eliminating steady flows after HFEs.

Note that the wording of the hydropower objective as presented in the EIS is "Maintain ***or*** increase Glen Canyon Dam electric energy generation, load following capability, and ramp rate capability, and minimize emissions and costs **to the greatest extent practicable, consistent with improvement and long-term sustainability of downstream resources** [emphasis added]." With this definition, all of the alternatives considered in the EIS satisfy the hydropower objective; however, the performance varies by alternative. It should be noted that Alternative D performed second best for hydropower out of all the action alternatives.

Several commenters provided letters addressing the role of hydropower in the purpose and need of this NEPA process. The joint leads feel the purpose and need as drafted reflects the appropriate role of hydropower given the authorities surrounding the operation of Glen Canyon Dam. In certain places we have edited the text to clarify the role of GCPA downstream resource priorities and hydropower. Water delivery and hydropower are fundamental principles that show

up as the first objectives of the LTEMP. The joint leads worked hard with the stakeholders to ensure representation of all interests. The GCPA is clear in its goals and the objectives that were outlined for the LTEMP reflect the goals of GCPA and the goals reflected in the "Law of the River". Please see the resource and objective goals outlined in the EIS.

2.11 EIS DID NOT CONSIDER A FULL RANGE OF ALTERNATIVES

Summary Comment: Commenters expressed disappointment that no alternative increased daily hydropower flexibility and expressed a desire to allow operation at full power plant capacity (with mitigation). Commenters disagreed with DOI's rationale for excluding the Full-Powerplant Capacity Operations Alternative - that it "would not meet the purpose, need, and objectives of the LTEMP including compliance with the GCPA."

Response: Contrary to statements in the comment, the LTEMP EIS did evaluate and present the results for an alternative that increased hydropower generation. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action Alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the EIS. The preferred alternative showed a better balance between resources to achieve the purpose and need of the proposed action.

As determined by the modeling conducted for Alternative B, a reduction in HFE frequency to no more than one every other year would reduce sandbar building with potential impacts on camping and riparian species. Implementation of full powerplant capacity operations ("hydropower improvement flows" of Alternative B) would have adverse impacts on a number of downstream resources including aquatic food base, native fish, riparian vegetation, wildlife, cultural resources, and recreation.

Regarding the "Full-Powerplant Capacity Operations Alternative", as explained in the EIS (see Section 2.3.10), this alternative was rejected because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose, need, and objectives of the LTEMP including compliance with the GCPA. However Alternative B described in Section 2.3.2 and analyzed in Chapter 4 includes a test of "hydropower improvement flows" that featured wide daily fluctuations (up to 20,000 cfs in some years and months).

Full powerplant capacity operations were considered and eliminated as an alternative as discussed in Section 2.3.10 because fluctuation levels to the degree proposed would have adverse impacts on many downstream resources and would not meet the purpose and need for this EIS. Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action Alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the DEIS. The preferred alternative showed a better balance between resources to achieve the purpose and need.

The EIS presented an analysis of historical hydrographs to determine how the alternatives would perform under the drier conditions of climate change conditions, and found that, although the resource impacts under climate change would be different from those under historic hydrology, the relative performance of alternatives would be consistent relative to each other. This indicated that Alternative D would continue to be the best of the alternatives under conditions resulting from climate change.

2.12 FLOWS SHOULD NOT DROP BELOW 8,000 CFS

Summary Comment: Commercial rafters note that it is critical to their operations and public safety that the actual, not mean, daily minimum flow never drops below 8000cfs. Minimum flows of 5000 cfs from 7pm-7am for Alternative D indicated in Table 2.1 (page 2-9) are inadequate and dangerous. Navigational safety for boating is compromised when actual flows drop below 8000 cfs due to exposed rocks and increased difficulty in navigating the channel. Further, rafters are concerned with the minimum water level over the entire 24-hour day period; water released overnight will have an effect on many boaters downstream in the subsequent daytime hours. Also, low flow minimums below that of the 8,000 cfs level will restrict the time off-river by slowing the on-river pace and in turn diminish the overall experience for the visitor.

Response: Under the No Action Alternative, current minimum releases from the dam are set at 8,000 cfs from 7 am to 7 pm and 5,000 cfs from 7 pm to 7 am. This flow pattern, averaging a minimum over 24 hours of 6,500 cfs, has been in place since the 1996 Record of Decision was signed. Lower flows travel at a slower rate of speed and flows attenuate as the water moves downstream. The current minimums that have been in place for 20 years would be continued under the preferred alternative. Additionally, monthly volumes in the preferred alternative represent a relatively even pattern, allowing for more predictable and stable flow patterns throughout the year, including the high visitation summer months.

The EIS evaluates impacts on recreation related to navigation, fluctuations, and safety. These evaluations considered the minimum flow during each 24-hr period and the maximum daily fluctuation of each alternative. The preferred alternative is very similar to the No Action Alternative with regard to navigation, fluctuation level, and safety. As for all experiments, the implementation of low summer flows, TMFs, and macroinvertebrate production flows would take into account unacceptable adverse impacts on key resources including recreation. If unacceptable adverse impacts on key resources were anticipated, the minimum flow for both of these experiments could be adjusted.

The EIS acknowledges that low flows would reduce the amount of time boaters could spend off river, and assesses the impacts of each alternative using a “time off river“ index. The preferred alternative is expected to result in a very small decrease (<2%) in this index relative to the No Action Alternative.

2.13 8,000 CFS FLUCTUATION LIMIT

Summary Comment: Many commenters expressed a preference to keep daily water release fluctuations capped at 8,000 cfs, stating that this will help preserve natural resources that provide habitat for endangered fish and the re-building of beaches along the Colorado River. High fluctuations, some also note, can diminish or reverse some of the benefits of the HFEs and make it very difficult on river rafters and guides as they manage and plan river trips and manage boats on the shoreline. Other commenters support removing the 8,000 cfs cap, stating that it is unsupported by the scientific literature and restricts the hydropower resource without regard to CRSPA provisions to the contrary, and that DOI has failed to show that it benefits other resources.

Response: Alternative B was originally crafted and submitted by CREDA, a power utility stakeholder. It has a greatly increased daily range compared to the No Action Alternative and it includes an experimental implementation of maximum powerplant capacity releases. This alternative showed a number of positive and negative impacts on a variety of resources as were disclosed in the EIS. The preferred alternative showed a better balance between resources to achieve the purpose and need of the proposed action.

The 8,000 cfs maximum daily fluctuation cap that is currently in place has been in place since 1996. The cap is present in both No Action and the preferred alternative. It was put in place in 1996 to address safety, recreation and sediment concerns. The LTEMP EIS analysis has found that the same concerns still apply. The 8,000 cfs maximum daily fluctuation is based on the 1995 Bishop study, which was reviewed by DOI experts and found to still be the best available information and appropriate for this EIS. The Bishop study surveyed both the river guides and the general public regarding preferences and the river guides reported a preference for a maximum of 8,000 cfs daily change for a "tolerable recreation experience" under relatively high average daily flows. See Appendix J, where table J-1 has been updated to show the survey responses at a range of flow levels The 8,000 cfs maximum daily fluctuation in the preferred alternative is consistent with the over 1,000 comment letters received from river guides and members of conservation groups on the DEIS specifically stating the preference for retaining the 8,000 cfs maximum daily fluctuation in the preferred alternative that is currently in place for No Action.

Implementation of full powerplant capacity operations ("hydropower improvement flows" of Alternative B) would have adverse impacts on a number of downstream resources including aquatic food base, native fish, riparian vegetation, wildlife, cultural resources, and recreation.

The increases in fluctuation described in comments were analyzed in the document in association with various alternatives and showed a number of positive and negative impacts to resources that led to those other alternatives not being identified as the preferred alternative. The preferred alternative performed the best with the fluctuation levels it currently has to address the concerns of endangered species, sediment, hydropower and other related resources.

Modeling also indicated that the higher fluctuation levels under Alternative B or E would result in a number of adverse impacts including impacts on sediment, aquatic food base, vegetation, and recreation.

2.14 EIS DID NOT ADEQUATELY CONSIDER THE EFFECTS OF CLIMATE CHANGE

Summary Comment: Commenters expressed that the DEIS fails to take climate change seriously, fails to analyze the impacts on the water supply system of climate change for the entire Colorado River including the ecology in the Grand Canyon due to the operation of Glen Canyon Dam and Lake Powell, fails to analyze the likelihood of a "Compact Call" on the Colorado River due to the water lost by evaporation and seepage due to the operation of Glen Canyon Dam and Lake Powell, and fails to analyze a full range of alternatives that should be considered due to climate change including the decommissioning of Glen Canyon Dam and the draining of Lake Powell, stating that the criteria used to eliminate these alternatives would be obsolete in the face of catastrophic reductions in Colorado River flows caused by climate change, while none of the current alternatives would be viable under such conditions.

Response: The LTEMP utilized the best available science provided through the peer reviewed Basin Study (Reclamation 2012) regarding climate change projections in the Colorado River. The hydrological traces generated for the Basin Study were utilized as described in Section 4.16.1 and Appendix C.

This EIS used 21 reconstructed historical hydrological traces that were reweighted based on the 112 climate change traces to represent the best current understanding of what might happen under the drier conditions of climate change. Based on this analysis, the weights on the hydrological traces had a small effect on the aggregate performance but did not change the rankings of alternatives. This result suggests the relative performance of the alternatives would be consistent regardless of the uncertainty of the effects of climate change, and that Alternative D would continue to be the best of the alternatives under a changed climate.

The LTEMP team developed a set of alternatives that represented the full range of reasonable experimental and management actions; met the purpose, need, and objectives of the proposed action; and were considered within the constraints of existing laws, regulations, and existing decisions and agreements. Other alternatives such as decommissioning of Glen Canyon Dam, "Fill Mead First" and "Run-of-the River" proposals were not included in the EIS because they would not meet the purpose, need, or objectives of the proposed action (see Sections 2.3.8, 2.3.9 and 2.3.10). These alternatives would not allow compliance with water delivery requirements including the Law of the River and 2007 Interim Guidelines (Reclamation 2007a,b), and would not comply with other federal requirements and regulations, including the GCPA. The performance of these alternatives under climate change during the 20-year LTEMP period was discussed in Section 4.16.2.

Regarding whether the annual volume of water moving from the Upper Colorado River Basin to the Lower Colorado River Basin should be changed for the purpose climate change considerations, annual volume determinations are presently implemented through LROC as currently implemented through the 2007 Interim Guidelines. Consistent with the GCPA, and the purpose and need for this proposed action, any changes to annual volume determinations are beyond the scope of this NEPA analysis. Accordingly, the Proposed Action in the draft EIS does not require the Federal agencies (NPS and BOR) to either create a plan for providing water to the

Colorado River in Grand Canyon during extended drought periods or develop a basin wide plan for the operations of all dams.

The Basin Study (Reclamation 2012) was peer reviewed and is the best available science regarding climate change projections in the Colorado River Study. The hydrological traces generated for the Basin Study were utilized as described in Section 4.16.1.2 and Appendix C. This EIS did not model the 112 climate change hydrologic traces generated as part of the Basin Study due to insufficient data to drive the complex suite of models. We used 21 reconstructed historical hydrological traces that were reweighted based on the 112 climate change traces to represent the best current understanding of what might happen because of climate change. Based on this analysis, the weights on the hydrological traces had a small effect on the aggregate performance but did not change the rankings of alternatives. This result suggests the alternatives are robust to uncertainty about climate change.

By utilizing historic hydrology information and climate change-weighted hydrology information, we evaluated the effects of alternative operations over the 20-year LTEMP period under a wide-range of hydrologic and sediment conditions. We used a complete set of integrated models to evaluate effects of these changes in hydrology and sediment on the full range of resources including aquatic resources, terrestrial vegetation and wildlife, endangered species, cultural resources, Tribal resources, recreation, and socioeconomics. We modeled scenarios where the pool elevation dropped below the estimated minimum power pool (3,490 ft) and the results showed that there was no significant difference in the relative performance of the alternatives (Section 4.2). As stated in Section 4.2.2 of the EIS, "For Lake Powell elevations, all alternatives show very similar percentages for elevations that are ≤3,490 ft. The percentage of traces ranges between 0 and 5 and remains relatively constant throughout the 20 year period." In addition, we looked at the cumulative impacts of LTEMP in combination with other past, present, and future projects. We determined that the alternatives were robust to projected climate change-related hydrologies and could operate within the constraints of each alternative over the 20-year LTEMP period.

2.15 GEOGRAPHIC SCOPE OF THE EIS

Summary Comment: One commenter stated that the DEIS fails to clearly distinguish between 1) the scope of the proposed activity, i.e., Colorado River Ecosystem, and 2) the area of impact associated with implementing any activity proposed under LTEMP, and that it is unclear why some resources are discussed beyond the specific geographic limitations of the Colorado River Ecosystem and other resources are not. The DEIS should remain consistent with the geographic scopes intended for the proposed activities and impacts identified throughout its discussions and analyses.

Response: The text of the EIS has been revised to better clarify the geographic scope (See Section 1.5.1). It should be noted that the areas of potential impact vary by resource by necessity to evaluate the impacts. For instance, the effects of dam operations on vegetation or sediment are much more limited geographically than the effects on air quality or hydropower. In the cumulative analysis section (4.17), the region of influence for each resource is defined in the second column of Table 4.17-2.

2.16 MONITORING TO SUPPORT ADAPTIVE MANAGEMENT

Summary Comment: Commenters on this issue requested that the lead agencies conduct long-term resource monitoring to support adaptive management and to measure progress toward achieving goals and desired future condition.

Response: Long-term-monitoring for adaptive management will continue under the LTEMP. GCMRC has developed a Science Plan for the LTEMP that will guide these monitoring activities.

2.17 INCLUDE A SUMMARY OF EXPERIMENTAL AND MANAGEMENT ACTIONS FOR THE RAINBOW TROUT FISHERY

Summary Comment: Commenters on this issue requested that the selected alternative and/or the Record of Decision include a summary of experimental and management actions that are proposed to benefit the Lees Ferry rainbow trout fishery.

Response: The FEIS includes descriptions of all experimental and management actions for the alternatives in Chapter 2. There is not a summary of trout related experiments for all alternatives in one section, however all aquatic resource experiments for Alternative D can be found in Table 2-9 and Section 2.2.4.6.

2.18 GLEN CANYON DAM SAFETY AND SECURITY

Summary Comment: A commenter stated that Reclamation's misrepresentation of the growing risks associated with GCDs operational safety, the security of its water storage and hydropower generation benefits, as well as threats to water quality, not only renders its suite of alternatives and assessments thereof, incomplete, but renders an injustice to the Colorado River society as a whole by denying the public a truthful and up-to-date assessment of the known risks associated with the continued operations of GCD and the implied benefits therein.

Response: It is not clear what safety risks this comment is referring to. Dam safety is a priority of the Bureau of Reclamation and is evaluated comprehensively through Reclamation's Dam Safety program on an -ongoing basis. These on-going evaluations are wholly independent of LTEMP and beyond the scope of this NEPA analysis. The co-lead agencies feel that this NEPA process takes a comprehensive "hard look" at the proposed action and alternatives that is fully consistent with NEPA.

2.19 EXPERIMENTAL UNCERTAINTY

Summary Comment: Commenters stated that the experimental framework included in Alternative D fails to provide any meaningful level of certainty, there is insufficient detail and information regarding experimental triggers, baselines, off-ramps, hypotheses, unacceptable adverse impact, and metrics to determine success, or adaptively managing under LTEMP, and

the framework vests sole discretion in the DOI to determine whether a given experiment will be conducted.

Response: Triggers for experiments are clearly articulated. For several fish experiments triggers were developed and defined through the consultation process with FWS with information provided from GCMRC another experts and cooperators. GCMRC also developed a science plan and will be intimately involved in the implementation of LTEMP experiments through the GCDAMP triennial budget process and on-going monitoring, evaluation and reporting. The Colorado River Ecosystem is a dynamic system with complex interactions and changing conditions from year to year. The preferred alternative established a balance between structure and flexibility for experimentation to be able to allow for adaptive management in response to both changing conditions and new information gathered from experimentation. The preferred alternative has a number of annual steps built into the process to coordinate with GCMRC, agencies and stakeholders to consider the conditions of the year and the appropriate experiments given those conditions. Triggers and 'off-ramps' are defined. The triggers for HFEs and LSFs are well defined. Many of the triggers for tools for fish management have intentionally been left to be more flexible in the EIS as those have been defined during the consultation process with the FWS and will be more clearly stated in the FEIS. Greater specificity regarding triggers for HFE implementation and humpback chub actions have been added to the EIS (Appendices O and P).

The implementation framework for Alternative D (Section 2.2.4.3 of the EIS) explicitly calls for the consideration of key resources when determining which experiments to conduct in any given year. The framework also establishes off-ramps that would identify when experiments should no longer be conducted due to unacceptable adverse impacts. As described in Section 2.2.4.4, DOI will also exercise a formal process of stakeholder engagement to ensure decisions are made with sufficient information regarding the condition and potential effects on important resources. GCMRC has developed a science plan that describes the information that will be gathered during implementation of the LTEMP, and how that information would be used in an adaptive management context. Appendix O includes information regarding triggers for fish actions.

2.20 IMPACTS ON BASIN FUND

Summary Comment: A commenter stated that impacts to the Upper Colorado River Basin Fund must be assessed and considered.

Response: In Section 4.13 and appendix K of this EIS there is extensive analysis of the revenues from Glen Canyon hydropower production contributing to the Basin Fund. There are other factors that affect the balance of the Basin Fund that are outside the scope of the actions analyzed in this EIS, however those would not vary by alternative so they were not analyzed in the LTEMP EIS.

2.21 DUE CONSIDERATION OF HYDROPOWER

Summary Comment: Commenters stated that the Department of Interior must balance numerous important, and often competing, factors in developing the final LTEMP. Commenters urged that due consideration and weight be given to the importance of hydropower in this process.

Response: Many objectives and resource goals were considered in the LTEMP EIS. Hydropower production was one of the key resources thoroughly evaluated in the EIS. No one alternative was found which met all goals and objectives. Alternative D performed the second best out of the action alternatives on the hydropower metrics while also meeting the purpose and need and providing the best balance of resource impacts to comply with the Grand Canyon Protection Act and protect, mitigate adverse impacts to, and improve downstream resources. The preferred alternative was identified as the best balance for meeting the purpose and need of the LTEMP EIS.

2.22 SUPPORT ALTERNATIVE F

Summary Comment: One commenter expressed a preference for Alternative F, seasonally adjusted steady flows, because it would mimic natural conditions, and thus improve tailwater temperature and sediment conditions and riparian ecosystems downstream. Peaking power provided by fluctuating flows could be replaced by utility scale photovoltaic solar power.

Response: Alternative D was chosen as the preferred alternative because it met the purpose and need of the proposed action while achieving the best balance between downstream resource protection and hydropower production. This analysis considered the means and costs of alternate sources of peaking capacity as applicable under the various LTEMP alternatives

3 AQUATIC ECOLOGY

3.1 ALTERNATIVES WILL NOT PROTECT COLORADO RIVER ECOSYSTEM

Summary Comment: Commenters noted that Bureau of Reclamation (BOR) and NPS are setting themselves up for failure by attempting to restore an entire ecosystem based on responses to sediment inputs, temperature, and power grid needs alone instead of basing Glen Canyon Dams hydrograph on historic flow magnitude, frequency, duration, timing, and rate of change. In addition, there is a growing body of evidence on life history adaptations that indicate that several species depend on very localized hydrological conditions for their survival and reproduction. The Colorado River Ecosystem is continually changing, and novel, unanticipated ecosystem developments occur nearly every year. Many environmental and economic uncertainties, both recognized and unknown, complicate future adaptive management of the Dam and the Colorado River Ecosystem. Ensuring flexibility and administrative responsiveness is essential. Also, contingency planning is needed on a regular (annual) basis to deal with surprise events or processes, such as the sudden eruption of non-native green sunfish in Glen Canyon in 2015. Other commenters stated that adaptive management is based on the strategy of not placing the entire ecosystem at risk to answer management questions. Many management questions should be explored through small-scale field experiments or through modeling, rather than subjecting the entire ecosystem to an experiment that might jeopardize component species or processes. Only in cases where whole-ecosystem experiments are known to work, should they be conducted (e.g., testing the impacts of springtime HFEs on fluvial geomorphology and river biota).

Response: The purpose and need for LTEMP clearly align with the Grand Canyon Protection Act, whose goal is “to protect, improve and mitigate adverse impacts to natural and cultural resources and visitor use for which both park units were established”. All alternatives, including the preferred alternative (Alternative D), have positive and negative impacts which are disclosed in the EIS analyses. The Colorado River Ecosystem is a dynamic system with complex interactions and changing conditions from year to year. The preferred alternative established a balance between structure and flexibility for experimentation to be able to allow for adaptive management in response to both changing conditions and new information gathered from experimentation. The preferred alternative has a number of annual steps built into the process to coordinate with GCMRC, agencies and stakeholders to consider the conditions of the year and the appropriate experiments given those conditions. The joint leads have concluded that Alternative D has more positives than negatives and provides the best balance to meet the purpose and need for this project and to comply with the Grand Canyon Protection Act and the Law of the River. For a summary of impacts among alternatives, see Table 2-14.

3.2 IMPACTS OF FALL HFEs ON FISH AND AQUATIC FOOD BASE

Summary Comment: A number of commenters believed that repeated/frequent fall HFEs may be adversely impacting the rainbow trout fishery and the aquatic food base. Others stated that HFEs should be either deferred or only conducted in the spring if the condition of trout or the food base in Lees Ferry is poor. Others stated that the effects of sediment-triggered fall HFEs on trout recruitment are uncertain, but fall HFEs are expected to have less effect on trout production than

spring HFEs. Some commenters believed that a connection could be made between three consecutive fall HFEs and an increase in brown trout recruitment. In addition, the Havasupai requested the development of a monitoring site to study the impacts from the backflow of the HFE into Havasu Creek as well as impacts on the endangered fish naturally occurring and introduced at this location.

Response: The effects of HFEs on aquatic resources were fully analyzed in Section 4.5. This section reports that fall HFEs have not been found to have negative impacts to the food base, to trout recruitment or to native or non-native fish generally. There is no evidence of the frequency of HFEs being related to brown trout recruitment. Prior to the implementation of any HFEs, there would consideration of conditions related to humpback chub, trout, and aquatic food base. The HFE implementation process includes meetings with the GCMRC, FWS, AZFGD and other partners to take into consideration annual conditions as well as any new information. If unacceptable adverse impacts are predicted or observed, then experiments may be discontinued or additional NEPA processes may be conducted.

DOI will discuss the idea of a Havasupai monitoring site near Havasu Creek with GCMRC to be considered in the science plan or the monitoring implementation details.

3.3 REDUCE NUMBER OF HFEs TO IMPROVE THE AQUATIC FOOD BASE

Summary Comment: Commenters expressed concern regarding the continuation and expansion of HFEs, both in terms of frequency and duration. HFEs scour and remove the aquatic food base resulting in the loss of the main food source for trout and downstream humpback chub. Studies suggest that it takes 1 to 1.5 years for the food base to recover to pre-HFE levels after any HFE event. This indicates that if HFEs are implemented one or more times annually, there will be little opportunity for the food base to recover which will increase stress on the endangered native fish. Therefore, any selected alternative should include no more than one HFE every other year.

Response: Flow effects (including HFEs) on the aquatic food base are discussed in Section 4.5.2.1, with a more detailed discussion in Section F.2.2.1 (Appendix F). Reducing the number of HFEs (e.g., no more than one HFE every other year) is not supported by the analysis presented in the EIS. As discussed in Section F.2.2.1 (Appendix F), repeated HFEs are expected to result in a more productive aquatic food base. Such results do not occur from infrequent HFEs. Nevertheless, the HFE‘s are experimental in nature and allow for some adaptation over time based on results within the bounds of environmental compliance. If the HFEs cause unacceptable adverse impacts, there is a process defined in the EIS to suspend the HFEs.

3.4 IMPACTS OF MINIMUM FLOWS BEFORE AND AFTER HFEs

Summary Comment: Several commenters support the idea of keeping flows low and stable before and after HFEs. The health of the rainbow trout fishery and the aquatic food base, water temperatures, and dissolved oxygen levels should all be considered when determining the minimum flow that will precede and/or follow a fall high flow experiment (HFE). In general,

flows below 8000 cfs should be avoided if the condition of trout or food base is poor, water temperatures are above average, and dissolved oxygen levels are below average

Response: The issues the commenter raises, the health of the rainbow trout fishery, the aquatic food base, water temperature, and dissolved oxygen levels would be considered as part of the assessment of resources listed in Section 2.2.4.3 that will be considered when determining the flows that would precede or follow an HFE. Though the LTEMP EIS analysis did not find that steady flows after fall HFEs present a risk to the humpback chub population, that experiment has been removed for a number of other reasons including that it would be difficult to measure the results.

3.5 PROVIDE ADDITIONAL INFORMATION ON MOST RECENT FALL HFEs

Summary Comment: Commenters requested the inclusion of results from the recent HFEs (2012, 2013, and 2014) throughout the LTEMP DEIS including the portion of Section of 4.5 which addresses flow effects on benthic invertebrates. Given the impact to the endangered species, hydroelectric capacity and environmental ramifications of purchased power to replace the effects of HFEs; the failure of the DEIS to include and consider all of the HFEs and the cumulative impacts represents a significant analytical flaw. In addition, the DEIS fails to, but must include an analysis of the results of the 2013 and 2014 HFEs on rainbow trout recruitment and humpback chub.

Response: Preliminary results of the more recent HFEs have been added to Sections 3.5 and 4.5 of the EIS.

3.6 SUPPORT CAREFUL TESTING OF TMFs

Summary Comment: A number of commenters support the careful testing trout management flows (TMF), but only when there is an identified need to reduce the number of young of the year rainbow trout in Lees Ferry; while recognizing Tribal opposition to TMFs. A TMF should only be tested if AZGFD is in agreement that the trout population can withstand a potentially very successful TMF experiment that eliminates a recruitment year class. Testing TMFs when young trout are not abundant may adversely affect the Lees Ferry trout fishery, is contrary to the "condition dependent" adaptive management approach, and may not lead to conclusive results on the effectiveness of TMFs as a management tool.

Response: The DOI considers TMFs as an important tool for minimizing risk to downstream endangered fish from trout regardless of the cause of trout population increases or migration. Text has been added to Section 2.2.4.6 to clarify that implementation of TMFs would consider resource condition assessments and resource concerns. Early tests of TMFs would be used to determine the effectiveness of TMFs and a best approach to trout management. TMFs may not be tested when there appears to be the potential for unacceptable adverse impacts to specific resources such as humpback chub. Triggers for the implementation of TMFs would be developed in consultation with the AZGFD and other stakeholders to determine the implementation based on resource conditions in the given year. For Alternative D (the preferred alternative), trout

management flows are triggered by the prediction of high recruitment of young-of-year trout regardless of the cause of trout population increases or migration.

Based on the best available information, extensive modeling and extensive dialog with subject matter experts, the joint leads believe there would be concerns associated with testing TMFs when the trout population and trout recruitment is too low as that might not provide the best conditions for testing this tool. The text in the EIS has been edited to reflect this concern. Experimentally, the best conditions for testing TMFs are when high trout recruitment is expected, such as during a high release volume/equalization year or after a spring HFE, however the conditions for both of these are somewhat unpredictable and infrequent. Also DOI recognizes the concern of several Tribes related to conducting TMFs and the concerns of trout fisherman about the status of the trout fishery when TMFs are tested. DOI has designed the process for experiments to include a detailed evaluation of the resource conditions for the year and an extensive coordination process to hear from Tribes, agencies and the AMWG stakeholders about the concerns present at the time of implementing the experiments

3.7 QUAGGA MUSSELS

Summary Comment: A few commenters expressed concern that a potential infestation of quagga mussels below Glen Canyon Dam will have an adverse environmental impact. Because of the range of alternatives were developed before quagga mussel infestation occurred, it will be critical to study how best to mitigate the environmental damage it may cause. It was believed that there is a high probability that quagga mussels will change the food base chain and conflict with the proposed need for low summer flows to improve the aquatic food base. It is unclear what will happen to productivity in the Glen Canyon Reach if organic matter is reduced as a result of quagga mussels becoming established in Lee‘s Ferry.

Response: Quagga mussels continue to be found in the Colorado River below Glen Canyon Dam. Their distribution is patchy and highly influenced by location-specific flow regimes. While the potential impact from quagga mussels is uncertain, their management is beyond the scope of the EIS. If required, they would be managed through other actions conducted by the NPS. The Kennedy (2007) report cited in the EIS points out that negative ecological impacts appear to be low and that moderate densities of quagga mussels may increase food available to fish, increase the complexity of habitat and stimulate additional benthic production. (A link to the report can be found at http://pubs.usgs.gov/of/2007/1085/.)

3.8 PROVIDE ADDITIONAL/UPDATED INFORMATION ON AQUATIC RESOURCES AND SPECIES

Summary Comment: Several commenters wanted to see additional or updated information on a particular aquatic resource or species. These included wanting the EIS to provide more recent information regarding the status of razorback suckers in Lake Mead and the Lower Grand Canyon. Another commenter wanted the EIS to include the most recent data on brown trout recruitment in the Lee’s Ferry section of the Colorado River. One commenter requested that the connection between mayflies, stoneflies and caddisflies and the fish community be more

thoroughly addressed. Another commenter was concerned about predation of larval humpback chub by juvenile and adult humpback chub, as this could be a significant factor in year-to-year recruitment. One commenter noted that to fulfill the requirements of the Endangered Species Act, the best scientific and commercial data available needs to be used.

Response: The assessment of potential impacts from LTEMP activities on aquatic resources and species in the EIS is based on an extensive review of the scientific literature and other available data; as well as input from federal and state agencies (including the FWS and AZGFD) and other interested stakeholders. Recent literature and information on the aquatic resources and species made available since publication of the DEIS has been incorporated into the EIS. In regards to listed fish species, the recently completed Biological Assessment (BA) for the LTEMP is included as Appendix 0 of the EIS. The aquatic ecology sections (Sections 3.5 and 4.5) have been modified to include information from the BA.

3.9 AZGFD MANAGEMENT PLAN

Summary Comment: Commenter wanted information added describing the Arizona Game and Fish Departments Fisheries Management Plan, Colorado River-Lees Ferry 2015-2025 (Rogers 2015). The plan includes implementing actions that may be considered ongoing actions. The AZGFD refined the goals and objectives for the Lees Ferry Fishery in that plan. The purpose of the plan was to set measurable goals and identify several strategies to reach these goals. This differs from the NPS comprehensive fisheries management plan which focused on stocking triggers for Lees Ferry in the event the fishery returned to conditions prior to MLFF where it was primarily supported by stocking. A key concern which is addressed in the AZGFD plan, and not in the NPS comprehensive fish management plan, is the definition and response to a catastrophic loss of the fishery. The AZGFD plan is a proactive approach that aligns with the NPS Comprehensive Fisheries Management Plan that seeks to avoid a catastrophic loss and to ensure that the highly valued recreational trout fishery is sustained or enhanced while minimizing impacts to humpback chub.

Response: The AZGFD management plan and NPS's Comprehensive Fisheries Management Plan are independent of the LTEMP EIS. Currently, there are aspects of the AZGFD plan that are not in agreement with the LTEMP or with the Comprehensive Fisheries Management Plan. These issues include HFEs triggered by dissolved oxygen conditions or trout population levels, and details related to stocking conditions. Because of these differences, at this time, the joint leads cannot include these objectives or reference this plan in its current form because several of the actions in the plan do not meet the purpose and need of the LTEMP or do not agree with the Comprehensive Fisheries Management Plan. The NPS is continuing to work with AZGFD to work toward agreement on these concerns.

4 CULTURAL RESOURCES

4.1 APPLICABILITY AND COMPOSITION OF CULTURAL RESOURCE METRICS

4.1.1 Wind Transport

Summary Comment: Commenters expressed concern with how effectively this metric captures the potential for wind transported sediment to help preserve archaeological sites along the Colorado River. The comments ranged from requests to remove the metric from the analysis to clarifications on how the components of the metric were developed.

Response: The text in the EIS was updated to include the results of several recently published studies on the extent and range that wind transported sediment can be distributed. The text was also modified to indicate that some Tribal members may not consider the reburial of sites by wind transported sediment to be a positive effect.

4.1.2 Time Off River

Summary Comment: Commenters expressed that the time-off-river metric, a measure of the time available to rafters for shore exploration during river trips and a function of river flow levels, is a poor measure of potential impacts on archaeological sites and should not play an important role in the EIS analyses. Commenters noted that while the metric is a logical construct, there is no evidence that more time off river leads to greater visitation because visitors have many other options for exploration and, further, that respectful visitation of Class I sites is actually expected and encouraged.

Response: In the cultural section, 4.8, this metric is presented as a **potential** for increased effects, rather than as a direct link to increased effects, because the monitoring of these sites which NPS has performed over the last 20 years has not shown a strong correlation or a cause and effect relationship. The metric was developed in response to concerns from the Tribes who have noted negative effects at archaeological sites due to visitors and their observations that additional time off river allows for boating parties to spend more time hiking and visiting sites. The value of the metric for cultural resources varied little among the LTEMP alternatives as noted in Section 4.8.

In the recreation analysis in Section 4.11, this metric measures the potential effects of alternate flow regimes on recreation and therefore is the most pertinent means of evaluating the LTEMP alternatives with respect to effects on recreation. In the recreation analysis, more time-off-river was considered a positive for recreation as it was used to "evaluate the opportunity for onshore exploration." The value of the metric varied little among the LTEMP alternatives (Figure 4.10-1), and thus had little value in differentiating them as noted in Section 4.11.2.

4.1.3 Glen Canyon Flow Effect Metric

Comment Summary: Commenters raised concerns with the choice of Ninemile Terrace as a proxy for other historic properties in GCNRA and also questioned the effectiveness of the metric as a predictor of erosion at archaeological sites in GCNRA because of a lack of direct studies on this topic.

Response: Text was added in Appendix H to further clarify why Ninemile Terrace is an effective proxy for other archaeological sites in GCNRA. The components of the metric are based on direct observations of effects from past HFEs on the terrace.

4.2 AREA OF POTENTIAL EFFECTS

Request disclosure on how APE was determined. Do not support the rim to rim application of the APE.

Summary Comment: Several commenters inquired about the Area of Potential Effect (APE) for the Section 106 of the National Historic Preservation Act review for LTEMP. The DEIS contained general language on this topic as consultation was on going when the DEIS was issued. Specifically they were seeking information on how the APE was determined and which historic properties were being included. There was a commenter who disagreed with defining the APE to include all historic properties within the canyon.

Response: Text in Chapters 3 and 4 has been updated to explain the differences between the analysis of potential effects between NEPA and NHPA Section 106. Reclamation and the NPS are developing a new programmatic agreement for the NHPA Section 106 process and to help guide management of cultural resources along the Colorado River. These consultations are on-going. Once the Cultural Programmatic Agreement is complete the information on the APE will be provided to the public.

4.3 LANDMARK STATUS FOR GRAND CANYON AND ITS RESOURCES

Summary Comment: Comments were received suggesting that the cultural resources found within the Grand Canyon warrant consideration as a National Historic Landmark and that nomination of the resources as a National Historic Landmark begin soon.

Response: The NPS is continuing consultations with the Tribes concerning future nominations for listing of resource in the National Register of Historic Places. However, the nomination of the canyon as a National Historic Landmark is beyond the scope of the LTEMP EIS.

5 CUMULATIVE IMPACTS

5.1 ADDITIONAL FORESEEABLE ACTIONS (INCLUDING MANAGEMENT PLANS) TO BE INCLUDED

Summary Comment: Commenters requested that additional foreseeable actions be included in the cumulative impacts analysis. Among them were the MLFF alternative (1996 ROD), releases of contaminated water into Lake Powell (related to mines), the AZGFD fisheries management plan, and the Flaming Gorge Dam and Aspinall Unit EISs.

Response: The cumulative impacts analysis was revised to include the additional foreseeable actions as requested and to account for the effects of these actions on various resources, as warranted.

5.2 REFINEMENT OF DESCRIPTION AND/OR IMPACT ASSESSMENT FOR FORESEEABLE ACTIONS CONSIDERED

Summary Comment: Commenters requested revisions to modify or update the descriptions of foreseeable actions identified; e.g., to flesh out the implications of the 2007 Guidelines to water resources or to update the status of the Clean Power Plan proposed rule. Other requests pertained to defining terms (e.g., the region of influence or the term "future projects"). Commenters also requested that descriptions of power plants (Four Corners and San Juan Generating Station), listed as foreseeable actions, be revised to reflect the current and scheduled modifications at those plants and that the implications of these changes to regional hydropower generation be addressed.

Response: The cumulative impacts analysis was revised to update descriptions of foreseeable actions and to account for the effect of these changes on water resources and hydropower, as warranted. Definitions of terms such as "region of influence" and "future projects" were added in Section 4.17.

6 HYDROPOWER

6.1 SCOPE OF ANALYSIS AND STUDY ELEMENTS

6.1.1 Hydropower Goals and Objectives

Summary Comment: Hydropower goal and objectives are not clear and use conflicting language in the various sections of the report.

Response: Text has been revised to make consistent throughout EIS.

6.1.2 Generation at Hoover Dam

Summary Comment: Analysis of changes in generation at Hoover Dam is beyond the scope of LTEMP because Hoover and Glen Canyon are statutorily separate.

Response: Although Glen and Hoover are statutorily separate and effect different entities, the power systems economic analysis focuses on power production costs and capacity expansion related expenditures for the grid as a whole not on the financial impacts for specific entities. Economic impacts on Lake Mead and Hoover Dam are the result of changes in monthly water release patterns from Lake Powell. These changes to impacts on power economics have been identified and therefore were included in the FEIS.

6.1.3 Cumulative Impacts on Power Systems

Summary Comment: Cumulative impacts on power systems were not adequately addressed.

Response: Text has been added to the EIS to address this concern in Section 4.17.

6.1.4 Analysis of Impacts on Basin Fund

Summary Comment: The impacts on Upper Colorado Basin Fund, cash flow and its ability to fund important research should be studied in more detail.

Response: Section 3.13.1.2 includes a description of the Basin Fund and states “Most of the revenues come from sales of hydroelectric power and transmission service.” This EIS did analyze revenues from Glen Canyon hydropower production and their contribution to the Basin Fund. See the extensive hydropower analysis in 4.13 and Appendix K. There are other factors that affect the balance of the Basin Fund; however, they are outside the scope of the actions analyzed in the LTEMP EIS and would not be affected by the LTEMP alternatives. It should also be noted that consideration of unacceptable adverse impacts on the Basin Fund is one of the considerations included in Section 2.2.4.3 as part of the implementation process for experiments that may affect hydropower.

6.1.5 Consideration of Impacts on Basin Fund

Summary Comment: Impact on Upper Colorado Basin Fund should be a secondary consideration when selecting a preferred alternative.

Response: DOI considers the Upper Basin Fund important to the LTEMP given its role in funding environmental activities. Consideration of unacceptable adverse impacts on the Basin Fund is one of the considerations included in Section 2.2.4.3 as part of the implementation process for experiments.

6.1.6 Power System Impacts on Climate Change

Summary Comment: Potential climate change impacts on LTEMP alternatives were not incorporated in the power systems analysis.

Response: Climate change effects on hydropower generation results are presented in Section 4.16.3. The LTEMP climate change analysis was based on the Basin Study (Reclamation 2012), which was peer reviewed and is the best available science regarding climate change projections in the Colorado River Study. The hydrological traces generated for the Basin Study were utilized as described in Section 4.16.1.2 and Appendix C. The Basin Study used 112 climate change hydrologic traces generated as part of the Basin Study, however due to insufficient data to drive the complex suite of models, we used a subset of 21 traces out of the 112 for the LTEMP EIS. These 21 reconstructed historical hydrological traces were reweighted based on the 112 traces to represent the best current understanding of what might happen because of climate change. Based on this analysis, the weights on the hydrological traces had a small effect on the aggregate performance but did not change the rankings of alternatives. This result suggests the alternatives are robust to uncertainty about climate change.

6.1.7 Sensitivity Analysis of Fuel Prices

Summary Comment: A sensitivity analysis using a range of projected utility fuel prices should have been conducted because natural gas prices are currently very low.

Response: Text was added to the EIS text acknowledging the possible effects of the currently low natural gas prices on results.

6.1.8 Clean Powerplant Legislation

Summary Comment: Clean powerplant legislation was not considered in the analysis.

Response: Information about clean powerplant legislation is included in the cumulative impacts Section 4.17, but that legislation is currently in draft form. In February 2016 the Supreme Court ordered EPA to stop enforcement until a lower court rules on a lawsuit. A ruling on the lawsuit will most likely not come until after the 2016 presidential election and enforcement may depend upon the results of the election as well. Because specifics are unknown at this time and it may be

tied up in litigation for many years, it was not appropriate to analyze it further than this in this EIS.

6.2 GENERAL OVERARCHING COMMENTS ON THE POWER SYSTEMS ANALYSIS

6.2.1 Adequacy of Power Systems Analysis

Summary Comment: The analysis is strongly biased against hydropower resources, incomplete, and significantly underestimates costs in all cases using simplified models and metrics for hydropower resource rendering it inadequate.

Response: The commenter has provided no evidence to support these conclusions. Therefore, we have no basis to determine whether or not they are accurate. We do not believe that the analysis is biased against hydropower resources, is incomplete, or underestimates costs. LTEMP used economic measures that are consistent with the ones used in other Upper Colorado River Basin environmental studies. The level of technical detail that was used to support the computation of these measures has in general exceeded the ones used in other studies, some of which only applied the GTMax-lite model. For the LTEMP analysis we also used the AURORA model to explore grid-wide interactions. All major assumptions are both noted and documented and rely on publically available sources such as those published by the U.S. Energy Information Administration (EIA) and the Federal Energy Regulatory Commission. There were several sensitivity analyses included in Appendix K to explore possible additional sources of costs. In response to utility cooperator comments on the DEIS, an additional analysis was added to Appendix K looking at a different mix of powerplant replacement technologies which could result in a higher estimate of capacity replacement costs. The text in Chapter 4 Section 4.13 was also updated to include a summary of those sensitivity analyses.

6.2.2 Ratepayer Analysis Flawed

Summary Comment: The retail ratepayer analysis that was included within the draft LTEMP EIS report is flawed because the agencies that conducted the analysis do not provide retail electric service, do not deal with issues that are directly related to the provision of retail electric service, do not have expertise with respect to retail electric rate making, and did not consult with retail electric service providers such as SRP when conducting the analysis.

Response: Retail rate analyses were primarily conducted by Edward Bodmer who led retail electricity rate and utility financial viability analyses for Western's Electric Power Marketing EIS. He is an experienced financial consultant who develops complex corporate project finance and simulation models. He provides expert testimony on financial issues before regulatory agencies and has taught customized in-house courses for Shell Oil, General Electric, HSBC, Citibank, CIMB, Lindlakers, Saudi Aramco and many other energy and industrial clients around the world. He also worked for a regulatory commission and has testified approximately 40 times on rate making issues both from a financial perspective and a rate allocation perspective. The

rate impacts were reviewed by experts in the field who had no problems with the overall approach. Formerly, Bodmer was the Vice President at the First National Bank of Chicago, where he directed created financial modeling techniques used in advisory projects. With respect to the comment that we did not consult with entities such as SRP, this is simply incorrect. We received comments, letters and made presentations where ratemaking entities were present. In addition, we did extensive research on the financial structure of the entities and reviewed financial data in the context of rate setting. In addition, the ratepayer methodology and results report were peer reviewed by three independent reviewers as well as by GCMRC.

6.2.3 Inputs to Capital Costs Analysis

Summary Comment: Capital costs should have been supplied by CREDA members since they actually build new powerplants and entities such as Argonne and Energy and Environmental Economics, Inc. (E3) do not.

Response: LTEMP assumptions regarding the characteristics of all capacity expansion candidates including capital investment costs are noted and documented in K.1.6.2. These costs are based on Energy Information Administration (EIA) data that are used for the EIA Annual Energy Outlook. This section discusses these costs and compares these to other estimates including those used by Western Electricity Coordinating Council (WECC) and those supplied by CREDA for a previous Upper Colorado River Basin EIS. LTEMP hydropower analysts are both well qualified and have extensive experience in applying these costs for economic analyses. We note that a very similar approach that also used EIA data sources was used by E3 for a study conducted for WECC.

As stated in Chapter 4, Section 4.13.1 "The LTEMP hydropower resources impact analysis was largely an economic analysis rather than a financial analysis. A financial analysis focuses on the revenues and costs accrued by a particular entity, including transfer payments, such as power transactions, taxes, and insurance. It also includes payments made by individual entities for previous investments. In contrast, an economic analysis focuses on societal costs and benefits. Transfer payments among entities are excluded because the total net change to society of these transactions is zero; that is, the amount paid by the buying entity equals the amount received by the selling entity. Also excluded from economic costs are past investments, such as those to construct power plants, because these expenditures have already been incurred on society and cannot be recovered. Similar to other power systems EIS analyses performed by Argonne, the economic analysis performed for LTEMP estimates changes to the U.S. economy as the result of altering operating criteria at Glen Canyon Dam. These economic costs include expenditures to build and operate new capacity in the future to replace Glen Canyon Dam Powerplant lost capacity and both fuel and variable operation and maintenance (O&M) costs associated with altering the dispatch of Western Interconnection generating units. A financial analysis was performed for the LTEMP EIS to estimate the wholesale (see Section 4.13.1.2) and retail rate impacts (see Section 4.13.1.3) on individual affected entities (e.g., individual FES utilities and their retail customers)."

6.3 LEGAL ISSUES

6.3.1 HFEs as Part of Long-Term Operations

Summary Comment: Bypass releases associated with HFE's that are conducted on a routine basis as part of a long-term operational plan are inconsistent with the "Law of the River" and that have not been addressed from a legal perspective.

Response: These releases are experimental and are being implemented in compliance with the Law of the River and specifically in compliance with laws related to the operations of Glen Canyon Dam. Experimental releases only change the monthly and hourly releases with annual volumes still complying with the LROC as currently implemented through the 2007 Interim Guidelines.

6.3.2 Irretrievable Loss of Hydropower

Summary Comment: Experiments cause an irretrievable loss of hydropower production, but there is no analysis included which would meet the requirement of 40 CFR 1506.1

Response: To the extent there is a loss of hydropower production in the future as a result of implementing the preferred alternative, this potential loss has been analyzed in the EIS. Analysis has been added to Section 4.17, and a discussion provided in Section 4.20.

6.4 TECHNICAL POWER SYSTEM ISSUES

6.4.1 Discount Rate

Summary Comment: Discount rate used in the analysis is too high and capital costs have not been escalated resulting in an underestimate of negative power impacts

Response: By policy, Reclamation is required to use the Principles and Guidelines (P&G) discount rate which is currently 3.375%. A rate of 1.4% was used in a sensitivity study, the results of which have been documented. Also, Reclamation P&Gs do not allow real capital cost escalation.

6.4.2 Capital Costs

Summary Comment: Capital costs are too low; all cost considerations for constructing a new generating plant were not included in developing capital and O&M costs.

Response: The economic cost to build a new generating unit (LTEMP costs) and the financial outlays that a utility incurs to build a new generating unit (CREDA costs) are fundamentally different. Utility outlays for taxes and insurance are excluded from an economic analysis because

these are transfer payments that are not part of the cost of construction. LTEMP did not include site specific costs that are advocated by CREDA because that level of detail is beyond a typical economic analysis for an EIS. It would be prohibitively time consuming and expensive to determine all possible sites for power plant replacement and all of the costs associated with those sites, and that level of analysis has never been performed for similar EIS documents on the Colorado River. EIA costs are based on typical values that we adjusted for broad regional construction costs considerations such as material and labor. In response to utility cooperator comments on the DEIS, an additional analysis was added to Appendix K looking at a different mix of powerplant replacement technologies which could result in a higher estimate of capacity replacement costs.

6.4.3 Exceedance Level

Summary Comment: There are concerns about exceedance level assumptions used to estimate firm Glen Canyon Dam Powerplant capacity.

Response: An analysis of Western's current marketing commitments shows that the assumption of 90% exceedance level used in the LTEMP EIS is consistent with their marketing planning assumptions. A 90% exceedance level means that there is up to a 10% risk of those commitments not being met in a given year. To address these concerns about future marketing commitment levels, a sensitivity study was performed on 50%, 90%, and 99% exceedance levels. Results are shown in Appendix K.1.10.4 and summarized in Chapter 4.13. These results generally conclude that lost Glen Canyon Dam powerplant capacity under all alternatives except for Alternative B have the highest capacity loss at the 50% exceedance level that progressively decreases through the 99% exceedance level (see Figure K.1-32 in Appendix K). We therefore performed an economic cost sensitivity analysis on these two levels to quantify reasonable cost "bookends."

6.4.4 Ancillary Service Assumptions

Summary Comment: There are concerns about ancillary service assumptions.

Response: Cooperators were concerned that using a lower ancillary service requirement could significantly affect Glen Canyon Dam dispatch, firm capacity levels, and economic evaluations. A simplified sensitivity analysis was therefore performed to gain a general appreciation for the impact of ancillary service assumptions on model outcomes. The analysis was performed on Alternatives A, D, and F under two disparate ancillary service market assumptions. Results should that difference in the combined net present value of capacity and energy was 0.14% or less. Under all cases, this small economic difference was primarily due to the existence of significant levels of "unused" Glen Canyon Dam Powerplant capacity which could be used to fulfill ancillary service obligations. This analysis is documented in Appendix K.1.10.8.

6.4.5 Modeling Assumptions

Summary Comment: There were questions about the modeling assumptions regarding locational marginal prices (LMP) responses to changes operations at Glen Canyon Dam and the Western Electricity Coordinating Council study (WECCi-leaks study).

Response: Text has been edited for clarity and both figures and reference to the WECCi Leaks study have been removed as it was not used as part of the LTEMP analysis.

6.4.6 Small Customer Representation

Summary Comment: The representation of small customers is unrealistic and flawed. Small customers are more limited in their choices of suppliers due to transmission and resources and do not have the financial resources or the load to build new facilities to replace capacity and energy losses.

Response: The representation of small customers is neither unrealistic nor flawed. For the power systems analysis (both expansion and dispatch modeling), we aggregated the small customers together for precisely the reasons outlined in the comment; namely, that small customers could not build their own facilities and are dependent upon other suppliers and power purchase agreements.

6.4.7 Small Customer Loads and Load Growth

Summary Comment: The representation of small customer loads and load growth rates are incorrect.

Response: Small customer load assumptions and simplifications are fully explained and disclosed. Because hourly generation levels were not readily available from publically available sources, we used normalized load profiles from other entities as approximations. Normalized load profiles express loads in terms of a fraction of the peak load such that the peak load is set equal to 1.000 and all other loads are less than 1.000 (i.e., hourly load/peak load). These load shapes were scaled to match estimated historical total load based on information that was collected for the retail rate 40 payer analyses. For example, the UAMPS normalized load profile was used to represent small customers in the west. It was selected because most of the 44 UAMPS members are small municipal systems that serve small to medium cities and towns that have attributes which are similar to many of WAPA's small customers. We judged that this modeling approach produces a reasonable approximation of aggregate small customer loads. In addition, errors occur equally under all alternatives and therefore probably have minimal effects on the comparative results.

6.4.8 System Expansion Plan

Summary Comment: Assumptions regarding a cooperative SLCA/IP system-wide expansion plan are overly simplistic and results in an underestimate of power impacts.

Response: Text revisions have been made for clarification. Power impacts have not been underestimated because this level of modeling and simplification is consistent with and improves upon previous EISs conducted for Glen Canyon Dam, such as the 2007 interim guidelines. Due to the complex nature of the grid, all power systems models with scopes that cover a large geographical area over a multiple year time span, such as the one conducted in support of LTEMP, need to make simplifying assumptions in order for the problem to be tractable. For LTEMP we tailored models and methods to meet study objectives; that are to rank alternatives in terms of economic costs and to gain an appreciation for relative costs among alternatives. As detailed in Appendix K, we performed sensitivity analyses on several key modeling assumptions to learn about the effect of these assumptions on model results and to obtain a reasonable estimate of potential outcomes. We also applied methods and models, such as AURORA, that were more detailed than those used for previous EIS's conducted on power facilities in the Colorado River Basin. We observed that the ranking are very robust changing little as a function of modeling assumptions. We also observed the GTMax-lite model that strips away many of the modeling complexities embedded within AURORA lead to very similar alternative rankings. Thus, we made assumptions and implications at the level appropriate for this type of analysis and have fully disclosed those assumptions in the EIS. We also discussed the possible implications of this simplification of model results. The document also includes several examples of joint powerplant/unit ownerships that currently exist in the study region. The power analysis methods, assumptions and results have been peer reviewed by three external experts and the peer review results are available on the LTEMP website.

6.4.9 Transmission Constraints

Summary Comment: Transmission system constraints on power exchanges in the region should have been included in the analysis.

Response: Detailed transmission system constraints on power exchanges in the region were not explicitly modeled because it would have significantly increased the size and complexity of the problem and it was not expected to have a significant impact on comparative results among alternatives. It is also consistent with previous EISs conducted for Glen Canyon Dam that also did not explicitly represent the transmission system. We did however include on- and off-peak costs on AURORA modeled energy flows (i.e., power transactions) among customers based on average historical transmission rates. These costs tend to dampen bulk power transactions among energy trading entities. The end result was that AURORA estimated generation levels are very similar to historical levels by both fuel type and at the utility level. We have disclosed methodologies, assumptions, limitations and results which were peer reviewed. It is noted in the EIS that the WAPA contract rate of delivery (CROD) will be identical under all alternatives. If feasible, customers can utilize the CROD to schedule the delivery of both WAPA energy and other energy transactions up to the contractual limit.

6.4.10 Renewable Portfolio Standards

Summary Comment: SLCA/IP customers such as SRP are not required to comply with State Renewable Portfolio Standards (RPS).

Response: We acknowledge that RPSs are not required of all LTF customers. SRP and Tri-State do have an internal program to set a target for building significant amounts of renewable or sustainable resources.

6.4.11 Costs of HFEs

Summary Comment: Costs to conduct experiments such as HFEs are underestimated because trading partners would take advantage of Western's inflexible situation during experiments.

Response: We acknowledge that the prices that WAPA is offered from its trading partners during HFEs sometime depart from overall market prices. This has financial implications for WAPA. The power systems economic analysis does not consider these financial transactions because there are no system-level economic impacts. The savings gained by entities that purchase at below market prices are exactly offset by financial losses for entities that sell below market price. The net economic impact is therefore zero.

6.4.12 Costs of Experiments

Summary Comment: The costs to conduct experiments are too low and experiments such as low summer flow would have a devastating impact on power.

Response: The analysis shows that a low summer flow experiment would not significantly, if at all, change annual hydropower production during low summer flow years. There would be an economic impact however with a decrease in NPV between $13.93 million and $21.01 million. Low summer flows are projected to occur infrequently; under the preferred alternative, low summer flow would be expected to be tested once in the second 10 years of the LTEMP period.

6.4.13 Impacts of Macroinvertebrate Production Flows on Hydropower

Summary Comment: Macroinvertebrate production flows may cause serious negative impacts on power and should be conducted in a way that is least damaging to hydropower.

Response: After the DEIS was published, hydropower assumptions and the modeling of macroinvertebrate production flows were revised based on input from WAPA, the results of which show a positive benefit to hydropower capacity. Revised results are consistent with analyses conducted by WAPA regarding a positive net benefit to power.

6.4.14 Effects at Hoover Dam and Glen Canyon Dam

Summary Comment: Concerns were raised about potential perceptions regarding changes in higher Lake Mead elevations and Hoover powerplant "benefits" offsetting Glen Canyon Dam economic impacts.

Response: To address these concerns the description of Hoover Dam impacts were substantially revised. The FEIS no longer refers to changes in the NPV of Hoover as a "benefit" or as "offsetting" alternative costs at Glen Canyon. We also indicate that the economics of Hoover and Glen Canyon are not directly comparable because the analyses used different levels of modeling details. Instead we indicate that the Hoover analysis was performed primarily to disclose the general direction and relative magnitudes of Hoover impacts.

6.5 RETAIL RATE ANALYSIS

6.5.1 Consideration of Wholesale Rate Input

Summary Comment: Retail electric rates were computed without accounting for wholesale rate charged by Western

Response: Wholesale rates were not used because: (1) the wholesale rate study was completed after the retail rate analysis; (2) through directly using data from the power systems model the direct connection between power system costs and rate impacts could be observed and the process was transparent; (3) the capital cost of constructing new capacity incurred by utility systems (such as Tri-state) was directly estimated rather than assuming Western would carry the burden of replacing the capacity. In addition, modeling was peer reviewed by three independent reviewers as well by GCMRC.

6.6 WHOLESALE RATE ANALYSIS

6.6.1 Assumptions

Summary Comment: Concerns regarding the bookends marketing assumptions selected for the wholesale rate analysis

Response: Wholesale rate bookends were chosen because they were thought to represent a reasonable range for the marketing of SLCA/IP power in the post-2024 period and illustrate that the effect of the SLCA/IP rates from the LTEMP EIS alternatives are, in part, driven by sales of AHP energy and capacity.

6.7 EDITORIAL COMMENTS

Numerous substantive editorial comments were submitted on hydropower sections in the DEIS including Sections 3.13, 4.13, and Appendix K. Where appropriate, the text of the EIS was modified to address the specific comments.

7 NATURAL PROCESSES

7.1 NATURALLY PATTERNED FLOW AND RUN-OF-THE-RIVER FLOW ALTERNATIVES

Summary Comment: One commenter suggested that the LTEMP should improve habitats by attempting to recreate the shape of the historic hydrograph by generally increasing water levels until June followed by a gradual ramp down to a lower level between September and February, with a possible late summer spike to simulate late-summer monsoons. The daily fluctuations with dramatic step-ups and step-downs in flow that now occur almost never occurred before the dam was in place.

Response: "Naturally patterned flow" and "Run-of-the-river" alternatives were considered but dismissed in the draft EIS (see Sections 2.3.2, 2.3.11).

7.2 REMOVE NATURAL PROCESSES FROM THE EIS

Summary Comment: One commenter wanted natural processes deleted from the EIS.

Response: No text change made. The natural processes goal was based on several of the Desired Future Conditions (see Appendix A of the EIS) and on NPS management policy.

7.3 NATURAL RESOURCE PERFORMANCE GOAL

7.3.1 Quantitative Performance Metric

Summary Comment: Several commenters stated that a quantitative performance goal should have been established for natural processes, possibly comparing alternative flows with pre-dam flows.

Response: The best available science and models were used in this EIS. There was not adequate information to develop a quantitative performance metric for pre-dam versus post-dam conditions in a consistent manner to facilitate comparison across alternatives for natural processes.

7.3.2 Goal to Restore Is Not Achievable

Summary Comment: A few commenters wanted the following sentence deleted: "For the LTEMP, the analogous natural processes resource goal is to 'restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems'." It is not possible to operate Glen Canyon Dam in a manner that could

fully restore natural processes and their drivers to those that occurred under unregulated conditions

Response: No text change made. The natural processes goal was based on several of the desired future conditions (see Appendix A of the EIS) and on NPS management policy. The EIS recognizes that management of dam operations and any subsequent effects on natural processes may not act to fully restore natural resources in the system. Rather, the EIS compares alternatives with regard to how alternative-specific temperature, flow, and sediment conditions may affect processes that depend on these conditions, and possible subsequent responses in natural resources, including not only maintenance of native biota in their current conditions, but also enhance or improve habitats and thus benefit associated biota.

7.3.3 National Park Service Natural Processes Management Policy and Goals

Summary Comment: One commenter noted that an important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals and natural ecological processes. NPS management policies state that (1) "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species" and (2) "the Service ... will try to maintain all components and processes of naturally evolving park ecosystems, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" (NPS 2006b). For the LTEMP, the analogous natural processes resource goal is to "restore, to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems." It is not possible to operate Glen Canyon Dam in a manner that could fully restore natural processes and their drivers to those that occurred under unregulated conditions." Since management policies are not dictum; why can they not be changed? The commenter further states that statements such as "rely on natural processes" and "try to maintain" are much different from "restore".

Response: Changing NPS Policy is outside the scope of the EIS. The EIS recognizes that management of dam operations and any subsequent effects on natural processes may not act to fully restore natural resources in the system. Rather, the EIS compares alternatives with regard to how alternative-specific temperature, flow, and sediment conditions may affect processes that depend on these conditions, and possible subsequent responses in natural resources, including not only maintenance of native biota in their current conditions, but also enhance or improve habitats and thus benefit associated biota

7.4 OPPORTUNITY TO EXPAND NON-FLOW MANAGEMENT OPTIONS TO IMPROVE AQUATIC AND RIPARIAN HABITAT

Summary Comment: A commenter noted that Glen Canyon Dam is presently functioning to protect native aquatic and riparian species from upstream and downstream threats. However, the very existence of the Dam is at odds with the National Park Service (NPS) Organic Act and the enabling legislation of Grand Canyon National Park. This means that the management objectives

of the NPS at Grand Canyon do not really include using the Dam to foster aquatic and riparian habitat rehabilitation. Reclamation and the NPS could be doing much more to improve riparian habitat quality, particularly now that much of the non-native tamarisk habitat along the river is declining due to tamarisk leaf beetle introduction. Collaboration of these two agencies in this DEIS and the Record of Decision is an opportunity to greatly expand non-flow management options to improve aquatic and riparian habitat area and quality.

Response: The LTEMP is intended to identify operational and experimental management alternatives specifically for protecting and enhancing aquatic, riparian, and terrestrial habitats and their associated biota, as well as protecting cultural resources and balancing human uses in the system. Alternatives considered in the EIS include flow conditions that may support improvements in riparian and aquatic habitats. The LTEMP also includes non-flow management options, such as mechanical trout removal, that may benefit native aquatic biota in the system. All the action alternatives also include a non-flow vegetation treatment experiment to address riparian vegetation including removal of invasive species and replanting of natives. The agencies have been working together, and expect to continue that collaboration beyond the ROD for protecting and improving natural and cultural resources while providing for cultural, recreational, and commercial uses and activities in the Grand Canyon National Park.

7.5 HFEs SHOULD BE INCLUDED IN THE EVALUATION OF EFFECTS TO NATURAL PROCESSES

Summary Comment: A couple of commenters stated that since HFEs have a direct effect to fisheries, plants, animals, and water quality, they should be considered in the effects on natural processes.

Response: HFEs were considered in the effects on all resources in Chapter 3, as well as on Natural Processes.

8 PROCESS AND POLICY

8.1 INCLUDE THPOs IN CONTACT LIST

Summary Comment: Commenters on this issue requested that THPOs be included in the list of groups to be contacted.

Response: Text has been modified as suggested and THPOs have been added to the list of groups to be contacted.

8.2 TRIBES INVOLVEMENT IN ALTERNATIVES DEVELOPMENT

Summary Comment: A commenter on this issue indicated that Tribes should have been invited to participate in alternative development like the Arizona Game and Fish Department was.

Response: Tribes were invited to be Cooperating Agencies in the LTEMP EIS process – see Section 5.1.3 for the process that was used to inviting and communicating with Tribes. Many meetings were held with Tribes throughout the alternative development process, the modeling development and results, the structured decision analysis, and the draft writing and editing to allow for input and comment. Meetings are still continuing with Tribes on the programmatic agreement and on a non-native fish agreement related to the LTEMP. Several traditionally associated Tribes are part of the AMWG process as well as being cooperators, and so were part of the LTEMP process through many meetings and webinars provided through that process.

8.3 SIERRA CLUB'S SCOPING COMMENTS

Comment Summary: The commenter on this issue requested that Sierra Club's scoping comments be added to the official public record and requested that their comments be addressed in the Final Environmental Impact Statement.

Response: We apologize that the Sierra Club scoping letter was inadvertently left out of the initial scoping report that was made available on the LTEMP website. Thank you for calling this to our attention in your comments on the DEIS and we have now added your scoping letter to that report and made the revised version available on our website. Your letter was reviewed and considered in the process of drafting the LTEMP EIS. Below is a summary of the issues you presented in your scoping letter and how we have addressed them in this EIS process.

1) Introduction – concern regarding declining conditions since the dam has been in place – 95% sediment loss, nutrient base, dissolved oxygen, temperature reduction, changes to flood regime, extirpated species, increasing non-native plant species.

Response: This list of concerns were considered in the preparation of the EIS. Chapter 3 of the EIS describes changes that have occurred in the Colorado River Ecosystem since construction of the dam.

2a) Legal Authorities - hydropower generation should be removed from the need statement.

Response: The purpose and need statement clearly articulates the responsibilities of the Secretary of the Interior under the Grand Canyon Protection Act (GCPA); the goal of which is to preserve, mitigate adverse impact to and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use. The purpose and need and alternatives evaluated in the EIS take direction from the GCPA and attempt to develop an alternative that meets the requirements of the GCPA and applicable Federal laws, regulations, and policies. In addition to Section 1802(a) of GCPA, the Secretary is required to follow numerous other Federal laws, including the 1956 Colorado River Storage Project Act. Both Section 1 quoted in the letter, and Section 7, direct the Secretary to generate the greatest practicable amount of power at Glen Canyon Dam. This requirement is also found in Section 1802(b) of the GCPA. Therefore, removal of power generation from the purpose and need statement in the EIS would be inconsistent with other parts of the GCPA.

2b) Scientific Framework – Full analysis of downstream resources. GCMRC involvement. Clear experimental framework, thresholds, triggers. Implement recovery of native species, and analyze alternatives that experiment with sediment augmentation, temperature modification and restoration of the natural hydrograph.

Response: The LTEMP EIS provided a full analysis of downstream resources that could be affected by the proposed action and alternatives. GCMRC was involved in the development of alternatives, in developing modeling approaches, in subject matter expert meetings throughout the process, in reviewing and editing the EIS, and in peer review of models and finally in the development of a science plan to guide the implementation of LTEMP once a final preferred alternative and ROD are in place. The reintroduction of extirpated species was outside the scope of the LTEMP as stated in Section 1.5.3. Early in scoping, we did consider some alternative concepts with new infrastructure, but determined that consideration of new infrastructure on the dam such as sediment augmentation and temperature modification were outside of the scope as well as economically infeasible at this time as stated in Section 1.5.3. In early scoping we did evaluate several alternatives that would have resulted in dam releases intended to mimic the natural hydrograph. However, preliminary modeling indicated several of those had unacceptable adverse resource impacts, particularly to sediment. Seasonally Adjusted Steady Flows was the most natural hydrograph in an alternative and was carried all the way through as Alternative G. The preferred alternative does incorporate two types of spring releases (sediment triggered and proactive spring HFEs) which provide peak flows that mimic the natural hydrograph to some degree.

3) Modification of Purpose and Need

Response: Please see the answer to Legal Authorities comment.

4) Impacts to Natural Resources – Sediments and Soils

Response: Sediment conservation was fully considered and analyzed in the LTEMP EIS using the best available science and modeling. See Sections 3.3 and 4.3. All of the action alternatives

included high flows of various types and frequencies. The effect of the flow regimes on natural processes and native species was considered in the analysis based on the best available information.

5) Impacts on Natural Resources – Threatened, Endangered and Sensitive Species

Response: Endangered, threatened and sensitive species were considered in the LTEMP EIS analysis based on the best available science and modeling. See Sections 3.5, 3.7, 4.5, 4.7.

6) Unsuccessful Native Fish Recovery

Response: Temperature and flow effects of the preferred alternative on native fish were evaluated in the LTEMP EIS. The preferred alternative includes a spring high flow, called a proactive spring HFE, which would occur generally at a time that the historical record indicates was when spring flooding in Grand Canyon typically occurred. Though proactive spring HFEs have been designed for sediment conservation purposes, they may provide experimental data through GCMRC monitoring efforts on effects to native fish. Though all of the alternatives are expected to have relatively similar effects on native and endangered fish, the preferred alternative includes several actions to manage nonnative fish and experiments designed to improve aquatic invertebrate populations in order to benefit native fish. The preferred alternative performed slightly better than No Action on several native and endangered fish metrics.

7) Unsuccessful Adaptive Management Program: The unsuccessful "Modified Low Fluctuating Flow Alternative" (MLFF) enacted in the Adaptive Management Program has not achieved the desired results of protecting the Canyon's resources including the beaches, the native fishes, and the cultural sites. New alternatives should be developed by the Grand Canyon Monitoring and Research Center to address scientific hypotheses regarding the best possible alternative for sediment retention (i.e., Wright et al. 2008) and mimicking the natural historic hydrograph.

Response: GCMRC helped in the development of alternatives and a seasonally adjusted steady flow alternative was considered as Alternative G. Several alternatives, including the preferred alternative, performed better than No Action on beach and sandbar building metrics.

8) Cumulative Impacts

Response: Cumulative impacts to vegetation, fish, wildlife and endangered species were analyzed in the LTEMP EIS (see Section 4.17). The EIS incorporates elements of, and will supersede, the HFE Protocol and Non-Native Fish Removal Protocol that have been in place since 2012.

9) Impacts on Natural Resources – Water Quality: Restoration of water quality must be addressed in the EIS taking into account the effects of different release structures and their effects on downstream ecology. The EIS should also consider salinity levels, water temperature, turbidity and suspended sediment, nutrients and dissolved oxygen concentrations. An additional critical factor that must be considered is the impact of drought

on the quality of dam releases. For example, when Lake Powell is lower, water releases are warmer than, and oxygen levels differ from, water released from a fuller lake

Response: Impacts to water quality in the Colorado River and reservoirs were considered in the LTEMP EIS. See Sections 3.2 and 4.2. Climate change was analyzed with respect to hydrological effects in Section 4.2. It should be noted that the LTEMP did not affect levels of Lake Powell and Lake Mead at an annual or great time scale; the scope of the LTEMP includes monthly, daily and hourly releases from Glen Canyon Dam, but not annual volumes from Glen Canyon Dam, so the effects to water quality were considered within this scope.

10) Impacts of Reduced Flows Associated with Climate Change: The LTEMP must specifically create a plan for providing water to the Colorado River in Grand Canyon during extended drought periods.

Response: Climate change was considered within the LTEMP EIS. The 2012 Colorado River Basin Study provided data for the EIS, and the modeling included a set of modeling runs to address climate change concerns. This climate change modeling did not alter the pattern of performance of the alternatives and the preferred alternative still performed well when considered in the context of projections regarding future climate change. The scope of the LTEMP includes monthly and hourly releases from Glen Canyon Dam, but not annual volumes from Glen Canyon Dam, so the scope of the analysis was considered with respect to for monthly and hourly changes.

11) Impacts on Natural Resources – Terrestrial Wildlife

Response: Impacts to terrestrial wildlife were considered in the LTEMP EIS in Section 4.7.

12) Impacts on Natural Resources – Vegetation

Response: Impacts to vegetation were considered in the LTEMP EIS in Section 4.6. There was considerable discussion between joint lead staff and GCMRC about different flows to benefit native vegetation species. We discussed the timing and scouring effects of various water flows that could disadvantage nonnative species. Modeling was performed using the best available vegetation model and GIS mapping information and the preferred alternative performed better than the No Action alternative for maintaining native vegetation condition. However, under all alternatives, vegetation condition is expected to decline over time. Because of this, a feature common to all of the action alternatives analyzed in this EIS is an experimental vegetation treatment project to address nonnative vegetation removal, native vegetation planting and other vegetation issues. This was developed in coordination with GCMRC and after discussions with other partners and Tribes.

13) Commenter Recommendations

Recommendation: Restore essential sediment and nutrients into the main stem of the Colorado River in the Grand Canyon.

Response: Sediment conservation was a resource goal as expressed in Section 1.4. More even monthly volumes and frequent HFEs are components of the preferred alternative to address sediment conservation.

Recommendation: Restore flow regimes to properly transport the sediment and nutrients within Grand Canyon, when and where it belongs. The 1994 Biological Opinion and the EIS referred to these as Seasonally Adjusted Steady Flows (USDOI 1995)

Response: The LTEMP EIS evaluated a seasonally adjusted steady flow option, Alternative G, however it was not identified as the preferred alternative as Alternative D showed a better balance to protect downstream resources.

Recommendation: Restore the seasonally variable water temperature in the main stem of the Colorado River through Grand Canyon. The 1994 Biological Opinion and the EIS referred to this as Selective Withdrawal by means of a Temperature Control Device (USDOI 1995). Look to the Temperature Control Device at Flaming Gorge Dam as a source of information and experimentation to guide planning at Glen Canyon Dam. Answer the question of "whether the potential benefits to the endangered fish of operating a TCD and warming the water outweigh the potential adverse effects from potential increases in nonnative predators, parasites and diseases, or other unintended, systemic interactions in the downstream environment." (USDOI USBOR 2007) It is entirely possible – even probable -- that native fish will perform better in the temperature environment in which they adapted (i.e., Clarkson and Childs 2000).

Response: Flow options for affecting temperature were considered as part of the LTEMP and the preferred alternative includes an experimental option for low summer flows. Temperature control devices were outside the scope of this project.

Recommendation: Implement a restoration and recovery program for the Colorado River corridor in Grand Canyon that includes the recovery of all species known to be native to Grand Canyon prior to the operation of Glen Canyon Dam.

Response: The reintroduction of extirpated species was outside the scope of this EIS and is discussed in Section 1.5.3. LTEMP EIS alternatives include experiments that are intended to improve conditions for ESA-listed species and other special status species. The LTEMP EIS team used the best available science and peer-reviewed modeling to determine the potential effects of these alternatives on these species. DOI has worked closely with FWS throughout the 5-year EIS process to ensure that the appropriate experiments, dam operations, and non-flow actions were identified as conservation measures. Formal consultation with FWS has resulted in a Biological Assessment and Biological Opinion on the effects of the proposed action on listed species and designated critical habitat, as presented in Appendix O of the EIS.

The original notice of intent to prepare the LTEMP EIS identified the need to determine whether to establish a recovery implementation program for endangered fish species below Glen Canyon Dam. The LTEMP team found that identifying the need to determine whether to establish a recovery implementation program (RIP) for endangered fish species below Glen Canyon Dam did not meet the purpose and need for the action.

Recommendation: Implement a non-native eradication program to minimize alien species in the Grand Canyon river corridor with a priority on those that prey on, compete with, or otherwise impair the health of native plants and animals. Non-native fish retention should not be a priority in designing new flow regimes.

Response: The LTEMP EIS included and evaluated a number of tools for address non-native fish and non-native vegetation. Some Tribes, particularly Zuni and Hopi, have concerns regarding non-native fish removal methods, so the preferred alternative contains some constraints and mitigation measures to address those concerns.

Recommendation: Complete the Little Colorado River Management Plan as recommended by the 1994 Biological Opinion (USDOI 1995).

Response: Development of this plan is considered outside the scope of the LTEMP EIS.

Recommendation: Address the dysfunction of the Adaptive Management Program. The AMP should be replaced by an open source and independent body of research and advisory scientists, where the monitoring and research data are consistently and thoroughly peer-reviewed prior to providing any recommendation to the Secretary of Interior. The Grand Canyon Research and Monitoring Center should have a significant role in creating the LTEMP, including choosing testable hypotheses, designing best-case flow scenarios to retain sediments and native species in Glen and Grand Canyons, and crafting monitoring regimes.

Response: We assume the commenter is referring to the Adaptive Management Work Group (AMWG) when they refer to the AMP. The GCMRC was involved throughout the LTEMP process and assisted as subject matter experts in with the modeling, analysis, experimental design and assisted with peer review of aspects of the LTEMP. The AMWG is a FACA committee established through the GCPA and exists to provide input to the Secretary of the Interior. Changes to the organization of the committee should be directed to the Secretary. Changes to the structure and focus of the AMWG are outside the scope of this EIS.

Recommendation: Assess how the river could be managed with shrinking reservoirs and emphasize water conservation in long-term dam and reservoir management plans. A study by the National Research Council has indicated that long-term drought is the likely outcome of climate change in the Southwest (NRC 2007). The Bureau should consider at what point river management – specifically, water and power needs – would be better served by maximizing water storage in Lake Mead rather than dividing it between Mead and Powell reservoirs. In fact, an article released just this week raises tensions about keeping Lake Mead full see http://www.climatecentral.org/blogs/dry-weather-is-drawing-down-lake-mead/, accessed 1/31/12). The Bureau should assess the comparative loss of water from bank storage and evaporation between these two maintaining both reservoirs, maintaining only Lake Mead, and an alternative where Lake Powell is kept low to reduce "losses" to infiltration and evaporation.

Response: The LTEMP EIS evaluated a range of annual hydrologic inflow scenarios. It also evaluated a range of monthly, daily, and hourly releases from the Glen Canyon Dam while complying with the LROC as currently implemented through the 2007 Interim Guidelines. The "Fill Lake Mead First" alternative was dismissed as it was outside the scope of the LTEMP. We

also addressed the impacts of climate change in the EIS, which could result in "shrinking reservoirs" in the future.

Recommendation: An alternative that examines what would be required to generate a flow magnitude equal to the pre-dam annual or bi-annual average peak flow, and/or a flow that exceeds the current annual average flow by the same proportion as a pre-dam peak exceeded pre-dam average annual flow, should be included, so that such a flow could be planned when water is available.

Response: Flows greater than 45,000 cfs were considered but dismissed as part of this process for a number of reasons including operational and safety concerns.

Recommendation: If beach sizes continue to shrink, recreational capacity should be adjusted downward to prevent exacerbating beach erosion, damaging cultural sites, and damaging vegetation.

Response: The preferred alternative is expected to increase beach and sandbar size. Visitation is a separate process and not an issue within the scope of the LTEMP EIS. Visitation is set currently through the 2006 Grand Canyon Colorado River Management Plan.

Recommendation: Specific trigger points to guide management decisions must be outlined in the plan. If the dam is truly to be adaptively managed, then the LTEMP must identify detectable thresholds that, if reached, will cause a change in operations to be executed.

Response: The adaptive management process and triggers are adequately addressed in this NEPA document. Section 4.1 and Appendices C and K of the LTEMP DEIS have detailed information on the extensive modeling that was performed with a variety of long term strategies and referring to uncertainties explicitly. The long term strategies were variations of the alternatives that turned various experiments "off" or "on" to model different combinations and frequencies of experiments under a variety of hydrologic inflow conditions. This extensive modeling was coupled with extensive literature review and subject matter expert input to provide thorough analysis. This is sufficient for a NEPA analysis. Additional details of experiments and monitoring will be developed through the AMP annual work plans. Greater specificity regarding triggers for HFE implementation and humpback chub actions have been added to the EIS (Appendices O and P).

Recommendation: A healthy Colorado River in Glen and Grand Canyons must be the top priority of all alternatives proposed in the LTEMP, in order to meet the requirements of the GCPA. There is no evidence that Glen Canyon Dam can be operated to restore species and beaches to their pre-dam condition. This plan should be devised as a last, best effort to restore the National Park Service lands downstream of Glen Canyon Dam. Planners should think holistically about what is required to achieve restoration goals, and create alternatives that aim for success. The cost of these alternatives may be high, but will represent the full cost of Glen Canyon Dam to the American public. We are subsidizing the services provided by Glen Canyon Dam by giving away parts of the Colorado River ecosystem for free, and we deserve to know what it will cost to replace all of it.

Response: The GCPA is central to the purpose and need for this project.

Recommendation: Consider the non-use economic value of the Colorado River to the power and water market area when conducting economic analyses.

Response: A non-use economic study was completed as part of the LTEMP EIS process, however it was completed after the release of DEIS. The results were very comparable to the previous Welsh 1995 study. The results of the new study have been incorporated in the FEIS in Section 4.14.

Recommendation: This is an Experimental and Management Plan. Experimentation must be a component of all alternatives. That is, clearly defined hypotheses, ample monitoring and data analyses, and timely reporting need to be included in every alternative.

Response: Experimentation is included in the LTEMP EIS. Triggers for sediment experiments are clearly articulated. For several fish experiments triggers were developed and defined through the consultation process with FWS with information provided from GCMRC and other experts and cooperators. GCMRC also developed a science plan and will be intimately involved in the implementation of LTEMP experiments through the triennial budget process and on-going monitoring, evaluation and reporting.

Recommendation: The Grand Canyon Monitoring and Research Center should be involved in the development of dam operations alternatives and analyzing the pros and cons of different flow regimes. They should provide significant input into developing testable hypotheses, monitoring regimes, and determining thresholds that will trigger operational changes.

Response: GCMRC was involved throughout the LTEMP EIS process.

Recommendation: Glen Canyon Dam is now approximately 50 years old, and its right spillways have never been tested. We have now experienced climate fluctuations that have come very close to testing both the highest capacity and the lowest capacity of the dam for controlling water flow into the Lower Colorado River. There needs to be a plan for dam failure, either by overtopping or by extremely low lake levels. The safety of the dam, spillways, and adjacent sandstone walls should be examined in this analysis.

Response: Dam safety is a priority of the Bureau of Reclamation and is evaluated comprehensively through Reclamation's Dam Safety program on an -ongoing basis. These on-going evaluations are wholly independent of LTEMP and beyond the scope of this NEPA analysis.

8.4 INVOLVEMENT OF COOPERATING AGENCIES AND SME TEAMS

Summary Comment: Commenters on this issue expressed concern regarding a lack of involvement by Cooperating Agencies on SME teams or in the analysis process, or requested more involvement in ongoing and future research and management of CRE resources.

Response: For the LTEMP EIS process there was a high level of involvement and interaction between the joint lead agencies, the Tribes, the cooperators and the stakeholders of the Adaptive Management Working Group (AMWG). There were also several opportunities for public input above and beyond what is required by NEPA. For over four years regular monthly calls were held with Tribes and cooperators, totaling over 50 meetings. Western Area Power Administration (WAPA) was involved in many additional meetings for alternative development and hydropower subject matter expert questions. Well over 150 meetings were held between the joint lead agencies, Tribes and stakeholders during the course of the development of the draft EIS. All cooperators, Tribes and AMWG stakeholders were provided the opportunity to comment on the purpose and need, objectives, resource goals, modeling metrics, modeling methods, and preliminary modeling results. All cooperators and Tribes were afforded review and comment on a preliminary draft of the EIS as well as the public draft EIS. The joint leads also held additional meetings with Tribes, held many consultation meetings with Tribal councils and provided Tribes the opportunity to submit text to fully reflect their perspectives on all resources within the EIS. Implementation details of experiments and monitoring tailored to the specific resource conditions of the year will be developed through the AMP and GCMRC annual work plans with communication and consultation with a number of partners and stakeholders.

8.5 LTEMP EFFECTS ON RESERVOIR OPERATIONS

Summary Comment: A commenter on this issue requested assurance that management actions and experiments proposed in the DEIS will not operate to modify determinations made under the Interim Shortage Guidelines for both Lake Powell and Lake Mead or to trigger a mid-year review of reservoir operations that would otherwise not occur.

Response: The scope of the LTEMP EIS was to evaluate a range of alternatives with different monthly, daily, and hourly releases from the Glen Canyon Dam. All alternatives are consistent with the LROC as currently implemented through the 2007 Interim Guidelines for annual release volumes. See Sections 3.2 and 4.2 for additional detail.

8.6 LIST RELEVANT LAWS AND MANAGEMENT DOCUMENTS

Summary Comment: A commenter on this issue stated that it is unclear as to how the extensive list of laws identified in the DEIS is specifically relevant to the proposed actions. The FEIS would benefit from identifying only those laws and management documents that are directly related and pertinent to the LTEMP process, or explaining why additional laws are included.

Response: Minor changes have been made. The text was revised to focus on the most relevant laws. There is a statement that these lists are not exhaustive.

8.7 APPLICATION OF STRUCTURED DECISION ANALYSIS (SDA)

Summary Comment: Some commenters questioned and did not support the use of SDA to help determine operations at Glen Canyon Dam, did not participate in the voluntary SDA process for

LTEMP, and rejected any reliance on SDA as the basis for operating Glen Canyon Dam to implement the LTEMP for the next 20 years. Some commenters stated that the DEIS relies on a flawed SDA and SDA should not be included in the DEIS as a basis for selecting a Preferred Alternative.

A commenter believed that the SDA overly relied on modelling outputs to claim objectivity and transparency when actual results depended heavily on the assumptions made in creating the models, inputs selected for running the models, and the manner in which the modeling analyses were made and results reported. The commenter believed that the DEIS relied on modeling outputs to justify a scientific and objective result without acknowledging the significant subjectivity that goes into creating and running the models in the first place.

A commenter believed that the DEIS is legally deficient because it relies on an inadequate and incomplete analysis of hydropower developed for the SDA process.

A commenter stated that the DEIS is Legally Inadequate because it Relies on Flawed Structured Decision Analysis. Specific to the hydropower Performance Metric, because of the varying degrees to which swings and weights are established for the various performance metrics, the hydropower metric is automatically given less weight than other metrics. The swing weighting is set up in such a way that sediment is weighted far more importantly than hydropower.

Response: In an effort to provide multiple opportunities for interested stakeholders to provide input in the LTEMP process, the National Park Service (NPS) and the Bureau of Reclamation (BOR) decided to incorporate facilitated structured decision analysis (SDA) into the LTEMP EIS process. The use of SDA in the LTEMP process was not required by NEPA, nor did it replace the NEPA impact analysis. Participation in the SDA process was a voluntary opportunity for stakeholder input. Text was modified to note that not all stakeholders were in support of the process. See Sections 1.7, 2.1 and Appendix C which explain that SDA one of the many tools utilized in this EIS. Text was revised to clarify the scope and authority of resource goals. As stated in Section 1.7, "While structured decision analysis informed the analysis of the joint leads, it was not the only method by which a preferred alternative was identified. The identification of a preferred alternative was based on the full DEIS analysis and considerations relating to qualitative and quantitative evaluations of impacts. Public comment, socioeconomic considerations, AMWG stakeholder input, and other factors were all considered in this decision." All models have limitations and this EIS includes disclosure of those limitations, as well assumptions. The models and the SDA analysis have also been peer-reviewed.

Section 4.1 and Appendices C and K of the LTEMP DEIS have detailed information on the extensive modeling that was performed with a variety of long term strategies. The long term strategies were variations of the alternatives that turned various experiments off or on to model different combinations and frequencies of experiments under a variety of hydrologic inflow conditions. This extensive modeling was coupled with extensive literature review and subject matter expert input to provide thorough analysis. This is sufficient for a NEPA analysis. EPA gave this document an LO-1 rating, the highest possible.

The swing weighting results were not used to quantitatively evaluate the impacts to hydropower in Chapter 4. Any analysis of swing weighting was independently used in Appendix C and was not the only criteria used for identifying a preferred alternative.

8.8 DOI DISCLAIMER

Summary Comment: A commenter recommended that the FEIS and ROD include appropriate disclaimer language to allow the various interested stakeholders to refrain from disputing or contesting general legal characterizations in the DEIS.

Response: DOI will consider the proposed disclaimer language for inclusion for the ROD.

8.9 DOI RESPONSE TO COMMENTS

Summary Comment: A number of commenters requested acknowledgement and response to their comments, that their comments be incorporated into the EIS, that revisions be shown as tracked changes. Commenters stated that they reserve the right to supplement their comments, and requested that their comment letter, material cited, and DOI response be incorporated into the LTEMP administrative record.

Response: Comments were solicited, collected, and incorporated into the FEIS in accordance with CEQ NEPA regulations and DOI policy and guidance.

8.10 COMMENT PERIOD DEADLINE

Summary Comment: A number of commenters stated that DOI had made several statements as to when comments needed to be mailed and received, causing confusion.

Response: All comments uploaded to the NPS PEPC site or received at Argonne with a postmark of May 9, 2016 were considered. The Federal Register notice states: “Reclamation and the NPS will accept‘ comments that are received or postmarked by May 9, 2016.”

8.11 LANGUAGE REGARDING LROC

Summary Comment: A commenter stated that the LTEMP EIS should not include subjective language regarding implementation of LROC or Interim Guidelines.

Response: Nothing in this document affects future decisions regarding the LROC. We have reviewed the text and modified as appropriate to make that clear.

8.12 DESCRIPTION OF HFE PROTOCOL AND NONNATIVE FISH CONTROL PROTOCOL FOR THE PREFERRED ALTERNATIVE

Summary Comment: Commenters suggested that the specific protocols for implementation of HFEs and nonnative fish control under the preferred alternative should be specified in the EIS rather than simply referring to the existing protocols.

Response: Protocols to be followed for implementation of HFEs and nonnative fish control are presented in the EIS in Section 2.2.4.6, Appendix O (Biological Assessment), and Appendix P (HFE protocol for the preferred alternative). Appendix O includes an attachment that describes the triggers to be applied to various experimental aquatic resource actions and the basis of those triggers.

8.13 CONSERVATION MEASURES TO BE APPLIED UNDER ALTERNATIVE D

Summary Comment: One commenter suggested that the conservation measures to be applied under Alternative D should be identified and described.

Response: Conservation measures to be applied under Alternative D are described in Section 2.2.4.6 and Appendix O (Biological Assessment) of the EIS.

9 RECREATION

9.1 NOTE ECONOMIC BENEFITS OF THE RECREATION INDUSTRY

Summary Comment: Commenters stressed the importance of accounting for the benefits of river recreation to the local economy and enumerated the various direct and indirect economic activities associated with recreation, including rafting trip fares paid by visitors, franchise fees paid by rafting companies, support of rafting services, outfitters and businesses in the area, and spending on car rentals, hotel stays and restaurants. One commenter suggested that trout fishing may not be as important as it is perceived to be.

Response: These issues were all considered in the recreation economics sections of the LTEMP EIS; see Section 4.14 and Appendix L of the EIS. The EIS analysis fully considered the direct and indirect economic effects of recreation use in the project area.

9.2 RECREATION RESOURCE GOALS INCOMPLETE

Summary Comment: Commenters expressed that recreation in the Grand Canyon has been understudied in general as compared to other resources and thus that recreation resource goals and impacts on recreation are not sufficiently articulated in the LTEMP EIS.

Response: Recreation is one of the aspects of the Grand Canyon Protection Act which is an inherent part of the purpose and need for the LTEMP EIS and Section 1.4 includes goals and objectives for recreation. Although there are a limited number of recreation studies, the LTEMP team utilized best available studies for this EIS and utilized modeling where appropriate to address many aspects of recreation. See Section 4.10.

9.3 ADOPT THE GOALS AND OBJECTIVES OF THE AZGFD FISHERIES MANAGEMENT PLAN

Summary Comment: Commenters requested that the goals and objectives of the Arizona Game and Fish Department be incorporated into the LTEMP EIS and that the Arizona Game and Fish Department Fisheries Management Plan- Colorado River-Lees Ferry (Rogers 2015) be cited along with the Park Service's Comprehensive Fisheries Management Plan in the discussion of the recreational fishery.

Response: The AZGFD management plan and NPS's Comprehensive Fisheries Management Plan are independent of the LTEMP EIS. Because of differences in aspects of the two plans, at this time, the joint leads cannot include the objectives of the AZGFD plan or reference this plan in its current form. See also response to comment summary 3.9.

9.4 ADOPTION OF MLFF FLOWS CORRESPONDED WITH DEGRADATION OF THE LEES FERRY FISHERY DROP IN VISITATIONS

Summary Comment: A commenter observed that angler satisfaction and use was very high in the 1970s and 1980s, but declined following the advent of MLFF and the implementation of HFEs.

Response: DOI has not identified any studies that attribute the reduction in angler use days or satisfaction to the advent of MLFF or the implementation of HFEs. No change to the EIS was made in response to this comment.

10 TRIBAL RESOURCES[1]

10.1 OPPOSITION TO MECHANICAL REMOVAL OF TROUT AND TROUT MANAGEMENT FLOWS

Summary Comment: Comments in this category generally oppose mechanical removal or trout management flows due to the adverse effects these actions would have on the cultural values ascribed to the Canyons and Rivers by the Hopi, Zuni and other Tribes. Of particular note are the adverse psychological and sociological effects to the larger Zuni community during mechanical removal and trout management flow actions, the taking of life without justification, and the seemingly opposing management objectives for trout. Additional comments support the Tribal perspective on these matters.

Response: DOI considers mechanical removal as an important tool for minimizing risk to downstream endangered fish from trout regardless of the cause of trout population increases or migration. DOI acknowledges the potential negative effects from all alternatives (and common to all actions) that include the taking of life in the Canyon through direct removal and/or trout management flows. We recognize the Hopi and Zuni perspective on mechanical removal and trout management flows and are committed to working with Tribal leadership on ways to address the ongoing concerns and ensure appropriate mitigation within the river corridor. Under the LTEMP EIS preferred alternative TMFs would only be used when triggered by situations where high numbers of young of the year are predicted. In years when TMFs or mechanical removal may be appropriate, the joint-leads would discuss the trout conditions of the year with AZGFD, GCMRC, and concerned Tribes prior to implementing to develop appropriate options to lessen the potential negative impacts from the proposed actions. In response to specific Zuni comments regarding Zuni perspectives on the adverse effects to their community, we have retained language in 4.9.3 and added language to a number of sections, most specifically in Section 4.9.1.3.

10.2 LACK OF TRIBAL REPRESENTATION IN DEVELOPMENT OF EIS

Summary Comment: Comments in the category generally question the representation of Tribes in the development of the EIS including whether or not Tribal members were part of the SME teams, how many Tribes were contacted in regards to the LTEMP EIS, and how many and what types of Tribal consultation meetings were held.

Response: NPS and Reclamation are committed to working with Tribal communities in order to better understand their concerns in regard to the LTEMP process. Initially, 43 Tribes, bands, and organizations were formally invited to enter into government-to-government consultation on the LTEMP EIS. Five chose to participate as Cooperating Agencies. Cooperating Agencies were invited to monthly conference calls to review progress and reach agreement on major issues

[1] Comments and responses related to Tribal concerns are also presented in Section 11, Socioeconomics and Environmental Justice.

during the preparation of the LTEMP DEIS. In addition, a number of face-to-face meetings as well as webinars and conference calls were held. Detailed information on the consultation process can be found in Chapter 5 and Appendix N. Under most resource sections there are also Tribal perspectives section where the concerns of Tribes are explained in their own words.

10.3 METRIC SHOULD NOT BE USED TO ANALYZE IMPACTS TO CULTURAL AND TRIBAL RESOURCES

Summary Comment: Comments under this category suggest that metrics used to analyze the impacts to cultural and Tribal resources were unwarranted. Specifically, comments suggested that there is little data to support the wind-blown sediment hypothesis and Sand Load Index in relation to availability of sediment for wind deposition and that Time Off-River is not a viable metric to evaluate visitor impacts to archaeological sites.

Response: We have used the GCDAMP Desired Future Conditions (DFCs) as a basis and as a guide for the resource goals and performance criteria. The Cooperating Agencies, Tribes and AMWG stakeholders were given several opportunities to comment on these for the LTEMP EIS and a number of changes were made based on those comments. We also sent the AMWG members and Cooperating Agencies a draft document of the resource goals and objectives on March 27, 2013 that further illustrated how the DFCs were used in developing each resource goal and objective.

The metric values for the Sand Load Index represent the potential for sand to be transported to cultural sites rather than the actual transport that would occur or the level of protection that transport may provide to cultural sites. The EIS acknowledges that the extent to which wind-deposited sediment can stabilize and protect archaeological sites is limited by the local geomorphology and vegetation. The text in Section 4.8.2 and Appendix H has been updated to reflect the most recently published studies regarding wind-blown sediment.

Tribes regularly monitor the condition of culturally important sites and resources within the Canyons. Many Tribes have noted intentional and unintentional damage to sites from visitors, including trailing, trampling, removal of vegetation, disturbance of artifacts, vandalism, and disruption of the sacred context through inappropriate behavior (See Sections 3.9 and 4.9). The time-of-river metric was included to respond this concern. The results showed that there was very little difference among the alternatives for time-off-river.

10.4 CULTURAL LANDSCAPES AND TRADITIONAL CULTURAL PROPERTIES NOT THOROUGHLY DISCUSSED

Summary Comment: Comments in this category suggest that Traditional Cultural Properties, have not been thoroughly analyzed and that the larger cultural landscape of the LTEMP study area, including the Grand Canyon as a Historic National Landmark was not acknowledged.

Response: The LTEMP EIS references forthcoming National Register of Historic Places nominations for the Hopi, Zuni, Navajo, and Hualapai TCPs in Section 3.9. The designation of

the Grand Canyon as a Historic National Landmark is outside the scope of this EIS; however, DOI will continue dialog with the Hualapai and other Tribes throughout the PA process and within the AMWG regarding the importance of cultural resources.

10.5 TRIBAL LANDS AND RESOURCES ON TRIBAL LANDS NOT TAKEN INTO CONSIDERATION

Summary Comment: The comment under this category suggests that the LTEMP EIS did not identify cultural resources on Hualapai and Navajo lands in the Introduction.

Response: The description of lands in this section uses terms based on geography of the canyons rather than on land ownership. Therefore, we feel the wording is appropriate as is; however, we did add text to reflect the perspective of various Tribal cultures regarding the interconnected nature of the cultural landscape.

10.6 IMPACTS TO HUALAPAI TOURISM OPERATIONS NOT THOROUGHLY ANALYZED

Summary Comment: Comments in this category were specifically from the Hualapai Tribe and indicated a concern with the lack of identification of potential impacts to Hualapai Tourism operations near Quartermaster Canyon as well as other Hualapai tourism operations.

Response: Potential impacts to Hualapai tourisms operations near Quartermaster Canyon and other Hualapai operations were consider in Sections 4.10. Based on the analysis conducted for the EIS, sedimentation near the Quartermaster Canyon would not vary significantly among the alternatives. The sedimentation this far down is primarily driven by other factors including the reservoir level at Lake Mead and annual release volumes which are outside the scope of the LTEMP EIS. Additional text was added regarding the details of Hualapai tourism operations in Sections 3.10 and 4.10 of the EIS. Text has been added under each alternative to clarify the impacts to Hualapai tourism operations.

10.7 TRIBAL PERSPECTIVES ON COMPONENTS OF THE COLORADO RIVER ECOSYSTEM

Summary Comment: Several commenters provided comments or text to add to Chapters 3 and 4 that expresses Tribal perspectives on components of the Colorado River Ecosystem such as fish, vegetation, and wildlife. The Zuni expressed concern related to the effects of management actions downstream of Glen Canyon Dam, specifically those directed towards fish, on the well-being of Tribal members.

Response**:** In most cases, the information provided by Tribes was incorporated as provided with only minor editorial modification as needed. Changes were made in Chapters 1, 2, 3, and 4.

10.8 EDITORIAL COMMENTS

Numerous substantive editorial comments were submitted by the Tribes on sections in the DEIS, including portions of Chapters 1, 2, 3, and 4, related to Tribal resources and concerns. Many of these comments were related to descriptions of resources or lands important to the Tribes, Tribal perspectives and views of specific resources in the Canyons or the Canyons as a whole and proper representation of Tribal views on aspects of the alternatives, especially actions that could affect aquatic ecology, vegetation, or wildlife within the Colorado River Ecosystem. In most cases, substantive editorial suggestions provided by Tribes were incorporated as provided with only minor editorial modification as needed.

11 SEDIMENT

11.1 CONCERN OVER EROSION OF SANDBARS AND BEACHES FOLLOWING HIGH FLOWS (I.E., HFEs)

Summary Comment: Commenters expressed concern that, while HFEs may provide benefits to certain beaches, they also create a net loss of sand and erosion to others.

Response: In Sections 3.3 and 4.3 there is discussion of the complexity of beach and sandbar response to HFEs. The geomorphology and other factors dictate that different HFEs build some beaches, but erode others and this is clearly stated but the average results are also considered and the modeling focuses on the average results. Based on the modeling and the extensive literature on sediment in the Grand Canyon, the preferred alternative is expected to perform well for sandbar and beach building and for many other downstream resources to comply with the GCPA. If there were unacceptable adverse impacts caused by HFEs, there is a process defined in the EIS through which HFEs would be suspended

11.2 SPRING HFES—UNCERTAINTY AND CONCERN OVER IMPACTS; MORE TESTING IS NEEDED

Summary Comment: Commenters emphasized that the uncertainties related to spring HFEs, resource trade-offs, and timing. They also noted that spring HFEs need to be experimentally tested and evaluated before adoption becomes an accepted management practice, but the current language surrounding the conduct of spring HFEs (as described in the Glen Canyon Dam High Flow Experiment Protocol Environmental Assessment) severely limits the potential for experimental testing of HFEs during the springtime period.

Response: DOI acknowledge that there are uncertainties regarding the potential impacts of spring HFEs and has reviewed the parameters under which springtime HFE's are conducted and the way in which the accounting periods are applied. Under the preferred alternative, there would be 4-7 spring HFEs on average over the 20 year period, which allows for testing and monitoring of impacts. Under the preferred alternative, spring HFE's are triggered based upon sediment triggers. GCMRC was consulted on the potential to modify the accounting periods and the scientists most familiar with the protocol did not believe it warranted a change in accounting periods.

11.3 EQUALIZATION FLOWS—CONCERN OVER INCREASED EROSION AND HIGHER RATE OF SEDIMENT TRANSPORT

Summary Comment: Commenters noted that equalization flows transport an enormous amount of sediment out of the system. As a result, they should be studied carefully and an effort should be made to change management practices to a proactive approach in order to minimize and mitigate the negative effects of equalization flows.

Response: The scope of this EIS does not include modification of annual volumes. Therefore alternatives that change equalization flows and other annual volumes were not included in this EIS. However, the EIS includes the full range of potential future releases, including equalization flows, to ensure a robust analysis of impacts to the alternatives. The alternatives analyzed in the LTEMP EIS looked at all practical approaches to conserving sediment via changes to monthly, daily, and hourly releases from the Glen Canyon Dam. Recognizing the science of sediment transport and flow, the range of alternatives include experimental proactive spring HFEs to mobilize and deposit or "park" sediment higher on the beaches in anticipation of annual releases greater than 10 maf. Further experimentation or approaches that may be devised in the future could be brought forward through the adaptive management program or GCDAMP triennial budget process and may or may not require additional NEPA compliance.

11.4 SEDIMENT SHOULD BE CONSIDERED A "SECONDARY" RESOURCE

Summary Comment: Commenters expressed concern that the characterization of sediment as the primary objective of the LTEMP EIS appears to be inconsistent with the AMWG-approved and Secretary-recognized identification of sediment as a "secondary" resource to be used to support other DFC resources (i.e., subset of the larger Colorado Ecosystem DFC).

Response: We have used the GCDAMP Desired Future Conditions (DFCs) as a basis and as a guide for the resource goals and performance criteria. The Cooperating Agencies, Tribes and AMWG stakeholders were given several opportunities to comment on these for the LTEMP EIS and we made a number of changes based on those comments. We also sent the AMWG members and Cooperating Agencies a draft document of the resource goals and objectives on March 27, 2013 that further illustrated how the DFCs were used in developing each resource goal and objective. The resource goals and objectives are based on the DFCs and consistent with them but relate more directly to the purpose and need of the LTEMP EIS. Recognizing the science of sediment transport and flow, several alternatives included proactive spring HFEs to mobilize and deposit sediment in anticipation of annual releases greater than 10 maf. Sediment conservation was a resource goal as expressed in Section 1.4.

11.5 CONCERN OVER SEDIMENT ACCUMULATION IN LAKE POWELL AND BEHIND THE DAM

Summary Comment: Commenters expressed concern related to the long-term accumulation of sediment into Lake Powell and its displacement of water storage, effect on flood control capacities, and potential impairment of downstream water delivery. Some commenters also requested a new and comprehensive sediment survey of Lake Powell, including a sediment removal plan.

Response: Long-term of accumulation of sediment into Lake Powell is an uncontrollable function of hydrology above Lake Powell and is also outside the scope of this EIS. The alternatives being considered do not affect the inflow of sediment into Lake Powell.

12 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

12.1 REGIONAL ECONOMIC IMPACTS ASSOCIATED WITH BOATING VISITOR EXPENDITURES

Summary Comment: Economic impacts associated with boating visitor expenditures on lodging, food and supplies, equipment sales and rentals, fuel, guide and license fees, etc. form an important part of the local and regional economy.

Response: The economic impacts associated with boating visitor expenditures are assessed in Section 4.14.2.3 of the EIS. The issues listed were considered in this analysis.

12.2 REGIONAL ECONOMIC IMPACTS ASSOCIATED WITH ANGLER VISITOR EXPENDITURES, IN PARTICULAR IMPACTS OF HFEs

Summary Comment: Economic impacts associated with angler visitor expenditures on lodging, food and supplies, equipment sales and rentals, fuel and guide and license fees, etc. form an important part of the local and regional economy.

Response: The economic impacts associated with visitor expenditures related to fishing are assessed in Section 4.14.2.3 of the EIS. The effects of HFEs were considered as well as the issues listed.

12.3 USE VALUES ASSOCIATED WITH ANGLING AND BOATING TRIPS

Summary Comment: Economic impacts associated with angler visitor expenditures on lodging, food and supplies, equipment sales and rentals, fuel and guide and license fees, etc., during HFEs would form an important part of the local and regional economy.

Response: Under current NPS regulations the number of angling boat trips would not change under any of the alternatives given the excess demand for boating permits, with no consequent impact on license revenues, or on employment and income in the region. In addition, access restrictions during HFE events under any given alternative may mean a slight decline in angler visits, slightly reducing license revenues, and employment and income in the region. These impacts are discussed in Section 4.14.2.3 of the EIS.

12.4 NON-USE VALUES ASSOCIATED WITH FISHING RESOURCES

Summary Comment: In addition to the economic impacts, use values associated with angling and boating trips, and non-use values associated with fishing resources are a significant part of the economic value of river resources.

Response: Use values associated with angling in the Upper Grand Canyon, and non-use values associated with fishing resources are assessed in Section 4.14.2.2 of the EIS.

12.5 ECONOMIC IMPACTS ON TRIBES

Summary Comment: Economic impacts of each alternative in individual Tribes should be considered in the EIS

Response: The economic impacts to Tribes were considered in the EIS in the recreation (4.10), Tribal Resources (4.9) and socioeconomics (4.14) sections. There were limitations based on the available data regarding hydropower impacts that precluded separating out impacts further by individual Tribe. The geographic location of minority and low-income populations in an 11-county region is described in Section 3.14.1.5 of the EIS. The environmental justice analysis described in Section 4.14.2.5 includes economic impacts on Tribal groups in the 11-county region as a whole. The impact of HFEs on Tribes is addressed in Section 4.14.2.4 of the EIS.

12.6 IMPACT ON WATER PROVISION

Summary Comment: Impacts of each alternative on water provision should be considered in the EIS.

Response: The scope of the LTEMP EIS was to evaluate a range of alternatives with different monthly, daily, and hourly releases from the Glen Canyon Dam. All alternatives are consistent with the LROC as currently implemented through the 2007 Interim Guidelines for annual release volumes. See Sections 3.2 and 4.2 for additional detail. Because the LTEMP EIS does not affect annual volumes, it will not affect water delivery, allocation or provision. Under the LTEMP variations of the reservoir elevations within the year are small and temporary and based on modeling would not affect potential water diversions from Lake Powell or Lake Mead.

12.7 REGIONAL ELECTRIC POWER ECONOMIC IMPACTS

Summary Comment: Regional economic impact of changes in retail rates and electric power capacity expansion on minority and low-income populations should be considered.

Response: The geographic location of minority and low-income populations in an 11-county region is described in Section 3.14.1.5 of the EIS. The environmental justice analysis described in Section 4.14.2.5 includes economic impacts on Tribal groups in the 11-county region as a whole. The impact of HFEs on Tribes is addressed in Section 4.14.2.4 of the EIS.

12.8 ECONOMIC IMPACTS OF ACTIVITIES OF CONFLUENCE PARTNERS OUT OF SCOPE OF EIS

Summary Comment: Economic impacts of the activities of Confluence Partners (the construction of a tram, walkway, restaurant and amphitheater) should be considered in the EIS.

Response: A full and comprehensive analysis of the impacts potential economic development activities by Confluence Partners was outside the scope of the EIS, however effects of the Grand

Canyon Escalade project based on available project information were considered within the cumulative impacts section (4.17).

12.9 DEPTH OF LITERATURE REVIEW ON USE VALUATION IN APPENDIX I

Comment Summary: The literature review on use valuation in provided in Appendix I does not provide a comprehensive overview of all the relevant literature on use values.

Response: The Appendix referred to (Socioeconomic Technical Information and Analysis) is now Appendix L. This appendix does not summarize use value literature, it provides a summary of the benefit transfer methods and models used to estimate recreation use values in the EIS. References were added in Chapter 3 (Section 3.14) and in appendix L to the Loomis 2014 study, which was a literature review to evaluate the potential for a passive use value for hydropower. More information on the background literature, data, and assumptions in applying the benefits transfer method to the analysis undertaken for the EIS can be found in Reclamation (2014).

12.10 MECHANICAL REMOVAL AND TROUT MANAGEMENT FLOWS

Summary Comment: The killing of fish through mechanical removal and trout management flows are objectionable to the Zuni sensibilities.

Response: Section 4.14.2.5 of the EIS recognizes that the Zuni have established a lasting familial relationship with aquatic life in the Colorado River, and that the taking of life through the mechanical removal of trout or TMFs is considered to be and adverse impact and an offensive, to the Zuni. Based on input and consultations with the Pueblo of Zuni, text has been included considering mitigations such as beneficial use of fish that are removed and Reclamation consulted with the FWS under Section 7 to make some adjustments to the preferred alternative. Based on those adjustments and 'tiers' that were added in the biological assessment (see Appendix O), mechanical removal is now a second 'tier' action, as other actions would be tried first as a 'first tier'. This may reduce the frequency of mechanical removal. Differences in the frequency of the mechanical removal of trout between alternatives are also addressed in this section of the EIS. Consultations continue with Tribes on potential mitigations through an agreement in process regarding non-native fish management.

13 WATER

13.1 CONSIDERATION OF CLIMATE CHANGE EFFECTS RELATED TO WATER SUPPLY REDUCTIONS, EVAPORATION, AND OPERATIONAL LEVELS OF LAKE POWELL

Summary Comment: Commenters emphasized the importance and requested the consideration of climate change effects (e.g., increased temperatures, droughts, etc.) related to water supply reductions, evaporation, seepage, and operational levels of Lake Powell.

Response: This EIS used 21 reconstructed historical hydrological traces that were reweighted based on the 112 traces to represent the best current understanding of what might happen because of climate change. Based on this analysis, the weights on the hydrological traces had a small effect on the aggregate performance but did not change the rankings of alternatives. This result suggests the relative performance of the alternatives would be consistent regardless of the uncertainty of the effects of climate change.

The Basin Study (Reclamation 2012) was peer reviewed and is the best available science regarding climate change projections in the Colorado River Study. The hydrological traces generated for the Basin Study were utilized as described in Section 4.16.1.2 and Appendix C. See also response to comment summary 2.14.

13.2 CONSIDERATION OF CLIMATE CHANGE IMPACTS ON WATER AVAILABILITY, INCREASED DEMAND, AND GREATER DEPLETION

Summary Comment: Commenters emphasized the importance and requested the consideration of climate change impacts (e.g., increased temperatures, droughts, etc.) on water availability, increased water demand (both diversion and consumptive), and greater depletion.

Response: Water depletion assumptions used for the LTEMP EIS represent the best available and documented data provided by and agreed to by the Basin States for use in CRSS modeling.

13.3 INFLUENCE OF TRIBUTARIES AND LAKE POWELL ON MAIN STEM AND LAKE MEAD SALINITY LEVELS

Summary Comment: Commenters inquired about the comparative salinity values and resulting influence of tributaries and Lake Powell on main stem and Lake Mead salinity levels.

Response: As addressed in the EIS in Sections 3.2 and 4.2, some tributaries, such as the Little Colorado River, are significant sources of salinity for the mainstem Colorado River. But, this is diluted as it enters the mainstem and moves downstream. There are also a number of smaller spring-fed tributaries that originate within the Grand Canyon reach, which tend to have very different physicochemical properties than the mainstem; however, their mean flows are so low that their contribution to water quality during base flow is not significant. For Lake Powell, broader patterns are described in the EIS; but, focus was placed on the forebay, since this is the

water that is released downstream. The salinity module of the CRSS RiverWare™ model was used to analyze changes in salinity concentration for Colorado River reaches from Lake Powell to Imperial Dam, which is located downstream of Hoover Dam and Lake Mead. The Salinity Control Act sets numerical criteria for salinity concentrations on the Colorado River. Results and analysis indicate that, regardless of alternative or operating conditions, salinity would not increase over time or exceed control criteria.

13.4 EDITORIAL COMMENTS

Numerous substantive editorial comments were submitted on sections in the DEIS related to water resources, including Sections 3.2, 4.2, and Appendix D. Most of these editorial comments focused on the specific wording of how Glen Canyon Dam would be operated to comply with existing laws and regulations related to water delivery, collectively known as the Law of the River. Where appropriate, the text of the EIS was modified to address the specific comments.

14 WILDLIFE

14.1 AVERTING THE RESPONSIBILITY TO PROTECT NATIVE SPECIES

Summary Comment: A commenter stated that DOI is averting its responsibility to protect native species because all of the alternatives would result in a decrease in native plant community cover. Special status wildlife species will also be impacted (i.e., every alternative causes losses of habitat for the Kanab ambersnail and every alternative threatens to negatively affect at least one other special status wildlife species). Also, all alternatives will cause wetland loss that will affect the northern leopard frog and Yuma clapper rail. Instead of attempting to create an alternative that prevents continued habitat loss, DOI is just attempting to slow the degree of loss. DOI is averting its legal responsibilities to protect endangered species and Grand Canyon National Park, instead of seeking real solutions.

Response: The purpose and need is consistent with the requirements of the Grand Canyon Protection Act and NPS Organic Act because it focuses on protection and preservation of park resources. Alternatives must meet those basic requirements. All alternatives perform similarly when evaluating effects to wildlife species, showing little difference among the alternatives (Tables 4.7-1 and 4.7-2), although the preferred alternative (Alternative D) shows a benefit to wildlife in general compared to the no action alternative (Alternative A), and Alternative D performed the best for vegetation condition overall and resulted in the least wetland loss. The potential benefits of the non-flow vegetation treatment experiment could not be modeled, but were addressed qualitatively in the EIS and would help to further improve vegetation condition. Alternative D was identified as the preferred alternative because it provided the best balance for protecting, mitigating and improve downstream resources.

14.2 HFE IMPACTS ON KANAB AMBERSNAIL

Summary Comment: Commenters stated that HFEs, including extended duration HFEs, could negatively impact the population of the Kanab ambersnail, a Grand Canyon endangered species. Recovery time of the ambersnail population and habitat scoured by HFEs can take 2.5 years and yet this effect was apparently not considered important to the development of Alternative D.

Response: Endangered and threatened species were considered in the LTEMP EIS analysis based on the best available science and modeling, while the FWS has been consulted throughout the preparation of the EIS. The purpose and need of LTEMP activities are consistent with the requirements of the Grand Canyon Protection Act and NPS Organic Act because they focus on the protection and preservation of park resources. Impacts to the Kanab ambersnail are addressed in Section 4.7.2.5, 4.7.3, and the recovery time of 2.5 years was stated in those sections and considered. Additional information is included in Appendix O (biological assessment) of the Final EIS. It should also be noted that new genetic information on the Kanab ambersnail indicates that it is no longer considered a distinct species and the FWS is considering a delisting process for this species.

14.3 OPERATE GLEN CANYON DAM IN A WAY THAT PROTECTS ALL WILDLIFE (INCLUDING LISTED SPECIES)

Summary Comment: A few commenters wanted the life and safety of all wildlife to be considered. They want the Glen Canyon Dam to be operated in a way that preserves wildlife. Wildlife, including listed species, need to be considered when making decisions on the future of the Grand Canyon. The purpose and need of the LTEMP should be to reverse past damage and prevent future damage to the species of Glen and Grand Canyons.

Response: Impacts on wildlife, including special status species, were considered in the LTEMP EIS in Section 4.7. The purpose and need of LTEMP activities are consistent with the requirements of the Grand Canyon Protection Act and NPS Organic Act because they focus on the protection and preservation of park resources. All alternatives must meet those basic requirements.

15 COMMENTERS, AFFILIATION, AND LOCATION WHERE RESPONSES TO COMMENTS ARE FOUND

An index presenting a list of individuals who submitted comments, their affiliated organizations (when provided), and the sections in this appendix where responses to issues raised in their comments is presented in Table Q-3. All individuals who provided a first or last name in their comment submittal to NPS's PEPC database or whose names were otherwise provided on comment letters submitted by other means are included. An affiliation was listed for an individual if it was clear from their submittal that the commenter was representing the organization and was not simply a member of the organization and commenting as an individual. The right-hand column presents the sections in this appendix where responses to substantive issues raised in commenter's letters are located.

TABLE Q-3 Commenter, Affiliation, and Location Where Responses Are Found

Commenter and Affiliation When Provided[a]	Sections Where Responses Are Found
Aaron, Kris	2.4; 2.13
Abate, Jo Ann	N/A[b]
Abbott, Gayle	2.4; 2.13
Abbott, Robert	3.2; 3.6
Abdel-Gawad, Aliaa	2.4; 2.13
Abrahamson, Dennis	N/A
Abshagen, WP	3.2; 3.6; 8.3
Adams , Mark	3.2; 3.6; 8.3
Adams, A.	2.4
Adams, Jon	2.4; 2.13
Adams, Mary	2.4; 2.13
Adams, Robert	N/A
Aderhold, Steven	2.4; 2.13
Adibi, Elise	2.4; 2.13
Aguirre, Elizabeth	N/A
Aguirre, Sonia	N/A
Ahearn, Mary Ann	2.4; 2.13
Ahrens, Christopher	2.4; 2.13
Aiken, Bianca	2.4; 2.13; 4.1.2; 7.3.1;; 11.3
Aiken, Edwin	2.4; 2.13
Aiken, Silas	2.4; 2.13; 4.1.2; 7.3.1; 11.3
Ainsley, Brian	2.4; 2.13
Akom, Denise	N/A
Alarie, Kim	N/A
Albanese, Dawn	2.4; 2.13
Albano, Tahyra	2.4; 2.13
Albert, Harrison	2.4; 2.13
Alcantara, Ivan	N/A
Alderson, George and Frances	2.4; 2.13

TABLE Q-3 (Cont.)

Alexander, Charles	N/A
Alford, Cassie	N/A
Allen, Charles	2.4
Allen, Donna	2.4; 2.13
Allen, III, Doug	2.4; 2.13
Allen, James	3.6
Allen, Johnnie	N/A
Allen, Mary	2.4; 2.13
Alloway, Richard	N/A
Altum, Angelika	N/A
Alvarez, David	2.4
Amaro, Gabriel	2.4
Amato, Julie	2.4
Ancel-Wisner, Annette	2.4; 2.13
Andersen, Brian	2.8
Andersen, Kelton (Utah Associated Municipal Power Systems)	2.6; 2.10
Anderson, Barry	2.4
Anderson, Dan	2.4; 2.13
Anderson, Dianne	2.4; 2.13
Anderson, Judith S	2.4; 2.13
Anderson, Karen	2.4
Anderson, Mona	2.4; 2.13
Anderson, Sylvia	2.4; 2.13
Anderson, Troy	3.2; 3.6; 8.3
Anderson, Wayne	2.4; 2.13
Anderson, William	2.4; 2.13
Andrew, Jeffrey	N/A
Andrews, Richard C.	N/A
Andrews, Rosalind	2.4; 2.13
Angel, Mary	N/A
Anton, Kathleen	2.4
Antuna, Martin	2.4; 2.13
Apolinar, Augustine	N/A
Arambula , Richard	3.2; 3.6; 8.3
Arbolaez, Fidel	2.4; 2.13
Archuleta , William	3.2; 3.6; 8.3
Arias, Elvira	2.4; 2.13
Arko Hargrove, Barbara	N/A
Armes, Hal	N/A
Armstead, Vetty	N/A
Armstrong, Leslie	2.4; 2.13
Arneson, Paul	2.4; 2.13
Arnold, Alan	2.4; 2.13
Arnold, Ben	2.4; 2.13
Arnold, Earl W. (Sespe Fly Fishers)	N/A
Artin, Thomas	2.8
Ary, David	N/A
Asher, Meredith	2.4
Ashton, Richard	2.4

TABLE Q-3 (Cont.)

Athavale, Anjali	2.4; 2.13
Atkins , Bettye	N/A
Atkins, Todd	N/A
Atwater, Chelsea	2.12
Auer, Patricia	2.4; 2.13
Aune , Brad	3.2; 3.6; 8.3
Aurigemma, Kaye	2.4; 2.13
Avins, Jeremiah	2.4
Ayres, Peter	2.4; 2.13
B, John	12.4
B, Peter	2.4
Babbitt, Susan	2.4
Babcock, Heather	2.1; 2.2; 2.8; 2.14; 13.1
Backlund , Stanley	3.2; 3.6; 8.3
Baclija, Martin	2.4; 2.13
Bacon, Patricia	N/A
Bader, Sandra	2.4; 2.13
Baecker, Grant	12.2
Baggerman, David	3.2; 3.6; 8.3
Bagnoli, Dana	3.2; 3.6
Bahn, Theodore	2.4; 2.13
Bahr, William	N/A
Baier, Mary Ann	2.4; 2.13
Bailey, Shayna	2.4; 2.13
Bails, Jean	2.4; 2.13
Bails, Kirk	2.4
Baker, Danny	N/A
Baker, John	2.4; 2.13
Baker, Ron	N/A
Baker-Smith, Gerritt and Elizabeth	2.4; 2.13
Balay, Joanne & Joseph	2.4; 2.13
Baldwin, Leland	N/A
Baley, Patricia	2.4; 2.13
Balfour, Michele	N/A
Balken, Eric	2.8; 2.14; 13.1
Balken, Eric (Glen Canyon Institute)	2.1; 2.2; 2.8; 2.14
Ball, Evelyn	2.4; 2.13
Ball, William	N/A
Ballard, Cynthia	N/A
Baltrip Balagas, Ayana	N/A
Banks , Jim	3.2; 3.6; 8.3
Banks, Janice	N/A
Banks, Wesley	2.4; 2.13
Bannon, Robert	12.2
Barbieri, Lynn	2.4; 2.13
Baresich, Dennis	2.4; 2.13
Barger, John	2.4; 2.13
Bariana, Ava	2.4; 2.13
Barker, Donald	N/A
Barker, Greg	2.8; 2.14

TABLE Q-3 (Cont.)

Barkley , David	3.2; 3.6; 8.3
Barkman, Jeff	N/A
Barlow, Coni	2.4
Barmann, Adriene	2.4; 2.13
Barnes, Alexander	2.4; 2.13
Barnes, Linda Sue	N/A
Barnett, Lance	N/A
Barondes, Lynda	N/A
Barr, Ford	2.4; 2.8; 2.13
Barradas, Carlos	2.4; 2.13
Barrett, Dorie	2.4; 2.10
Barrington, Tim	2.4
Barry, Karyn	N/A
Bartkowicz, Richard	2.4; 2.13
Bartleman, Mark	2.4; 2.13
Basford, Jerry	3.2; 3.6; 8.3
Bashore, Thomas	2.4; 2.13
Bass, Linda	N/A
Bates, Bryan	2.4; 2.11; 2.13
Batina, John	N/A
Battaly, Robert	2.4; 2.13
Battle, Adriana	N/A
Bauman, Joan-Marie	2.4; 2.13
Baxter, Lou	2.4; 2.13
Bayer, Robert	3.2; 3.6; 8.3
Beam, Stephanie	N/A
Beatini, Tom	2.4; 2.13
Beattie, Jane H	N/A
Bechtel, Paul	2.4; 2.13
Beck, Deborah	N/A
Beck, Kim	2.4; 2.13
Becker, Elaine	2.4; 2.13
Bedell, Diane	N/A
Begaye, Russell (The Navajo Nation)	4.2; 7.5; 8.1; 10.2; 10.8
Beil, William	2.4; 2.13
Belcastro, Bernadette	2.4; 2.13
Belcastro, Frank	2.4; 2.13
Bell, Don	N/A
Belles, Mark	N/A
Bello, D	2.4; 2.13
Bellows, David	N/A
Bender, Jerry	3.2; 3.6; 8.3
Bender, Kae	2.4
Bendixen, Kirsten	N/A
Benedetto, Mona Stephanie	N/A
Benford, Alan	2.4; 2.13
Benjamin, Frank	N/A
Bennett, E	3.2; 3.6; 8.3
Bennett, Faye	N/A
Bennett, Mary	2.4; 2.13

TABLE Q-3 (Cont.)

Bennett, Robert	2.4; 2.13
Bennion, Joseph	2.4; 2.13
Bennion, Lee	2.13; 4.1.2;; 12.2
Benson, Andy	2.4; 2.13
Benson, William	2.4; 2.13
Benware, BettyAnn	2.4; 2.13
Bergen, Joanne	N/A
Bergeron, Brad	2.4
Berglund, John	3.6
Bergstedt, Charlie	2.4; 2.13
Bernon, Douglas	2.4
Bernstein, Joel	2.4; 2.13
Bernstein, Laura Ann K	N/A
Bertani, Christy	2.4; 2.13
Berteaux, Elizabeth	2.4
Bessette, Wayne	2.4; 2.13
Bhattacharji, Lee	2.4
Bickel, Michael	2.4; 2.13
Biddle, Maxine	2.4; 2.13
Bieritz, David	N/A
Biggs, Susan	N/A
Billeaud, Theresa	2.4; 2.13
Bilodeau-Lanne, Michelle	N/A
Bilton, Gretchen	2.4; 2.13
Bilwin, Gina	2.4; 2.13
Bing, Donna	2.4; 2.13
Bircher, K Kay	2.4; 2.13
Bird, Paul	2.4; 2.13
Bishop, Cori	2.4; 2.13
Bishop, Norman	2.4
Blackwell-Marchant, Patricia	N/A
Blake, Frank	2.4; 2.13
Blanton, Robin	N/A
Blaustein, John	2.4; 2.13
Bleifeld, Neil	2.4; 2.13
Bloch, Mark	2.4; 2.13
Blombach, Ann	2.4; 2.13
Blome, Ronald	N/A
Bloxsom, Daniel	3.2; 3.6; 8.3
Boardman, Scott	3.2; 3.6
Bobb, Douglas	3.6
Bobnick, Jacqueline	N/A
Bocchino, Jackie	2.4
Boche, Philip	N/A
Bockino, Alida	2.4; 2.13
Bodine, Frank	2.4; 2.13
Boguske, Matthew	N/A
Boisvert, Chantal	2.4; 2.13
Bolen, Dk	2.4
Bollinger, Lesley	2.4

TABLE Q-3 (Cont.)

Bonds, John	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Boone, James	2.4
Boone, Jim	2.4; 2.13
Booth, Robert	2.4
Borie, Edith	2.4; 2.13
Boris, Donna	2.4; 2.13
Bornholtz, Gavin	2.4; 2.13
Borrelli, Silvana	2.4
Bortoletto, Federico	N/A
Boston, Lovie	N/A
Bottrell, Gregory	3.2; 3.6; 8.3
Boucher, J	2.4; 2.13
Boumali, Omar	N/A
Bowden, Joan	2.4; 2.13
Bowen, Mary Ellen	2.4; 2.13
Bowers Margarita	14.3
Bowers, Carla	2.4
Bowers, Robert	3.2; 3.6
Bowie, Martin	N/A
Boyce, Ashley	2.4
Boyce, Justin	2.4
Boyd, Kerry	2.4; 2.13
Boydston, Charlene	2.4; 2.13
Boyer, David	2.4; 2.13
Boynton, Robin	2.4; 2.13
Brachman, Phyllis	2.4; 2.13
Bradley, Kathy	2.4; 2.13
Bradley, Mark	2.4; 2.13
Bradley, Shari	N/A
Bradley, Stacey	2.4; 2.13
Bradshaw, Barbara	N/A
Bradshaw, Jacqui	N/A
Braithwaite, Georgia	2.4; 2.13
Bramblett, Sharon	2.4; 2.13
Brandt, Deborah	N/A
Brandt, Vicky	2.8
Brault, Robert	N/A
Breckenridge, Bonnie	2.4; 2.13
Breckenridge, Claudia	3.2; 3.6
Breedlove, Elizabeth	2.4; 2.13
Brehmer, Dianne	N/A
Breitenstein, Mark	3.2; 3.6; 12.2
Brenner, Jared	2.4; 2.13
Bridges, Linda	N/A
Brigham, Lawrence	2.4; 2.13
Brinker, Mary Jo	N/A
Brinkley, Mike	2.4; 2.13
Brochhagen, Ann	2.4; 2.13
Brocious, Pamela	2.4
Brockett, Peter	2.4; 2.13

TABLE Q-3 (Cont.)

Brockway, Barbara	2.4; 2.13
Broe, Paula	2.4; 2.13
Bromage, Joan	2.4; 2.13
Brookover, Cicely	3.2; 3.6; 8.3
Brooks , William	3.2; 3.6; 8.3
Brooks, Carrie	2.4; 2.13
Brooks, Dorothy	N/A
Brooks, Prudence	N/A
Brown, James	2.4; 2.13
Brown, Jessica	2.4; 2.13
Brown, Lolly	2.1; 2.2; 2.8; 2.14; 13.1
Browning, Henry	N/A
Bruce, John	2.4
Brunick, Cathy	2.4; 2.13
Brunson, Richard	3.6
Bruton, Babette	2.4; 2.13
Bryan, Karol	N/A
Bryant, Elizabeth	2.4; 2.13
Buck, Mary Lou	2.4
Budlong, Tom	2.1
Budziack, Thomas	3.6; 12.2
Buech, Heidi	2.4
Buell, Nancy	2.4
Bular, Ed	3.2; 3.6
Bullis, Robert	2.4; 2.13
Bunch, Eugene	N/A
Bundy , Jay	3.2; 3.6; 8.3
Burback, Heidi	2.4; 2.13
Burger, Nancy	N/A
Burgess, Wendy	2.4; 2.13
Burgett, Debbie	2.4; 2.13
Burk, Robert	N/A
Burke, Bryan	2.8
Burke, Maureen	2.4; 2.13
Burks, Paul	N/A
Burland, Marcia	2.4; 2.13
Burress, Edward	2.4; 2.13
Burstein, Mimi	2.4; 2.13
Burt, Barry	3.2; 3.6; 8.3
Buschatzke, Thomas (Arizona Department of Water Resources)	2.4; 3.6; 5.2; 8.3; 12.11; 13.1; 13.3, 13.4
Bushnell, Martha	2.4; 2.13
Buss, William	2.4; 2.13
Busse, Chris	2.4
Buszmann, Jeff	N/A
Butler, Sam	2.4; 2.13
Buttacavoli, Rhonda	2.4
Buvala, Ken	3.2; 3.6; 8.3
Byerley, Erica	2.4
Byland, John	N/A

TABLE Q-3 (Cont.)

Byrnes, Kelly	2.4
Byrum, Nancy	2.4; 2.13
C., Bob	3.2; 3.6; 8.3
Caballero, Luis	2.4; 2.13
Cacciapuoti, Anthony	2.4; 2.13
Cagey, Sharon	N/A
Calame, Jane	N/A
Caldwell, Pamela	2.4
Calhoun, Ashley	N/A
Calig, Charles	2.4
Caltagirone, Michael	3.2; 3.6; 8.3
Camp, Ward	3.2; 3.6; 8.3
Campbell, Allan	2.4; 2.13
Campbell, Grant (South Florida Audubon Society)	2.4
Campbell, Jacqueline	N/A
Campbell, Jerry	2.4; 2.13
Campbell, Nancy	2.4; 2.13
Campbell, Susan	N/A
Cannon, John	2.4; 2.13
Cano, Martha	2.4; 2.13
Canter, Linda	N/A
Cantor, Francine	2.4; 2.13
Caplin, Marilyn	N/A
Caputo, Michael	2.4; 2.13
Carley, Daniel	2.4; 2.13
Carlile, Carol	N/A
Carlson, J. Tyler (Mohave Electric Cooperative, Inc.)	2.4; 2.10
Carlson, Robin	N/A
Carlson, Sandy	2.4; 2.13
Carnahan, Michael	12.4
Carney, Marilyn	2.4; 2.13
Carolan, Daniel	3.2; 3.6; 8.3
Carpenter, Steven	2.4; 2.13
Carrasco Serrano, Grace	2.4; 2.13
Carrico, John	2.4; 2.13
Carrillo, Stephen	2.4; 2.13
Carrington, Martha	2.4; 2.13
Carroll, Celia (Wilderness Fly Fishers of Santa Monica)	2.5; 3.2; 3.3; 3.4; 3.5; 12.2
Carter, D.	2.4; 2.13
Carter, Michelle	2.4; 2.13
Case, Nicole (Northwest Public Power Association)	2.6; 2.10
Casey, Nancy	N/A
Cassens, Clarence	3.2; 3.6
Castri, Serenella	2.4
Caswell, Susan	N/A
Catches, Margaret	2.4
Catlin, Linda	2.4; 2.13
Caywood, Wayne	N/A
Cefola, Elaine	N/A
Chaffin, Claudia	2.4; 2.13

TABLE Q-3 (Cont.)

Chalfen, Karen	2.4
Chalker, Mikki	2.4; 2.13
Chambers, John	2.1; 2.2; 2.8; 2.14; 13.1
Chambless, Rochelle	2.4
Chang, Bill	2.4; 2.13
Chapman, Andrew	2.4
Chappell, Christina	2.4; 2.13
Chardon, Denise	2.4; 2.13
Chase, Linda	2.4; 2.13
Chasse, Rob	2.1; 2.2; 3.6
Chati, Janet	N/A
Chavet , Kent	3.2; 3.6; 8.3
Chelak, Mark	N/A
Chen, Allan	2.4; 2.13
Cherrington, Howard	2.4
Child, Katrina	2.4
Christ, Andrew	2.4; 2.13
Christensen, Kelly	3.6; 12.2
Christie, Tess	N/A
Christman, Margaret	2.4; 2.13
Christman, Mary	N/A
Christo, Jeffrey	N/A
Christopher, Bruce	2.4; 2.13
Christopher, Lucy	2.4; 2.13
Chunko, Mike	3.2; 3.6; 8.3
Chunko, Mike	3.2; 3.6
Chwalisz, Bart	2.4; 2.13
Claggett, Suzanne	2.4; 2.13
Claridge, Jeanne	2.4; 2.13
Clark, Carolyn	2.4; 2.13
Clark, James A. Jr.	2.4; 2.13
Clark, Pam	2.4
Clark, Todd	2.4; 2.13
Clark, Zulma	N/A
Clarke, Tom	2.4; 2.13
Claus, Carol	2.4; 2.13
Clayton, David	N/A
Clement, Susan	2.4
Cleveland, Al	2.5
Cling, Marvin	2.8
Clinton, 86001	N/A
Clough, Cyndi	2.4; 2.13
Coahran, Scott	N/A
Coates, Charles, Sr.	3.2; 3.6; 8.3
Cobb, Robert	2.4; 2.13
Cobb, Sandra	2.4; 2.13
Coble, Melvin	3.6
Coburn, Della	N/A
Coffee, Eileen	N/A
Cohen, Annelisa	N/A

TABLE Q-3 (Cont.)

Cohen, Daniel	2.4; 2.13
Cohen, David	N/A
Cohen, Francine	2.4; 2.13
Cohen, Howard	2.4; 2.13
Cohen, Judy	2.4; 2.13
Cohen, Sheara	2.4; 2.13
Cohen, Yoel	2.4; 2.13
Coleman, Timothy	2.4; 2.13
Colingsworth, Julia	N/A
Collins, Carol	2.4; 2.13
Collins, Jennifer	2.4; 2.13
Colten, Lora	2.4
Colton , Joseph	3.2; 3.6; 8.3
Columbia, James	2.4; 2.13
Colver, Frank	2.1; 2.2; 2.8; 2.14; 13.1
Colver, Matthew	2.1; 2.2; 2.8; 2.14; 13.1
Combes, Dale	N/A
Comella, John	N/A
Comer, Patrick	2.4; 2.13
Commarata, Anthony	2.4; 2.13
Conforti, Susan	2.4; 2.13
Conner, Kathleen	2.4; 2.13
Conner, Lisa	N/A
Conrad, Lori	2.4; 2.13
Conroy, Beverly	N/A
Conroy, Faith	2.4; 2.13
Conroy, James	2.4; 2.13
Conroy, Jim	2.4; 2.13
Cook, Barry	N/A
Cook, Charlotte	N/A
Cook, Jason	3.2; 3.6
Cook, Joy and Mike	N/A
Cook, Susan	N/A
Cook, Suzanne	2.4; 2.13
Cooley, Marian	2.4; 2.13
Coon, John	2.4; 2.13
Coonfield, Sherril	N/A
Coons, Kathryn	2.4; 2.13
Cooper, Charlene	2.4; 2.13
Cope, Denys	2.4; 2.13
Copeland, Sue	N/A
Copenhaver, Patricia	N/A
Coppotelli, Heide Catherina	2.4; 2.13
Corby, Kathleen	2.4; 2.13
Cordaro, Tom	2.4
Cordero, David and Ann	2.4; 2.13
Corkey, Peter	N/A
Cornelia, Jared	2.4; 2.13
Corriere, Jim	N/A
Corry, Ronit	N/A

TABLE Q-3 (Cont.)

Costa, Lynn	2.4; 2.13
Cottingham, Charlie	N/A
Couch, Sandra	N/A
Coulter, D. Mountainhawk	3.2; 3.6; 8.3
Coulter, David	3.2; 3.6; 8.3
Counterman, Michael	12.2
Courtney, Andy	3.2; 3.6
Courtright, Anne	2.4; 2.13
Covell, Sandi	2.4; 2.13
Cowan, Christina	2.4; 2.13
Cowin, Caryn	2.4; 2.13
Cox, Chadwick	2.4; 2.13
Cox, Jerry	2.5
Cracchiolo, Clara	N/A
Craig, Ann	2.4; 2.13
Cramer, Marilyn	2.4; 2.13
Cresseveur, Jessica	2.4; 2.13
Creswell, Sandra	N/A
Croft, Samuel	N/A
Crosland, Richard	2.4; 2.13
Cross, Dave and Rita	2.4; 2.13
Crow, Benita	2.4; 2.13
Crowley, John	N/A
Cruger, Kurt	N/A
Crumpacker, Barb	N/A
Crumpacker, Nancy	2.4; 2.13
Cuddy, William	2.4; 2.13
Cuff, Kermit	2.4; 2.13
Cui, Michael	N/A
Culmore, Matthew	N/A
Cummings, Joan	N/A
Cunningham, David	3.2; 3.6; 8.3
Curtis, Helen	2.4; 2.13
Cutting, Ken	12.4
Cwyk, Francine	3.2; 3.6
Cyzner, Steven	2.4
Czingula, Christian	N/A
D, Mary	2.4; 2.13
Daetz, Douglas and Gisela	2.4; 2.13
Dagney, Orysia	N/A
Dailey, Susan	2.4; 2.13
Dalla, John	2.4; 2.13
Daly, Charles	2.4; 2.13
D'Ambra, John	N/A
Daniel, Kian	N/A
D'Anne, Denise	N/A
Dannels, Paul	3.2; 3.6; 8.3
Dannevig, John	N/A
Dasher, Don	2.4; 2.13
Dashiell, James	2.4; 2.13

TABLE Q-3 (Cont.)

Dashiell, Mannyson	2.4; 2.13
Dashiell, Marilyn	2.4; 2.13
Davidson, Paul and Mary	N/A
Davis , Alan	3.2; 3.6; 8.3
Davis, Eleanor-Ann	2.4; 2.13
Davis, Glenn	2.4; 2.13
Davis, Lisa	2.4; 2.13
Dawson-Barker, Joelle	N/A
De La Torre, John	2.4; 2.13
Dean, Nancy	N/A
DeAngelis, Victor	N/A
Deborah, N/A	N/A
Decell, Kerri	2.1; 2.2; 2.8; 2.14; 13.1
Deese, Donna	N/A
DeGraw, Catherine	2.4
Deihl, Richard	2.4
Del Valle, Javier	N/A
Delaney , Patrick	N/A
Delaney, Janet	2.4; 2.13
Delehant, Raymond	2.4; 2.13
Deltognoarmanasco, John	2.4; 2.13
DeMars, Matthew	2.4; 2.13
Demonbrun, Carl	N/A
Demorest, Cynthia	2.4; 2.13
Denis, Laurie	2.4; 2.13
Denissen, Paula	N/A
Dennedy, Frank, Daniel	3.2; 3.6; 8.3
Denninger, Sandra	N/A
Dervin, John	N/A
Deskins, Merrill	2.4
Desroches, Don	N/A
Devine , Timothy	3.2; 3.6; 8.3
Devlin, Summer	N/A
deVos, James (Arizona Game and Fish Department)	3.2; 3.6; 3.9; 5.1; 9.3; 12.3
Diamante, Nina	N/A
DiBlasi, Dawn	2.4
Dickinson, Amanda	N/A
Dietriech, Kevin	3.2; 3.6; 8.3
Dillman, Michael	2.4; 2.13
Dillon, John (Grand Canyon River Outfitters Association)	2.13; 8.5; 12.1; 12.2
Dills, Robert	2.4; 2.13
Dimock, Brad	2.4
Dimock, Donald	N/A
Dingleberry, Pat	2.4
Dingman, S. Lawrence	2.4; 2.13
DiRenzo, Jennifer	2.4; 2.13
Dishion, Catherine	N/A
Diss, Marybeth	2.4
DiVall, Nelson	N/A

TABLE Q-3 (Cont.)

Dixon, Joyce	2.4; 2.13
Doherty, Jeanne	2.4
Dombroski, Ed	N/A
Dominiak, Adam	2.4
Donnelly, Stephen	2.4; 2.13
D'Onofrio, Adam	2.4; 2.13
Donovan, Elaine	2.4; 2.13
Dorfman, Ellen	2.4
Dorn, John	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Dorr, Kelly	N/A
Dougherty, Janet	2.4; 2.13
Downes, Susan	2.4; 2.13
Downing, Larry	N/A
Dowson, Eleanor	2.4; 2.13
Drahos, Ronald	2.4; 2.13
Drake, Mercy	N/A
Drake, Tracy	2.4; 2.13
Dresben, Fred	3.2; 3.6; 8.3
Dreyer, Daniel	N/A
Driessen, Lynn	2.4; 2.13
Driskell, Shelley	2.4; 2.13
Drummond, William (Mid-West Electric Consumers Association)	2.1
Duckworth, Michael	12.4
Duffus, Kathleen	N/A
Dujon, Phyllis	2.4; 2.13
Dunaetz, Ron	N/A
Dunbrack , Jan	N/A
Duncan, Kimberly	2.4; 2.13
Duncan, Pat	2.4
Duncan, Renee	2.4
Dunkley, Julianne	2.4; 2.13
Dunn, Elmo	2.4; 2.13
Dunn, Timothy	2.4; 2.13
Dunn, W. Ronald (Strawberry Anglers Association)	3.2; 3.6; 8.3
Dunwell, Nancy	2.4; 2.13
Durrer, Mary	N/A
Durrum, Kathy	N/A
Dutschke, Stephen	2.4; 2.13
Dzhonova, Iveta	2.4; 2.13
Eames, Mary	2.4; 2.13
Early, Lance	2.4; 2.13
Earnshaw, Shinann	2.4
Eaton, Kathleen	2.4; 2.13
Eaton, Lorena	2.4
Ebert, Erik	2.4
Eckerle, Lissa	N/A
Eddy-Lee, Gladys	2.4; 2.13
Edmonson, Michele	N/A
Edmunds, Alicia	N/A

TABLE Q-3 (Cont.)

Egger, Kathleen	2.4; 2.13
Eglin, Jennifer	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Eichel, Richard	2.4; 2.13
Eisenberg, Andrea	N/A
Eive, Gloria	2.4; 2.13
Elkins, E	2.4; 2.13
Ellenbecker, Marvin	N/A
Elliot, Nan	2.4; 2.13
Elliott, Lynn	2.4; 2.13
Elliott, R	2.4
Ellis, Julie	N/A
Elson, Adam	2.4; 2.13
Embry, Judith	2.4; 2.13
Emerson, Chelsea	2.4; 2.13
Emery, Susan	2.4; 2.13
Enger, Carolyn	N/A
Engler, Pamela	2.4; 2.13
English, Jeff	12.4
Entress, Greg	3.6; 12.4
Epstein, Harry	N/A
Epstein, Kelly	2.4; 2.13
Erb, Cheryl	N/A
Erbs, Lori	2.4; 2.13
Ernst, Cathie	2.4
Escobar, Victor	2.4; 2.13
Espinoza, Debra	2.4; 2.13
Estel, Karen	2.4
Estrada, Jennifer	2.4; 2.13
Evans, Bronwen	2.4; 2.13
Ewert, Henry	N/A
Ewing, Peter	2.4; 2.13
Ewoldsen, Brooke	N/A
F, Annette	14.3
Fabian, Bill	2.4; 2.13
Faegre, Dirk	2.4
Fahey, Keith	2.4
Fairchild-Ehm, Audrey	N/A
Faires, APRIL	N/A
Falcone, Janet	2.4; 2.13
Falcone, Pamela	N/A
Falconer, Russ	3.2; 3.6; 8.3
Fallon, Laura	2.12
Fantano, Theodore	2.4
Farber, Carol	2.4; 2.13
Farmer, Bonnie	2.4; 2.13
Fary, Jim	N/A
Fasano, Marianne	2.4; 2.13
Fear, Marge	N/A
Fearey, Donna	2.4; 2.13
Fehr, Richard	2.4

TABLE Q-3 (Cont.)

Fei, Eddijohn	2.4
Fenley, Bette-Burr	N/A
Ferguson, Charlene	N/A
Ferguson, David	3.2; 3.6; 8.3
Ferguson, Roy	3.2; 3.6; 8.3
Ferman, Pam	N/A
Fermin, Christina	N/A
Fernandez, Daniel	2.4; 2.13
Fickling, Karl	2.4; 2.13
Fidler, Vicki	N/A
Fiederer, Conrad	N/A
Fiedler, David	2.4; 2.13
Field, Patrick	2.4
Fielder, Linda	2.4
Fields, Mark J	2.4
Finch, Bonnie	N/A
Fine, Cindy	2.4; 2.13
Fink, Christine	N/A
Fink, Harry	2.4; 2.13
Finkelstein, David	2.4; 2.13
Finkelstein, Sheldon	2.4; 2.13
Finley, Diane	N/A
Finley, Patricia	2.4; 2.13
Finn, Peter	2.4; 2.13
Fisch, Greg	2.4; 2.13
Fischer, Elaine	2.4; 2.13
Fischer, Fred	2.4; 2.13
Fish, Richard	2.4; 2.13
Fisher, Judith	2.4
Fisher, Michael	N/A
Fishleder, Sam	N/A
Fitzpatrick, John	2.4; 2.13
Fladager, Susan	2.4; 2.13
Flanagan, Marianne	2.4; 2.13
Flanigan, Kevin (New Mexico Interstate Stream Commission)	5.2; 6.4.12; 8.11; 13.2, 13.4
Fleetwood, Patricia	N/A
Fleischer, Tim	2.4; 2.13
Fleming, Nancy	2.4
Fletcher, Carol	2.4; 2.13
Fletcher, Ken	3.2; 3.6; 8.3
Flickinger, R Charles	2.4; 2.13
Flores, Regina	2.4; 2.13
Flory, John	2.1; 2.2; 2.8; 2.14; 13.1
Floyd, Joel	2.4; 2.13
Fluker, Richard	2.4
Fogarty, Geraldin	N/A
Foley, Doris	N/A
Follansbee, Meghan	N/A
Fonken, Miryam	2.4

TABLE Q-3 (Cont.)

Forbes, Doreen	2.4
Ford, Michael	2.4; 2.13
Forlie, Kai	2.8
Forschner, Jillian	2.4; 2.13
Forwand, Arlene	N/A
Fosburgh, Eric	2.4; 2.13
Fost, Rebecca	2.4
Foster, Dawn	2.4; 2.13
Fouche, David	2.4; 2.13
Fox, Cinnamon	N/A
Fox, Lyndsey	2.1; 2.2; 2.8; 2.14; 13.1
Fraikor, Fred	3.2; 3.6; 8.3
Franchi, Irena	2.4; 2.13
Francis, Stuart	N/A
Franckowiak, Paul	N/A
Franco, Merrill	2.4; 2.13
Frank, Henry	2.4
Frank, Mitzi	2.4
Frankel, Myrna	2.4; 2.13
Frantz-Crafton, Candy	N/A
Franzmann, Paul	2.4; 2.13
Fraser, Bonnie	2.4; 2.13
Fraser, Evelyn	2.4; 2.13
Frazee, Janis	2.4; 2.13
Fredricks, Judith	2.4; 2.13
Frerichs, Joan	N/A
Frey, Brenda	N/A
Frey, Lawrence	2.4; 2.13
Friedel, Diane	2.4; 2.13
Friedman, Thomas	N/A
Friehauf, Mike	3.2; 3.6; 8.3
Friel, Bernard	2.4
Friel, Bernard P.	2.4
Fromowitz, Allen and Carol	N/A
Fuessel, Chere	N/A
Fugate, John	3.2; 3.6; 8.3
Fugina, Vincent	3.2; 3.6; 8.3
Fuller, George	2.4; 2.13
Fuller, Roy	2.4; 2.13
Fulmer, James	2.4
Furno, Saragh	N/A
Fusi, David	3.2; 3.6; 8.3
G, C.	2.4; 2.13
G, Derek	2.2; 3.6; 12.2
Gabriel, Robert	2.4; 2.13
Gaines, Marsha	2.4; 2.13
Galindo, Thomas	3.2; 3.6; 8.3
Gallo, Gina	N/A
Gambriel, John	2.4; 2.13
Gannon, Kristine	N/A

TABLE Q-3 (Cont.)

Garber, Barbara	2.4; 2.13
Garcia, Jeffery	2.4; 2.13
Gardner, Chris	2.4
Garey, JG	2.4; 2.13
Garnas , D	3.2; 3.6; 8.3
Garratt, Liz	2.4; 2.13
Garrity, Coleen	2.4; 2.13
Garton, Katie	2.4; 2.13
Garvey, Patrick	2.4
Gates, Joanne	N/A
Gauthier, Dale	3.6
Gay, Larry	2.4; 2.13
Geis, Emery	3.2; 3.6; 8.3
Gelbart, Susannah	N/A
Gelles, Kat	2.4; 2.13
Gensler, Donna	N/A
George, Thomas (State of Colorado, Colorado Water Conservation Board)	2.2; 2.5; 2.15; 2.20; 6.1.2; 6.1.3; 6.4.12; 6.4.13; 8.6; 8.7; 8.8; 8.12; 10.8; 12.6; 13.4
George, Thomas (Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming & Upper Colorado River Commission)	2.2; 2.5; 2.19; 2.20; 3.6; 5.1
Gerak, Edward (Buckeye Water Conservation & Drainage District)	2.2; 2.9; 3.5; 5.2; 11.1
Gerber, Steve	12.2
Gerstenfeld, Judith	3.2; 3.6
Ghirardelli, Susan	2.4
Giantomasi, David	N/A
Giasson, Bertrand	N/A
Gibbon, Jocelyn	2.4; 2.14
Gibson, Jody	2.4; 2.13
Giere, Linda	2.4; 2.13
Gilbert, Don	N/A
Gill, Stephanie	N/A
Gillies, Dan	N/A
Gilligan, Michael	2.4; 2.13
Gilliland, Charles	2.4
Gilmore, Myra	2.4; 2.13
Ginn, Kenneth	2.4; 2.13
Girard, Brian	N/A
Girvin, Darrylin	2.4; 2.13
Gist, Sally	2.4
Gitlin, Alicyn (Sierra Club - Grand Canyon Chapter)	2.8; 2.14; 3.1; 3.4; 3.8; 7.1; 8.3; 13.1; 14.1; 14.2
Glascock, Katherine	N/A
Glass, Perri	N/A
Glasser, Mark	N/A
Gleaton, Dianne	N/A
Glenn, Alice Ann	2.4; 2.13
Glessing, Kathryn	N/A
Gliva, Stephen	2.4; 2.13
Gloeckler, Bill (Grand Canyon Whitewater)	12.1; 12.2

TABLE Q-3 (Cont.)

Gloyd, Jan	N/A
Glynn, John	2.4; 2.13
Godich, Marcia	2.4; 2.13
Goebel, Fred	2.4; 2.13
Goebel, Lawrence	N/A
Goertz, Harry	3.2; 3.6; 8.3
Goetschius, Lascinda	N/A
Goforth, Kathleen (U.S. Environmental Protection Agency, Region IX)	N/A
Golden, Gene	N/A
Golden, Kathleen	2.4
Goldstein, Arthur	N/A
Goldstein, Dale	2.4; 2.13
Gonzales Nielsen, Rosemarie	N/A
Gonzalez, Joy	N/A
Gonzalez, William G	2.4; 2.13
Goodale, Margaret	2.4; 2.13
Goodrich, D'Arcy	2.4; 2.13
Goodwin, Elizabeth	2.4; 2.13
Goodwin, Margaret	N/A
Goodwin, Tom	3.2; 3.3; 3.6
Gorrin, Eugene	2.4; 2.13
Gorsetman, Mark	2.4; 2.13
Gottlieb, Olga S.	2.4; 2.13
Gould , Michael	N/A
Gould, Jo Anne	N/A
Gover, Pat and Gary	2.4; 2.13
Goyette, Marc	N/A
Goyette, Margo	2.4
Grabar, Christine	N/A
Grace, George	2.4; 2.13
Grace, Harry	2.4; 2.13
Grace, Howard	N/A
Graffagnino, Mary Ann and Frank	2.4; 2.13
Graham, James	2.4; 2.13
Graham, James	3.2; 3.6
Graham, Jim	2.4; 2.13
Grames, Patricia	2.4; 2.13
Granakis, George	2.4
Granlund, Fred	2.4; 2.13
Grasso, Jen	N/A
Gray, Heather	2.4; 2.13
Gray, Richard	3.2; 3.6
Gray, Tony	N/A
Green, Jesse	2.4; 2.13
Greene, Minna	N/A
Greenfield, Cariln	2.4; 2.13
Greenhalgh, Diana	2.4; 2.13
Greenhill, Barry	N/A
Greenlee, Philip (International Federation of Fly Fishers)	2.5; 3.2; 3.3; 3.4; 3.6; 12.2

TABLE Q-3 (Cont.)

Gregory, Paul	N/A
Gregory, Probyn	3.2; 3.6; 8.3
Greif, Kevin	2.4
Grenard, Mark Hayduke	2.8
Grenci, Ann	N/A
Gresko, Andrew	N/A
Grierson, Phillip	2.4; 2.13
Griffin, Byron	2.4; 2.13
Griffin, Leah	2.4; 2.13
Griffiths Vega, Joan	2.4; 2.13
Grisez, Bernard	2.4; 2.13
Griswold, Dave	2.4; 2.13
Griswold, Tracy	2.4; 2.13
Gritsch, Maria	2.4; 2.13
Grom, Jeff	N/A
Groshardt, Joanne	N/A
Gross, Linda	N/A
Gross, Todd	N/A
Grove, Earl	2.4; 2.13
Grove, Stephen	2.4; 2.13
Grover, Justin	3.2; 3.6; 8.3
Grover, Justin	2.4; 2.13
Grube, Mary Alyce	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Grzanna, Maureen	N/A
Guard, Mary	2.4; 2.13
Guckian, Michael	2.1; 2.2; 2.8; 2.14; 13.1
Guenther, Lavaune	N/A
Guile, Roger	3.6
Guinnup, David	2.4; 2.13
Guion, William	2.4; 2.13
Gullam, Paul	2.4; 2.13
Gunning, John	2.4; 2.13
Gunter, Karlene	2.4; 2.13
Gunther, Ken	2.4; 2.13
Gutierrez, Laura	2.4; 2.13
Gwinn, Carol	N/A
H, Dennis	2.4; 2.13
Haag, James	2.4; 2.13
Haarr, Lars	N/A
Haber, Steven	2.4; 2.13
Hackel, Helena	N/A
Hackett, Marcia	2.4
Hackman, Jim	2.1; 2.2; 2.8; 2.14; 13.1
Hackney, Stephen	2.4; 2.13
Haertel, Melissa	2.4; 2.13
Hafer, Sarah	2.4; 2.13
Hahn, Robert	N/A
Hahn, Theodore	N/A
Hahus, Donna	N/A
Haines, Thomas	2.4; 2.13

TABLE Q-3 (Cont.)

Haley, Patty	N/A
Hall, Beth	2.4
Hall, Diana	2.4; 2.13
Hall, James	2.4; 2.13
Hall, Janice	N/A
Hall, Sue	N/A
Hallett, Mark	2.4; 2.13
Halloran, Michael	N/A
Halpain, Dale	N/A
Hamill, John (Trout Unlimited; International Federation of Fly Fishers)	2.5; 3.2; 3.3; 3.4; 3.6; 5.1; 8.3; 9.3; 12.2; 12.3
Hamilton, Lynn (Grand Canyon River Guides, Inc.)	2.13; 4.1.2; 7.3.1; 9.2; 10.3; 11.3
Hamilton, Roy	N/A
Hammer, Brian	N/A
Hammer, Dorothy	N/A
Hammerstad, Charles	3.2; 3.6; 8.3
Hampton, Hugh	N/A
Hand, David	3.2; 3.6
Handelsman, Robert	2.4; 2.13
Hanlon, K	2.4; 2.13
Hansen, Greg	3.2; 3.6; 8.3
Hansen, Jan	2.4; 2.13
Hanson, Bruce & Michelle	2.4; 2.13
Hanson, David	N/A
Hanson, Norman	2.4
Hanson, Norman	N/A
Harden, Ronald	2.4; 2.13
Harding, Steve	3.2; 3.6
Hardt, Vincent	2.4; 2.13
Hardy, Wallace	3.2; 3.6
Harker, William	2.1; 2.2; 2.8; 2.14; 13.1
Harland, Donald	2.4; 2.13
Harmer, Jill	2.4
Harmon, Amy	2.4; 2.13
Harmon, Chris	3.2; 3.6; 8.3
Harmon, Gail	2.4; 2.13
Harned, Kristin	2.4; 2.11; 2.13
Harper, Barbara	2.4; 2.13
Harper, Dennis	3.2; 3.6; 8.3
Harper, Rebecca	2.4; 2.13
Harper, Robin	2.4; 2.13
Harrington, Warren	N/A
Harris, Candice	2.4; 2.13
Harris, Debra	2.4; 2.13
Harris, Gail	N/A
Harris, James	2.4; 2.13
Harris, Susan	2.4; 2.13
Harrison, David	2.4; 2.13
Harrison, Marie	2.4; 2.13
Hartman, Jenifer	2.4; 2.13

TABLE Q-3 (Cont.)

Hartman, Todd	2.4; 2.13
Harvey, Richard	3.2; 3.6; 8.3
Haskell, Michael	2.4; 2.13
Haslip, James	N/A
Hatch, Steve (Hatch River Expeditions)	12.1; 12.2
Hathaway, Susan	2.4; 2.13
Hauenstein, Cathleen	2.4; 2.13
Haugen, David	2.4; 2.13
Haverfield, Heather	2.4; 2.13
Hawkins, Phillip	3.2; 3.6
Haycock, Robert	2.4; 2.13
Haydock, John	3.6; 8.3
Hayes, Christine	2.4
Hayes, Tim	N/A
Haymans, Deanna	2.4; 2.13
Hays, Dennis	2.4; 2.13
Hays, Helen Logan	2.4
Hayworth, Steven	2.4; 2.13
Hazen, Alona	2.4; 2.13
Head, Kris	2.4; 2.13
Heald , Douglas	3.2; 3.6; 8.3
Heap, Francesca	2.4
Heathman, Susan	2.4; 2.13
Heck, David	3.2; 3.6
Hedgcock, Charles	2.4; 2.13
Hedges , Bill	3.2; 3.6; 8.3
Hediger, JoAnn	N/A
Heffron, Joshua	2.4; 2.13
Hegedus, Barbara	N/A
Heide, Andra	2.4; 2.13
Heilmann, James	2.4; 2.13
Heinle, Janet	2.4; 2.13
Heinly, Bridgett	2.4; 2.13
Heinz, Guenter	2.4; 2.13
Helmer, Kathleen	2.4; 2.13
Helmick, Rick	3.2; 3.6; 8.3
Helstien, Sherie	2.4
Hendry, Dawn	2.4
Hengesbaugh, Matt	2.4; 2.13
Henninger, Maryann	2.4; 2.13
Henry , David	3.2; 3.6; 8.3
Henry, Amy	2.4
Henzel, William	2.4; 2.13
Herman, Dorothea	N/A
Hernandez, Patricia	2.4; 2.13
Herrera, Desiree	2.4; 2.13
Herrera, Lois	2.4; 2.13
Herrick, Michael	2.4; 2.13
Herrman, Chris	N/A
Hertz, Richard	3.6

TABLE Q-3 (Cont.)

Herzog, Robert	N/A
Hessler, Charles	2.4; 2.13
Hessler, Charles	2.4; 2.13
Hewelt, Karen	N/A
Heyde, Christiane	N/A
Heyneman, Amy	2.4; 2.13
Heywood, Austin	N/A
Hibbs, Howard	3.2; 3.6
Hicks, Robert	2.4; 2.13
Hiestand, Nancy	2.4; 2.13
Hill, Gerry	3.2; 3.6; 8.3
Hill, Marilyn	2.4; 2.13
Hill, Mark	N/A
Hillard, Dale	2.4; 2.13
Hilliard, Donald	2.4; 2.13
Hills, Richard	2.14
Hilton, Bill	2.4; 2.13
Hinderberger, Sacha	2.4
Hines, Marianne	N/A
Hinkle, Connie	2.4; 2.13
Hinkley, David	2.4
Hinton, Terry	N/A
Hirschenbein, Randy	2.4; 2.13
Hirschman, Mark	2.4; 2.13
Hiscox, Tom	3.2; 3.6; 8.3
Hissom, Terry	N/A
Hlat, Mike	2.4; 2.13
Hoagland, Linda	2.4; 2.13
Hobbs, Joan	N/A
Hobbs, Pat	2.4; 2.13
Hodie, Jake	2.4; 2.13
Hoenigman, Vince	2.4; 2.13
Hoey, Roseanne	2.4
Hofer, Ricardo	2.4; 2.13
Hoffman, Chrissy	2.4; 2.13
Hoffman, Jane	2.4; 2.13
Hoffman, Janice	N/A
Hoffman, Lincoln	2.4; 2.13
Hoffman, Marc	2.4; 2.13
Hofheins, Paul	2.4; 2.13
Hogan, Mary	2.4
Hogan, Randolph	2.4
Holbert, Cynthia	2.4; 2.13
Holbo, Chadwick	3.2; 3.6; 8.3
Holbrook, Jon	2.4; 2.13
Holbrook, Scott	3.2; 3.6
Holder, Gary	2.4; 2.13
Holland, Brett	2.4; 2.13
Holland, J.	2.4; 2.13
Hollington, Jason	N/A

TABLE Q-3 (Cont.)

Hollinrake, Mark	2.4; 2.13
Holman, Clarisse	N/A
Holmes, David	2.4; 2.13
Holt, Arve	2.4; 2.13
Holthouse, Dave	2.4; 2.13
Holtzman, Dorothy	2.4
Holtzman, Julie	2.4
Honanie, Herman (The Hopi Tribe)	2.9; 4.1.1; 8.1; 10.1; 10.7, 10.8
Honigsblum, Alexander	2.4; 2.13
Honore, Stephanie	2.4; 2.13
Hope, Phillip	2.4; 2.13
Hopkins, Larry	2.4
Hoppe, Lindy	N/A
Horn, Stephanie	2.4; 2.13
Horowitz, Laura	2.4; 2.13
Horton, Deanna	N/A
Horton, Derek	N/A
Horzepa, Judith	N/A
Hosea, David	2.4
Hottenstein, Tara	2.4; 2.13
Hougaard, David	3.2; 3.6; 8.3
Houston, Meghan	2.4; 2.13
Hovorka, Ah	N/A
Howard, Bryan	N/A
Howard, Lex	2.8
Howard, Nancy	2.4; 2.13
Howell, Dorothy (Payson Fly Casters Club)	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2; 12.4
Howland, Cynthia	2.4; 2.13
Howse, Peter	2.1; 2.2; 2.8; 2.14; 13.1
Hubbard, James	2.4; 2.13
Hubbell, Linda	2.4; 2.13
Hubbs, Dawn (Hualapai Nation)	4.2; 4.3; 8.2; 10.4; 10.5; 10.6; 10.8; 12.5
Hudgins, Jerry	2.4; 2.13
Huerta, John	2.4
Huffman, Shelia	N/A
Hughes, Barbara	N/A
Hughes, Laurel	2.4; 2.13
Hughes, Lisa	2.4; 2.13
Huie, Jonathan	N/A
Hulsey, Tamara	2.4; 2.13
Hunnicutt, Joan	N/A
Hunt, Timothy	3.2; 3.6; 8.3
Hunter, Stanton	N/A
Huntoon, Kristin	2.4; 2.13
Hurabiell, John	3.2; 3.6; 8.3
Hurley , Pat	3.2; 3.6; 8.3
Hurliman, Heidi	2.4
Hus, Richard	3.2; 3.6; 8.3
Hutchinson, Bryce	N/A
Hutchinson, Terrance	N/A

TABLE Q-3 (Cont.)

Huycke Mccall, Ruth	N/A
Hyams, Mark	2.8
Hyde, David	2.8; 2.14; 13.1
Ibenthal, Brian	3.2; 3.6; 8.3
Ihle, John	2.4; 2.13
Iltis, Michael	2.4; 2.13
Imar, Delaney	2.4; 2.13
Imlay, Marc and Alice	2.4; 2.13
ImMasche, Sonia	2.4
Ingemi, Lynn	N/A
Ingham, Lula Kay (Katie)	2.4
Ingraham, Carolyn	2.4; 2.13
Ionina, Kate	2.4; 2.13
Iovino, Teresa	2.4; 2.13
Iseri, Martin	N/A
Iverson, Steve	2.4; 3.13
Jackman, Rob	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Jackson, Harold	N/A
Jackson, James	2.4; 2.13
Jackson, Sue	2.4; 2.13
Jackson, Warren	2.4; 2.13
Jacob, Lynn	N/A
Jacobel, Richard	2.4; 2.13
Jacobi, Allen	N/A
Jacobson, Susan	2.1; 2.2; 2.14
Jamal, Kate	2.4; 2.13
James, Leslie (Colorado River Energy Distributors Association)	1.1; 1.2; 1.3; 1.4; 1.5; 2.1; 2.2; 2.6; 2.7; 2.10; 2.14; 2.19; 2.20; 3.3; 3.8; 4.1.1; 4.1.2; 4.1.3; 5.2; 6.1.2; 6.2.1; 6.2.3; 6.3.2; 6.4.1; 6.4.2; 6.4.3; 6.4.4; 6.4.5; 6.4.7; 6.4.11; 6.4.14; 6.5.1; 6.6.1; 6.7; 7.2; 7.3.2; 8.8; 8.9; 9.4; 10.3; 12.9
James, Nadine	2.4
Jansen, Sam	2.8; 2.13; 2.14; 4.1.2; 7.3.1; 11.3
Janzen, Gayle	2.4; 2.13
Jardine, Guy	3.2; 3.6; 8.3
Jarvis, Michael	N/A
Jasper, Alan	2.4; 2.13
Jastromb, Virginia	N/A
Jeavons, John	N/A
Jeffries, Stephen	3.2; 3.6; 8.3
Jeka, Lynn (Western Area Power Administration)	1.2; 1.3; 5.1; 6.13; 6.23; 8.4
Jennings, Joanna	N/A
Jennings, Scott	2.4; 2.13
Jennings, Sid	N/A
Jensen, Margaret	2.4
Jensen, Sterling	3.2; 3.6; 8.3
Jobe, Laura	2.4
Jobling, Catherine	2.4
Johannsen, Mary	2.4; 2.13
Johnsen, David	2.4; 2.13

TABLE Q-3 (Cont.)

Johnsen, Harold	2.4; 2.13
Johnson, Arnold	N/A
Johnson, Brett	3.2; 3.6
Johnson, Bruce	2.4
Johnson, Chessa Rae	2.4; 2.13
Johnson, Deborah	N/A
Johnson, Douglas	2.4
Johnson, G.G.	2.4; 2.13
Johnson, Jay	N/A
Johnson, Karen	N/A
Johnson, Martha	2.4; 2.13
Johnson, Rich	3.2; 3.6; 8.3
Johnson, Russell	2.4; 2.13
Johnson, Todd	N/A
Johnson, Vicki	2.4; 2.13
Johnson, Viginia	N/A
Johnston, Philip	2.4; 2.13
Jones , Martin	3.2; 3.6; 8.3
Jones, Andrea	2.4; 2.13
Jones, Lauel	2.4
Jones, Terri	2.4
Jones, Tina	N/A
Jonkosky, Cassandra	N/A
Jonkosky, Charles	N/A
Joos, Sandra	2.4; 2.13
Jordan, Catherine	2.4
Jordan, Kris	3.2; 3.6; 8.3
Jordan, S.	2.4
Jordan, Yashoda	N/A
Jorgensen, Bob	N/A
Jorgensen, John	2.4; 2.13
Judy, Paul	N/A
June, Ana	2.1; 2.2; 2.8; 2.14; 13.1
Jussaume, Carol	2.4; 2.13
Justice, Cheryl	2.4; 2.13
Justice, Robert (Electrical District #7)	N/A
K, Matt	N/A
K,J.	N/A
Kacser, Linda	N/A
Kadar, Zach	2.4; 2.13
Kaiser, Terry	3.2; 3.6; 8.3
Kalman, Janet	2.4; 2.13
Kalscheuer, Maria	N/A
Kane, Leah	2.4; 2.13
Kane, Linda	N/A
Karanjawala, Eric & Armin	2.4; 2.13
Karns, Gary	N/A
Karr, Sheena	2.4; 2.13
Karrs, David	3.2; 3.6; 8.3
Kartman, Sue	2.4; 2.13

TABLE Q-3 (Cont.)

Kashinski, David	2.4; 2.13
Kastel, Diane	2.4; 2.13
Katten, DC	N/A
Katz, Ron	2.4; 2.13
Kaufman, Andrea	2.4; 2.13
Kaufman, Barry	2.4; 2.13
Kaufman, Joan	2.4
Kaufman, Melanie	N/A
Kava, John	3.2; 3.6
Kawa, Sandra	2.4; 2.13
Kawszan, Karen	2.4; 2.13
Kaye, Jackie	2.4; 2.13
Kearns, Peter	N/A
Keck, Robert	2.1; 2.2; 2.8; 2.14; 13.1
Keegan, Barbara	2.4; 2.13
Keegan, Helen	N/A
Keenan, Thomas	N/A
Keeton, Hank	2.4; 2.13
Keim, Lisa	2.4; 2.13
Keiser, Robert	2.4
Keith, Kristin	2.4; 2.13
Kellermann, Thomasin	N/A
Kelley, Dorinda	N/A
Kelly, Diane	2.4
Kelly, Donell	N/A
Kelly, Steve	3.6
Kelly, Wayne	2.4; 2.13
Kelm, Kathleen	2.4; 2.13
Kemper, Erik	N/A
Kendrick, Cindy	2.4; 2.13
Kendy, Arthur	2.4; 2.13
Kent, Ellen	N/A
Kentfield, Maren	N/A
Kepner, Sethsue	2.4; 2.13
Kerivan, Andrea	N/A
Kerman, Paul	2.4; 2.13
Kern, Alicia	2.4; 2.13
Kerwell, Cherrie	2.4; 2.13
Kerwin, Patrick	N/A
Kessler, Susan	2.4; 2.13
Kettelhut, H.	N/A
Key, Laurence	2.4; 2.13
Keymolent , Claudia	2.4; 2.13
Khalsa, Mha Atma S.	2.4; 2.13
Kibler, JK	2.4
Kieffer, Ramsay	2.4
Kiel, Edward	3.2; 3.6
Kilpatrick, Leslie	2.4; 2.13
Kincaid, Ted	2.4; 2.13
Kindel, Karen	2.4

TABLE Q-3 (Cont.)

King, Kathy	N/A
King, Kelly	N/A
King, Ruth	N/A
King, Stephen	N/A
Kingsley, Robert	2.4; 2.13
Kinkead, Timothy	N/A
Kirk, Nancy Jo	2.4; 2.13
Kirkpatrick, Mary	2.4
Kirsh, Julie	N/A
Kite, Richard	2.4; 2.13
Kittle, Pat	2.4; 2.13
Kitts, Michele	N/A
Kizer, David	2.8; 2.14; 11.5
Klass, David	2.4; 2.13
Klass, David	2.4; 2.13
Klein, Mark	2.4; 2.13
Kline , Regan	3.2; 3.6; 8.3
Klinkhamer, Trevor	12.2
Klipfel II, George	2.4; 2.13
Knickerbocker, Al	N/A
Kniess, Betty	2.4; 2.13
Knight, Robert	N/A
Knoll, Carolyn	2.4; 2.13
Knorr, Carl	2.4; 2.13
Knuth, Dean	2.4; 2.13
Koch, James	2.4; 2.13
Koch, Joann	2.4; 2.13
Koch, Susanne	N/A
Koeser, Leland	N/A
Koessel, Karl	2.4; 2.13
Koivisto, Ellen	2.4; 2.13
Kolessar, Gregg	N/A
Komisarof, Jeff	N/A
Konzen, Susan	2.4; 2.13
Korec, Karen	2.4
Kosec, Dawn	2.4; 2.13
Koterba, Michael	2.4; 2.13
Kraft, Tessa	2.4; 2.13
Krai, Kevin	3.2; 3.6
Kramarz, Karen	2.4
Kramer, Eileen	2.4; 2.13
Kramer, Gavin	2.4; 2.13
Kramer, Grant	2.4
Kramer, Laura	2.4; 2.13
Krasnoff, Joshua	N/A
Krause, Doug	2.4; 2.13
Krause, Roger	3.2; 3.6; 8.3
Krause, William	2.4; 2.13
Krehbiel, Robb	2.4; 2.13
Krell, Elinore	2.4; 2.13

TABLE Q-3 (Cont.)

Krieger, Gena	2.4; 2.13
Kring, Juli	2.4; 2.13
Krone, Jeannene	2.4; 2.13
Krueger, David	2.4; 2.13
Krumpos, Steven	3.2; 3.6; 8.3
Krupa, Dave	N/A
Kubik, Cathy	N/A
Kuciej, Walter	2.4; 2.13
Kuhn, Kerry	2.4; 2.13
Kulka, Wally	3.2; 3.6; 8.3
Kuppler, Curtis	2.4; 2.13
Kusick, Paul	N/A
Kust, Melina	2.8
Kuter, Ann	N/A
Kuykendall, Gregory	3.2; 3.6
La Falce, Stephen	3.2; 3.6; 8.3
La Falce, Stephen (Trout Unlimited - Grand Canyon Chapter)	2.5; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
La Falce, Stephen (Trout Unlimited - Arizona Council)	2.5; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Labasco, Christopher	2.4; 2.13
LaBranche, Laura	3.2; 3.6; 8.3
Lack, Phil	2.4
Lackey, Mercedes	3.6
LaCognata, Dale	2.4
Lacy, Sharon	2.4; 2.13
Ladd, Larry& Karen	2.4; 2.13
Ladimer, Martin	2.4; 2.13
Lafleur, Steven	2.4; 2.13
LaFour, Liz	N/A
Lago, Don	N/A
Lagonegro, Sean	2.4
Laieski, Caleb	2.4; 2.13
Lair, Jennifer	2.4
Lam, Ofelia	2.4; 2.13
LaMaack, Larry (Wyoming Municipal Power Agency)	2.6; 2.11; 2.13
Lamb, Patricia	2.4
Lambert, Howard	N/A
Lamiquiz, David	N/A
Lamons, Kristina	2.4; 2.13
Land, Martha	2.4; 2.13
Landry, Michael	3.2; 3.6; 8.3
Landry, Michael	3.2; 3.6; 8.3
Lane, Debra	2.4; 2.13
Lane, Troy	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Lanfranchi, LJ	2.4; 2.13
Lange, Elena	N/A
Lange, Marlena	2.4; 2.13
Lanka, Mike	2.4; 2.13
Lantry , Gavin	3.2; 3.6; 8.3
Lanus, Howard	N/A

TABLE Q-3 (Cont.)

Lanzetta, Dante	2.4; 2.13
LaPlaca, Lisa	2.4; 2.13
LaRoche, David	2.4
Larsen, Lance	3.2; 3.6; 8.3
Lash, Cal	2.8
Lashaway, Lisa	2.4
Lasley, Barbara	2.4; 2.13
Latona, Jaron	2.4; 2.13
Latta, George	2.1; 2.2; 2.8; 2.14; 13.1
Lausmann, Vance	2.4; 2.13
LaVonne, Nadine	N/A
Lawler, Lynn	N/A
Lawrence, Christopher	N/A
Lawrence, Pat	2.4
Lawson, Barbara	N/A
Layfield, Elizabeth	2.4; 2.13
Lazor, John	2.4; 2.13
Lea, Susan	2.4
Leal-McBride, Odilia	N/A
Learmann, Prisca	2.4; 2.13
LeClair, Peg	2.4; 2.13
Ledger, Patrick (Arizona Electric Power Cooperative, Inc.)	2.1
Lee, Madeleine	N/A
Lee, Miree	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Lee, Robert	2.4; 2.13
Lee, Virginia	2.4; 2.13
Leeuw, Lyn	N/A
Lehmann, Andre	2.1; 2.2; 2.8; 2.14; 13.1
Leichter , Lew	3.2; 3.6; 8.3
Leifker, M.	3.2; 3.6; 8.3
Leland, Lora	2.4; 2.13
Lemkuil, Rita	N/A
Lenchner, Nicholas	2.4; 2.13
Lenz, Andrew	2.4; 2.13
Leo, Carlos	2.4
Lesser, Rob	2.4; 2.13
Leve, Kristin	2.4; 2.13
Levesque, Paul	2.4; 2.13
Levin, Jon	2.4; 2.13
Levine, Lynn	N/A
Levitus , Walt	3.2; 3.6; 8.3
Levy, Linda	2.4
Lewis, O	2.4; 2.13
Lewis, Rita	2.4; 2.13
Lewis, Sherman	2.4; 2.13
Lewis, Tom	N/A
Liaudat, Claudia	N/A
Lichtenberger, Wayne	3.2; 3.6; 8.3
Liebeskind, Al	2.4

TABLE Q-3 (Cont.)

Lieder, Cecilia	N/A
Liesche, Kenneth	2.4; 2.13
Liggio, Eleanor	2.4; 2.13
Lilling, Glenda	2.4; 2.13
Lindsay, Brenda	N/A
Lindsay, Leslie	2.4; 2.13
Linna, Patricia	N/A
Lipsey, Joseph	2.4; 2.13
Lipsky, carol	2.4
Lish, Jeannine	2.4; 2.13
Liske, Patricia Ann	2.4
Liss, Mary	2.4; 2.13
Little, Dennis, Jr.	N/A
Little, Roy	3.2; 3.6; 8.3
Littlefield, Joan	N/A
Litwin, Linda	N/A
Livingston, Deborah	2.4; 2.13
Llewellyn, Suzanne	N/A
Lo, Jen	N/A
LoCicero, Robert	2.4
Lockett, Jennifer	2.4; 2.13
Locklear, Clyde	2.1; 2.2; 2.8; 2.14; 13.1
Logan, Newton	3.2; 3.6; 8.3
Lojo, Rosemary	N/A
Lolli, Mark	2.4; 2.13
Long, Dave	N/A
Long, Ernest	2.1; 2.2; 2.8; 2.14; 13.1
Long, Judith	N/A
Loomis , Rea Ann	2.4
Loosli, Ed (The Wildlife Trust)	2.4
Loper, Brigitte	2.4; 2.13
Lorentz, Marcel	N/A
Lotak, Justin	2.4; 2.13
Love, Mary	2.4; 2.13
Lowans, Jennifer	2.4; 2.13
Lowery, Joanne	2.4; 2.13
Lucas, Mary	2.4; 2.13
Luddon, Barbara	2.4; 2.13
Lueck, Donna	2.4; 2.13
Lundgren, Scott	2.4; 2.13
Lupenko, Andy	2.4; 2.13
Lupori, Stacy	2.4; 2.13
Lusby-Denham, Anne	2.4
Lusche, Jim	3.2; 3.6; 8.3
Luttich, Stu	2.4; 2.13
Luzier, Maresa	N/A
Lynch, Doris	2.4
Lynch, Frances	2.4; 2.13
Lynch, John	N/A

TABLE Q-3 (Cont.)

Lynch, Robert (Irrigation and Electrical Districts Association of Arizona)	2.3; 2.6; 2.10; 2.11; 2.21; 8.10; 11.1; 11.2; 11.4; 12.10
Lyon, R. Terry	N/A
Lyons, Kathi	2.4; 2.13
M., Henry	2.4; 2.13
MacAlpine, Barbara	2.4; 2.13
Macan, Edward	2.4; 2.13
MacArthur, June	N/A
MacDonald, John	2.4
Maciel, Marie	2.4; 2.13
Mackay, Leslie	2.4; 2.13
MacKenzie, Michelle	2.4; 2.13
Mackin, Tom (Coconino Sportsmen)	2.4
MacLeod, Dianna	2.4; 2.13
MacRaith, Bonnie	2.4; 2.13
MacRobbie, Todd	3.6
Madden, Kevin	3.2; 3.6
Magallon, Katie	N/A
Magee, W.L.	3.2; 3.6; 8.3
Makinen, Marvin	N/A
Mallett, Barbara	N/A
Malloy, Jerry	2.1; 2.2; 2.8; 2.14; 13.1
Malone, Michael	2.4; 2.13
Maloney, Liam	N/A
Malven, Tania	2.4
Manderscheid, B.	13.1
Mang, J.	2.4; 2.13
Mangrum, Carl	3.2; 3.6
Mangum, Laurie (St. George Energy Services)	2.4; 2.10
Mangus, Tracey	2.4; 2.13
Manka, Joann	2.4
Mannering, Natalie	2.4; 2.13
Manresa, Howard	2.4; 2.13
Mansfield, Tim	12.4
Marano, Gina	2.4; 2.13
Marasco, Summer	2.4; 2.13
Marchello, Linda	2.4
Marckini, David and Julia (First United Methodist Church)	2.4
Marcus, Marilyn	2.4; 2.13
Margulis, Elise	N/A
Mark, Robert	2.4; 2.13
Markham, William	N/A
Marks, J.B.	N/A
Marquis, Sharon	N/A
Marrs, Cynthia	2.4; 2.13
Marsden, Michael	3.2; 3.6; 8.3
Marsett, Robert	N/A
Marsh, David	3.2; 3.6; 8.3
Marsh, Sherry	N/A

TABLE Q-3 (Cont.)

Marshall, Linda	2.4
Marshall, Robert	N/A
Martin, Chase	2.4
Martin, Drew	2.4; 2.13
Martin, Gerry	N/A
Martin, Joanna	N/A
Martin, Joel	3.2; 3.6; 8.3
Martin, Michele	2.4; 2.13
Martinez, Brittany	2.4; 2.13
Martinez, Janie	N/A
Martinez, Ora Marek (The Navajo Nation)	4.2; 7.6; 8.1; 10.2; 10.7; 10.8
Martinez, Rebecca	2.4; 2.13
Martini, Denise	2.4; 2.13
Marvick, Vicki	2.4; 2.13
Marvin, Cindy	N/A
Maschke, Nicole	N/A
Maseda-Gille, Sheila	2.4; 2.13
Massey, Carolyn	2.4; 2.13
Mastri, Francis	2.4; 2.13
Matejka, Harry	2.4; 2.13
Matelski, Lauren	2.4; 2.13
Mathis, Leanne	2.4; 2.13
Mathis, Marty	2.12
Matsui, Vicky	2.4; 2.13
Mattes, Dale	2.4; 2.13
Mattis, Henry	N/A
Matusik, Barbara	2.4; 2.13
Maynard, Bruce	2.4
Maynard, Linda	N/A
Mazzuca, R	2.4
McAdoo, Hosea	N/A
McAlister, Kevin	2.4; 2.13
McAllister, Bud	2.4; 2.13
McAllister, Robert	2.4
McAlpine , Emily	2.4
McBride, Nancy	2.4; 2.13
Mccarthy, Shirley	2.4; 2.13
McCarty, Jesse Louis Henry	N/A
McClow, John (State of Colorado)	2.2; 2.5; 2.15; 2.20; 6.1.2; 6.1.3; 6.4.12; 6.4.13; 8.6; 8.7; 8.8; 8.12; 10.8; 12.6; 13.4
McClung, Judy	N/A
McConnell, David	3.2; 3.6; 8.3
McConnell, Suzanne	N/A
McCormic, Lori	N/A
McCormick, Molly	2.4; 2.22
McCreary, Jan	2.4; 2.13
McCulloch , Arch	2.4
McCulloch, Samuel	N/A
Mccurdy, Robert	3.6
McDaniel, Barbara	N/A

TABLE Q-3 (Cont.)

McDaniel, Jared	2.8
McDonald, Barbara	2.4; 2.13
McDonald, Brian	3.6
McDonald, Carolyn	2.4; 2.13
McDonald, Kim	N/A
McDonald, Stacey	2.4
McFall, Cynthia	N/A
McFarland, Brian	2.4; 2.13
McFee, Matt	N/A
McGaughey, Mary	N/A
McGilligan, Micky	N/A
McGillivary, M	N/A
McGlone, Colleen	2.4; 2.13
McKee, Wendy	2.4; 2.13
McKibben, Michael	3.2; 3.6; 8.3
McKinnie, Robert	N/A
Mclaughlin, Dagmar	2.8
McLaughlin, Michael	3.2; 3.6; 8.3
McLean, Patricia	N/A
McLeod, Roderick	N/A
McMahon, Lally	2.1; 2.2; 2.8; 2.14; 13.1
McManus, Veronica	2.4
McMillan, Sharon	2.4
McMullen, Colleen	2.4; 2.13
McNeil, Kerry	2.4; 2.13
McPherson, Tom	N/A
McQueen, Harry	2.4
McVie, Christina	2.4; 2.13
McWilliams, Glen	2.4; 2.13
Mecke, Mike	2.4
Medina, Rachel	2.4; 2.13
Medlock, Richard	2.4
Mee, Diane	N/A
Mee, William (Agua Fria Village Association)	2.4; 2.13
Meehan, Ellie	2.4
Meeker, Helen	2.4; 2.13
Meeker, Tobias	2.8
Meeks, Mark	2.4
Meham, Owen	N/A
Mehle, Anthony	2.4; 2.13
Meinerding, Tony	N/A
Melby, Jane	N/A
Mellica, Jason	2.8
Menasco, Mika	N/A
Mendel, Chris	2.4; 2.13
Mendes, Ruth	2.4
Mendieta, Vince	2.4; 2.13
Mendousa, Tony	2.4; 2.13
Menyuk, Paula	N/A
Mercante, Ron	2.4

TABLE Q-3 (Cont.)

Mercieca, Charles (International Assoc. of Educators for World Peace)	N/A
Merideth, Dennis	N/A
Merk, Michael	N/A
Merki, Stefan	2.5; 12.2
Mernitz, Richard	3.2; 3.6
Merrick, Diane	N/A
Merrigan, Anita	N/A
Merrill, Jim	2.22
Messer, Gretchen	2.4; 2.13
Metelica, Nikita	2.4; 2.13
Mettitt, B	N/A
Metzler, Michael	3.2; 3.6; 8.3
Meuer, Rita	N/A
Meute, Nancy	2.4; 2.13
Meyer, Douglas	2.4; 2.13
Meyer, Roger	N/A
Meyers, Beth	N/A
Mignella, Amy (Arizona Tribal Energy Association)	2.3; 2.7; 2.21; 12.5
Miles, Robert	2.4; 2.13
Miles, Robert	3.2; 3.6
Miller, D Rex	2.4
Miller, Ed	2.4
Miller, Joe (Gila Trout Chapter 530 Trout Unlimited)	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Miller, Kathleen	3.2; 3.6; 8.3
Miller, Mark	3.2; 3.6; 8.3
Miller, Pamela	2.4; 2.13
Miller, Robert	2.4; 2.13
Miller, Susan	2.4; 2.13
Miller, Travis	2.4; 2.13
Milley, John	3.2; 3.6; 8.3
Milligan, Douglas (Salt River Project)	2.1; 2.7; 2.8; 2.10; 2.11; 2.13; 4.1.1; 5.2; 6.1.8; 6.2.2; 6.2.3; 6.4.5; 6.4.7; 6.4.10; 6.4.11; 6.6.1; 6.7; 10.2; 10.3; 11.4
Millis, Eric (Utah Division of Water Resources)	8.9
Milonas, Nikolaos	2.4; 2.13
Minchuk, Gene	N/A
Minert, Carolyn	2.4; 2.13
Minich, Chris	2.4; 2.13
Mink, Daniel	2.4; 2.13
Minsky, Nina	N/A
Mitchell, Crystal	2.4
Mitchell, Michael	2.4; 2.13
Mitchell, Ruby	2.4; 2.13
Mitchell, Yolanda	2.4; 2.13
Mizel, Monroe	2.5
Mock. Randall (Randy)	2.4; 2.13
Modarelli, David	2.4; 2.13
Moe, Darrick (Minnesota Rural Electric Association)	2.10

TABLE Q-3 (Cont.)

Moffatt, James	N/A
Moffatt, James	N/A
Moffit, Ian	3.2; 3.6; 8.3
Moir, Dolie	N/A
Molling, Corrine	N/A
Monaghan, Dina	N/A
Monfredini, Janet	N/A
Monie, Sherry	2.4; 2.13
Monroe, James R	2.4; 2.13
Monson, Michael	2.8; 2.14
Monson, Todd	N/A
Montelongo, Monica	N/A
Montoro, Ernest	N/A
Moody, Richard	2.4; 2.13
Moon, Peggy	2.4; 2.13
Moore, Ariel	2.4; 2.13
Moore, Chris	2.5; 3.6; 12.2
Moore, Chris	2.4; 2.13
Moore, Greg	3.2; 3.6
Moore, Lucy	N/A
Moore, Malc	N/A
Moore, Matt	2.4
Moore, Nancy	2.4; 2.13
Moore, Robert	N/A
Moore, Thomas	N/A
Moorehead, Elisabeth	2.4; 2.13
Mooz, William	2.4
Morales, Susan	N/A
Moran, Patricia	N/A
Morebellob, Sam	3.2; 3.6; 8.3
Moreira, Rui	2.4; 2.13
Morel, N/A	2.4
Morello, Phyl	2.4
Morgan, Edward	2.4; 2.13
Morgan, Julie	N/A
Morgan, Michelle	N/A
Morgan, Sarah	2.4; 2.13
Morin , Inez	2.4; 2.13
Moritz, Robert	N/A
Morris, John	3.2; 3.6; 8.3
Morris, Lynn	N/A
Morris, Peter	3.2; 3.6
Morris, William	2.4; 2.13
Morrison, N	2.4; 2.13
Morrow, James	3.2; 3.6; 8.3
Mosca-Clark, Vivianne	N/A
Mosel, Sharon	N/A
Moser, Rich	N/A
Moshier, Katharine	N/A
Mothley, Drucilla	N/A

TABLE Q-3 (Cont.)

Motz, Mary	2.4; 2.13
Moulton, Jamie	2.8
Mourant, Wanda	N/A
Moyer, Steve (Trout Unlimited)	2.5; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Mudrick, Stephen	2.4; 2.13
Mueller, Ray	2.8; 2.14
Mugglestone, Lindsay	2.4; 2.13
Mulholland, Jane	N/A
Mullen, Charles	2.4
Munar, Dwayne	2.4; 2.13
Munday, Sherrie	2.4
Mundine, Jennifer	N/A
Munsell, Steven	2.4
Murchison, Mary	2.4
Murdoch, Sarah	N/A
Murphy, Brian	3.6
Murphy, Dacia	2.4
Murphy, Daniel	2.4; 2.13
Murphy, John	3.2; 3.6; 8.3
Muss, Jeff	2.4; 2.13
Myers, Jillyn	2.4; 2.13
Myers, Stephen	N/A
Myers-Davis, Alan	N/A
MYl, David	3.6
Mylrea, Mary Ellen	2.4; 2.13
NA[c] (Arizona Raft Adventures LLC, Arizona)	2.5; 12.4
NA, Aaron	2.4; 2.13
NA, Adam	2.4; 2.13
NA, Cameron	3.6
NA, Charleen	2.4; 2.13
NA, Darina	N/A
NA, Karen	N/A
NA, Kristine	2.4; 2.13
NA, Martha	2.4; 2.13
NA, Michelle	2.4; 2.13
NA, NA (Arizona River Runners)	2.12; 12.1
NA, Nick	N/A
NA, Paul	N/A
NA, Peter	N/A
NA, Robert	2.4
NA, Ronald	N/A
NA, Shannin	2.4; 2.13
NA, Shawn	N/A
NA, Tom	2.4
NA, Victor	2.4; 12.2
NA, Wendy	N/A
NA, NA (Western River Expeditions)	2.4; 3.7; 9.1; 12.1; 12.2
NA, NA (Petition)	3.2; 3.6; 8.3
Naciri, Nour	2.4; 2.13
Naegele, Alice	N/A

TABLE Q-3 (Cont.)

Nagel, Clinton	2.4; 2.13
Nahill, Brad	2.4; 2.13
Naidich, Sandra	N/A
Naples, Jean	2.4; 2.13
Nappi, Glenn	2.4; 2.13
Nazzaro, Alan	2.4; 2.13
Neal, Stacy	2.4
Nearing, Sue	N/A
Nebergall, Bradford (Tri-State Generation and Transmission Association, Inc.)	2.1; 2.2; 2.3; 2.7; 2.9; 2.10; 2.19; 3.2; 4.1.3; 4.2; 5.2; 6.4.6; 6.4.8; 6.4.9; 7.3.3.; 8.9; 10.1; 14.2
Nedeau, E. James	2.4; 2.13
Neff, Laura	2.4; 2.13
Nelson, B.	2.4; 2.13
Nelson, Bob	2.4; 2.13
Nelson, David	2.4; 2.13
Nelson, Dennis	2.4; 2.13
Nelson, Don	3.2; 3.6; 8.3
Nelson, Jared	2.5
Nelson, Justin	3.2; 3.6; 8.3
Nelson, Robert	3.2; 3.6; 8.3
Nemko, Roy	N/A
Neste, George	2.4; 2.13
Neste, Lisa	2.4; 2.13
Netti , Steve	3.2; 3.6; 8.3
Neumann, Nancy	2.4; 2.13
Newman, Eric	N/A
Newman, Ricki	2.4; 2.13
Nichols, Carmen	N/A
Nichols, Nathaniel	2.4; 2.13
Nicholson, Jane	2.4
Nicolai, Nicola	2.4; 2.13
Nielsen, Leonor	N/A
Niemiec, Michael	2.4; 2.13
Nieters, Lenore	2.4; 2.13
Nimkin, David (National Parks Conservation Association & Grand Canyon Trust)	2.4; 2.13; 6.1.5; 7.3; 10.1; 10.3
Nitido, Vincent	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Noble, Bruce	N/A
Nochimson, Martha	2.4; 2.13
Nolan, Antoinette	2.4; 2.13
Noll, Fred	2.4
Noon, Gail	N/A
Norbury, Christopher	2.4; 2.13
Nord, Randall	2.4; 2.13
Nordberg, Hella	2.4; 2.13
Norden, Michael	2.4
Norman, John	2.4
Norris, Dick, Jr	2.4; 2.13
Novak, Nancy	2.4; 2.13
Novak, Trina	2.4; 2.13

TABLE Q-3 (Cont.)

Novkov, Russell	N/A
Nowack, Laura	N/A
Nowell, Jerry	3.2; 3.6
Nowicki, Susan	N/A
Noyes, Alan	2.8
Nudi, Floyd	2.4; 2.13
Nunez, Stephanie	N/A
Nunn, Tom	3.2; 3.6; 8.3
Nussbaum, Rhoda	2.4; 2.13
Nutini, Michael	2.4; 2.13
Nylen, Eric	2.4; 2.13
O, Ryan	N/A
Oakes, Dorothy	2.4; 2.13
Oakley , Jane	N/A
Oates, Judy	N/A
Oates, Tim	N/A
Oba, Peggy	2.4; 2.13
Obert, Leonard	N/A
Obr, Brooks	2.4; 2.13
O'Brien , lEE	3.2; 3.6; 8.3
O'Brien, Laura	2.4; 2.13
O'Connell, John	2.4
OConnor, Dan	2.4
O'Connor, Susan	2.4; 2.13
ODear, Elizabeth	2.4
Odom, Cassandra	N/A
O'Donnell, Richard	N/A
Ogella, Edith	N/A
Ogrosky, Wendell	3.2; 3.6; 8.3
Ohara, Stanley	3.2; 3.6; 8.3
Ohlendorf, Carol	2.4; 2.13
OKeefe, Alice	2.4; 2.13
Olander, Alan	2.4; 2.13
Olch, Jonathan	3.2; 3.6; 8.3
Oldfield, Barbara	N/A
Olivares, Yvonne	2.4
Olsen, Donna	2.4
Olson, Bruce	N/A
Olson, Jason	3.2; 3.6; 8.3
Olson, Lynn	2.4; 2.8; 2.13
Ommen, Elizabeth	N/A
Orcholski, Gerald	2.4; 2.13
O'Reilly, Patricia	2.4
Orlinski, Patricia (West Valley Neighborhoods Coalition)	2.4
Orr, Jenne	2.4
Osada, Susan	2.4; 2.13
Osborn, Carole	2.4; 2.13
Osborne, Kenneth	2.4; 2.13
OSteen, Karen	2.4; 2.13

TABLE Q-3 (Cont.)

Ostler, Don (Upper Colorado River Commission)	2.19; 4.1.1; 6.3.1; 6.4.12; 6.4.13; 6.4.14; 6.5.1; 8.8; 10.3
Ostopoff, Christine	2.4
Ostrander, William, Jr	2.4; 2.13
Ostwinkle, Stephen	3.6
Ouellette, Tracy	2.4; 2.13
Outland, Jennifer	2.13
Overton, Steve	2.4; 2.13
Owen, Cheryl	2.4
Owens, Hilery	2.4
Owens, Mary	2.4; 2.13
Ozias, Julie	2.4; 2.13
Pace, Ann	N/A
Packer, Patti	2.4; 2.13
Padula, P.S.	2.8
Paige, Richard	N/A
Paisley, Lorna	N/A
Pakaln, Laura	2.4; 2.13
Paley, Leon	2.4; 2.13
Palmer, Carol	N/A
Pannaman, Stanley	2.4
Panteah, Val (Pueblo of Zuni)	2.7; 3.3; 4.1.1; 10.1; 10.8; 12.10
Panza, Mike	N/A
Papesch, Peter	2.4
Pappas, Robin	N/A
Paradise, Brian	2.4
Parker, Delores	2.4; 2.13
Parker, Jin Adams	2.4; 2.13
Parker, Larry	3.2; 3.6
Parker, Mark	3.2; 3.6
Parker, Patricia	2.4
Parkins, Janet	2.4; 2.13
Parks Antonio, Mary Anne	2.4
Parus, Christine	N/A
Paschel, Richard	2.4
Pasqua,John	N/A
Patten, Robin	2.4; 2.13
Patton, Therese	2.4; 2.13
Pauls, Terry	2.4; 2.13
Pawlowski, Vincent (Association for the Tree of Life)	2.4; 2.13
Paxton, G.	2.4; 2.13
Pearlman, Karen	2.4; 2.13
Pecha, Richard	N/A
Pehrson, Danny	N/A
Pelleg, Josh	N/A
Pellegrino, Colby (Southern Nevada Water Authority)	4.1.3; 5.2; 8.8; 8.12; 10.1; 13.3; 13.4
Peltzer, Bryan	3.6; 12.4
Pence, Joanne	N/A
Pender, Jacqueline	2.4; 2.13
Percy, Patrick	N/A

TABLE Q-3 (Cont.)

Perdios, Dan	2.4
Perez, Thomas	2.4; 2.13
Perkins, Guy	2.4; 2.13
Perkins, Marie	2.4; 2.13
Perry, Saul	N/A
Person, Wayne	2.4; 2.13
Peteinaraki, Maria	N/A
Peters, Kathleen	2.4; 2.13
Peters, Robert	N/A
Petersen, Diane	2.4; 2.13
Petroni, John	N/A
Pettibone, Jon	N/A
Pettigrew, Jill	N/A
Pflug, Maria	N/A
Phares, David	N/A
Pharris , Charles	3.2; 3.6; 8.3
Phillips, George	2.4; 2.13
Phillips, Patrick	N/A
Phillips, Thomas	2.4; 2.13
Phillips-Calapai, Jean	2.4; 2.13
Picchetti, Gloria	2.4; 2.13
Picciani, Laureen	N/A
Picker, Seth	2.4; 2.13
Pickett-Harner, Molly	N/A
Pieniazek, Annette	2.4; 2.13
Pier, Philip	3.2; 3.6; 8.3
Pierce, Arden	2.4; 2.13
Pierson, James	2.4; 2.13
Pike, Ryan	12.1
Pillar, Ina	N/A
Pineda, Faye	N/A
Pinkham, Debra	2.4
Pinto, Juliann	2.4
Piske, Barbara	2.4
Pistorius, Stephen	3.6
Pitagora, Robert	2.11; 2.13
Plastas, Harold	N/A
Platt, David	2.4; 2.13
Pocius, F. Jay	N/A
Podorson, Myra	N/A
Pogel, G.	2.4; 2.13
Poland, Dianne	N/A
Polefka, Thomas	2.4; 2.13
Polk, Nora	2.4; 2.13
Pollack, Michael	2.4; 2.13
Pollock, Robert	N/A
Pons, Scott	2.4; 2.13
Poole, Richard	N/A
Pooler, Carole	2.4; 2.13
Pope, Priscilla	N/A

TABLE Q-3 (Cont.)

Pope, Susan	2.4; 2.13
Porter, Betsey	2.4; 2.13
Porter, Brian	2.4; 2.13
Porter, K.T.	2.4; 2.13
Porter, Sharon	N/A
Portney, Thomas	2.4; 2.13
Portnoy, Dennis	2.1; 2.2; 2.8; 2.14; 13.1
Potochnik, Andre	2.4; 2.11; 2.13; 2.16
Potter, Dave	2.4
Pottinger, Hans	N/A
Potucek , Kimberly	2.4; 2.13
Povill, Jon	2.4
Powell, Lance	2.4; 2.13
Powers, Marlene	N/A
Powers, Sheila	2.4; 2.13
Prezant, Jennifer	N/A
Price, Charles	3.2; 3.6
Price, Norman	N/A
Prochowski, Richard	N/A
Proffitt, Terry and Karen	2.4; 2.13
Proteau, Mary	2.4; 2.13
Provance, D.	2.4
Purcell, Douglas	2.4; 2.13
Purington II, Ken	N/A
Pynn, Doug	N/A
Quammen, Parker	2.4; 2.13
Querner, Kathleen	2.4
R, Lynn	N/A
Raftery, Rita	N/A
Rahn, Gerald	N/A
Raitt, Jacob	N/A
Ralston, Aron	2.4; 2.13
Ramirez, Carina	N/A
Ramirez, Hank	2.4; 2.13
Ramo, Carol	2.4; 2.13
Ramos, Joann	2.4; 2.13
Randall, Dorene	N/A
Rangel, Louise	2.4; 2.13
Ranz, Lauren	2.4; 2.13
Raper, Connie	2.4; 2.13
Rappaport, Alexandra	2.4; 2.13
Rasmussen, Nancy	2.4; 2.13
Ratcliff, Steve	3.2; 3.6; 8.3
Ratcliff, Philip	2.4; 2.13
Ray, Jack	2.4; 2.13
Ray, Linda	2.4; 2.13
Ray, Mike	2.4; 2.13
Raychaudhuri, Sumana	2.4; 2.13
Re, Sa	2.4
Reames, Robin	2.4

TABLE Q-3 (Cont.)

Redstone, Ray	N/A
Redstrom, John	N/A
Reed, Dirk	N/A
Reed, Jennifer	12.8
Reeder, Ben	2.4; 2.11; 2.13
Reeder, William	N/A
Rees, Michael	2.4; 2.13
Reichel, Tom	N/A
Reid, Nancy	2.4; 2.13; 12.2
Reid, W.S.	3.2; 3.6; 8.3
Reilly, Holly	2.4
Reimer, Dana	12.2
Reinking, Tom	3.2; 3.6; 8.3
Reischl, Terri	N/A
Reisman, Emil	N/A
Reiter, Jane	2.4
Reiter, Steve (Old Pueblo Chapter of Trout Unlimited)	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Renard, Robert	3.2; 3.6
Rennacker, Ann	2.4
Renton, Kristen	2.4; 2.13
Rever, John	3.6
Revilla, Oscar	2.4; 2.13
Rexford, Bridgett	N/A
Reynolds, Ronda	2.4; 2.13
Rhodes, Janet	2.4; 2.13
Rhodes, Robert	2.4
Rice, Marybeth	2.4; 2.13
Rich, Chris	3.6
Richardson, Gail	2.4; 2.13
Richardson, James	3.6
Richardson, Matt	3.2; 3.6; 8.3; 12.2
Richardson, Virginia	N/A
Richey, Charles	2.4; 2.13
Ricketts, Carolyn	2.4; 2.13
Riddle, Carolyn	N/A
Ridenour, Rod	2.4; 2.13
Rieck, Michael	N/A
Riffle, Lew (Santa Barbara Flyfishers)	2.4
Riger, Richard	N/A
Riggs, Richard	2.4; 2.13
Rigney, J.	2.4; 2.13
Rimbeaux, B.	2.4
Ringgaard, Line	2.4; 2.13
Riopelle, Robert	2.4; 2.13
Ripp, Rudolph	2.4; 2.13
Risley, Paul	N/A
Rist, Wally (Grand Canyon Private Boaters Associations)	2.4
Rittenhouse, Nancy	N/A
Rivera, Sergio	2.4; 2.13

TABLE Q-3 (Cont.)

Roache, Jim	3.2; 3.6
Roberson, Gracie	2.4; 2.13
Roberts, Duane	N/A
Roberts, Keith	3.2; 3.6; 8.3
Roberts, Sally	2.4; 2.13
Roberts-Ibarra, Suni	N/A
Roberts-Moneir, Nancy	2.4; 2.13
Roberts-Shepherd, Ruth	2.4; 2.13
Robinson, Aaron	2.4; 2.13
Robinson, Craig	N/A
Robinson, Dameta	2.4; 2.13
Robinson, Don	2.4; 2.13; 12.3
Robinson, Ellen R.	N/A
Robinson, Joyce	2.4
Robinson, Laura	2.4
Robinson, Richard	N/A
Robinson, Richard	2.4; 2.13
Rocha, Candace	2.4; 2.13
Roden, Karen	N/A
Roebuck, Marge	N/A
Roegner, Debby	2.4; 2.13
Roenneburg, Drew	2.4; 2.13
Rogers, Lilith	N/A
Rohmer, John	3.2; 3.6; 8.3
Role, Abraham	2.4
Rolf, Carol	2.4; 2.13
Rollo, Pat	2.4; 2.13
Romain, Bella	2.4; 2.13
Romano, David	3.2; 3.6; 8.3
Romanowski, Scott	2.4; 2.13
Romero, Monika	2.4; 2.13
Romesburg, Denise	2.4; 2.13
Romig, Mark	2.4; 2.13
Ronan, Thomas	2.4
Ronneburg, Pat	3.2; 3.6; 8.3
Rood, Edson	3.2; 3.6; 8.3
Rosen, Paul	N/A
Rosenblatt, Jon	N/A
Rosenblood, Jamie	2.4
Rosenblum, Stephen	2.4
Rosenfeld, Ryan	3.2; 3.6; 8.3
Rosenstadt, William	N/A
Roske, Adam	2.4; 2.13
Ross, B. Elliot	2.4; 2.13
Ross, Jean	2.4; 2.13
Rosser, Ellen	2.4; 2.13
Rotermund, Kristy	2.4; 2.13
Roth, Lu	2.4; 2.13
Rothschild, Louis	2.4
Rothschild, Quinn	2.5

TABLE Q-3 (Cont.)

Rothschild, Teal	N/A
Rowe, Spencer	2.1; 2.2; 2.8; 2.14; 13.1
Rowe, William	N/A
Rowell, Patricia	2.4
Rowitz, Roger	2.4; 2.13
Royer, Allen	2.4; 2.13
Rubenstein, Harvey	2.4; 2.13
Rubino, Karen	N/A
Rubino, Vincent	2.4; 2.13
Ruhl, John	2.4; 2.13
Ruiz, Mabel	N/A
Ruiz, O.	2.4; 2.13
Rutkowski, Robert	2.1; 2.2; 2.4; 2.8; 2.13; 2.14; 13.1
Ryaby, James	3.2; 3.6; 8.3
Ryan, George	2.4; 2.13
Ryan, Jack	2.5
Ryan, Joanne	2.4; 2.13
Ryan, Patricia	2.4
Ryerson, William	2.4; 2.13
Sacherer, Janice	2.4; 2.13
Sadowskas, Bruce	2.4; 2.13
Sailer, Randy	2.4
Salazar, Gladys	2.4; 2.13
Salomone, Michael	N/A
Samelson, Audrey	2.4; 2.13
Samoylo, Charles	N/A
Samp, Cecelia	2.4
Sanchez, Ralph	2.4; 2.13
Sanders , Raymond	3.2; 3.6; 8.3
Sanders, David	2.4
Sangster, Carol	2.4; 2.13
Santi, Giri	2.4; 2.13
Sargent, Jackie (Platte River Power Authority)	2.1; 2.3; 2.6; 2.9; 2.10; 2.13; 2.19; 8.9; 8.10
Sarracino, Brendon	3.2; 3.6; 8.3
Sarraille, Marijeannee	2.4; 2.13
Sass, Sherry	2.4; 2.13
Sauerman , Jacqueline	2.4; 2.13
Sawall, Erwin F.	2.8
Sawyer, Mary	2.4; 2.13
Saxon, Diana	2.4; 2.13
Sayler, Becky	2.4; 2.13
Scar, Dick	N/A
Scarpace, Leonard	3.2; 3.6; 8.3
Scarpelli, Kenneth	2.4; 2.13
Scarry, Patrick	2.4; 2.13
Scavezze, Barb	2.4; 2.8; 2.13
Schade, Corey	2.4; 2.13
Schafer, Maggie	N/A
Schafer, Peter	2.4; 2.13
Schaming, Carol	2.4; 2.13

TABLE Q-3 (Cont.)

Scharin, Lisa	N/A
Scherer, W.	2.4; 2.13
Schetzer, Kathryn	2.4; 2.13
Schindele, Paulette	2.4; 2.13
Schindler, Maury	2.4; 2.13
Schlein, Elizabeth	N/A
Schlesinger, Sybil	2.4; 2.13
Schmid, Genevieve	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Schmidt, Ted	N/A
Schmidt, Wayne	2.4
Schmitt, Eileen	N/A
Schmitt, Jeff	2.5; 2.17; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Schmittauer, John	N/A
Schneebeli, Christiane	N/A
Schneider , Edward	2.4; 2.13
Schneider, L.	2.4; 2.13
Schneller, Douglas	2.4; 2.13
Schoech, D.	2.4; 2.13
Scholl, Barbara	N/A
Scholl, Susan	N/A
Schreier, Bryna	N/A
Schultz, Peter	2.4
Schultz, William	2.4; 2.13
Schupp, Norma	2.4; 2.13
Schwartz, Angela	2.4; 2.13
Schwartz, Deirdre	2.4
Schwartz, Robert	2.4; 2.13
Schwartzberg, Lora	2.4
Scilluffo, Joe	2.4; 2.13
Scopes, Leslie	11.5
Scott, Brian	2.4; 2.13
Scott, Carol	N/A
Scott, Kim	2.4; 2.13
Scott, Mark	N/A
Scott, Raeann	2.4; 2.13
Scranton, Chris	2.4; 2.13
Seals, Suzanne	2.4; 2.13
Sealy, Berenice	2.4; 2.13
Searles, Dave	2.4; 2.13
Season, Ron	2.4; 2.13
Sebastian, Scott	N/A
Sedlock, Evan	3.2; 3.6; 8.3
Sees, Heather	3.2; 3.6; 8.3
Seidner, Dan	12.4
Selbin, Susan	2.4; 2.13
Selig, Stephanie	12.3
Sell, David	2.1; 2.2; 2.8; 2.14; 13.1
Seltzer, Elizabeth	N/A
Seltzer, Rob	2.4; 2.13
Sennett, Frank	N/A

TABLE Q-3 (Cont.)

Sensing, Wanda	2.4; 2.13
Serafino , Stephen	N/A
Sergio, Janette	2.4; 2.13
Severson, Dona	2.4
Sewald, Michelle	2.4; 2.13
Seymour, Linda	2.4; 2.13
Shaffer, Susan	2.4; 2.13
Shapiro, Jane	N/A
Sharfman, William	2.4; 2.13
Sharpton, Debra (Southwest Council International Federation of Flyfishers and the Sierra Pacific Flyfishers)	N/A
Shaw, Lori	N/A
Shear, Julie	2.4; 2.13
Sheets-Johnstone, Maxine	N/A
Sheetz , Jamie	3.2; 3.6; 8.3
Sheetz, Jennifer	2.4
Sheffer, Jeanne	2.4; 2.13
Shelley, Martha	2.4; 2.13
Sheridan, Michelle	2.4; 2.13
Sherman, David	2.4; 2.13
Sherman, Marcia	N/A
Sherman, Rick	2.4; 2.13
Sherwood, Kate	2.4
Shields, Michele	2.4; 2.13
Shiffrin, Joyce	N/A
Shirley, Cameron	3.2; 3.6; 8.3
Shitama, Celeste	2.4; 2.13
Shogren, Martha	N/A
Short, John	2.4
Shouse, Corbin	2.4; 2.13
Shultz, Betty Jane	N/A
Shushan, Cheryl	N/A
Sicklesteel, Cory	8.3
Sidwell, Sarah	2.8
Siegfried , Daniel	3.2; 3.6; 8.3
Siegwald, Joan	2.4; 2.13
Sifuentes, D.G.	2.4; 2.13
Sikand , Vikram	2.4; 2.13
Silver, Ron	2.4; 2.13
Silver, Victoria	N/A
Simle, Anna	2.4; 2.13
Simmerman, Scott	N/A
Simmons, Adrienne	2.4; 2.13
Simmons, Chuck	2.4
Simons, Anita	2.4; 2.13
Singleton, Jon	2.4; 2.13
Sinnott, Larkin	N/A
Sjoden, Eric	N/A
Skaggs, Brian	2.4

TABLE Q-3 (Cont.)

Skarada, Darcy	2.4; 2.13
Skiendzielewski, Danielle	N/A
Skinner, Russell	N/A
Skipworth, Carl	2.4; 2.13
Skirbunt-Kozabo, William	2.4; 2.13
Skow, Loren	N/A
Skrzypczak, Lida	N/A
Skuce, David	3.2; 3.6; 8.3
Skup, Debra	2.4; 2.13
Slater, Dan	3.2; 3.6
Slaughter, Angela (Colorado River Commission of Nevada)	4.1.3; 5.2; 6.4.14; 6.5.1; 6.7; 8.12; 13.3; 13.4
Sloat, Dale	2.4; 2.13
Sloat, Jan	2.4; 2.13
Slote, Karen	2.4; 2.13
Sluis , Janet	3.2; 3.6; 8.3
Smarr, Janet	2.4; 2.13
Smart, David	3.2; 3.6; 8.3
Smereck, Amy	2.4
Smetana, Carol	2.4; 2.13
Smith , Bryan	3.2; 3.6; 8.3
Smith, April	2.4; 2.13
Smith, Bradley	2.4; 2.13
Smith, Dea	N/A
Smith, Donald	3.2; 3.6; 8.3
Smith, Fendrick	2.4; 2.13
Smith, G. Austin	2.4; 2.13
Smith, Jean	2.4; 2.13
Smith, Judith	2.4
Smith, Latimer	2.12
Smith, Lib	N/A
Smith, Mack	2.4; 2.13
Smith, Mary Jordan	N/A
Smith, Mollie	N/A
Smith, Moreland	2.4; 2.13
Smith, Neill	N/A
Smith, Phyllis	N/A
Smith, Roger	2.4; 2.13
Smith, Sean	8.3
Smock, Amanda	2.4
Smoot, Leslie	2.4; 2.13
Smudin, Carole	N/A
Sneath, Barbara	2.4; 2.13
Snider, Jay	2.4; 2.13
Snow, N/A	N/A
Snyder, Cindy	2.4; 2.13
Snyder, Joanne	N/A
Snyder, Paul, Jr	3.2; 3.6; 8.3
Snyder, Robert	2.4; 2.13
Sobanski, Sandra	2.4; 2.13

TABLE Q-3 (Cont.)

Sodos, Michael	2.4; 2.13
Solomon, David	N/A
Solomon, David	N/A
Solomon, Phillip (Deseret Power Electric Cooperative)	2.6; 2.7; 2.10; 2.12; 2.21; 8.1
Solum, Mary	2.4; 2.13
Somers, Jeff	2.4; 2.13
Sorensen, Colleen	2.4
Sorokwasz, David	3.2; 3.6
Sorum, Robert	2.4; 2.13
Souza, P.	2.8
Spangle, Steven (U.S. Fish and Wildlife Service)	2.2; 2.9; 3.2; 3.6; 3.7; 3.8; 8.12; 8.13; 11.2
Sparger, Janet	2.8
Sparks, Alan	3.6
Sparrow, Deb	2.4; 2.13
Spaulding, D.	N/A
Speakman, David	N/A
Species, Scott	2.4; 2.13
Speer, Mark	3.2; 3.6; 8.3
Spence, Liter	2.4
Spengler, Brett	2.4; 2.13
Spiegel, Karen	2.4; 2.13
Spilker, Mike	3.2; 3.6; 8.3
Spillane, Rita	2.4
Spilsbury, Delaine (Bristlecone Alliance)	N/A
Spinelli, Nancy	2.4
Spirakis, Jenn	N/A
Spokony, Irving	2.4
Spragins, John	2.4; 2.13
St. Angelo, Richard	2.4
Stadnik, George	2.4; 2.13
Stambaugh, Joseph	12.2
Stan, Talila	N/A
Standley, Ron	N/A
Stanley, Edwin R	N/A
Stanley, Norm	2.4
Staples, Laura	N/A
Stark, Rodney	2.4; 2.13
Stauffer, Ron	2.4
Staveley, Gaylord (Canyoneers, Inc.)	5.2; 12.4
Staveley, Laura (Canyon Explorations Expeditions)	9.1; 9.2; 12.1; 12.4
Steele, Jon	3.2; 3.6; 8.3
Steele, William	3.6
Steenstra, Philip	12.4
Stefanic, Karen	N/A
Stein, Herbert	2.4; 2.13
Steinberg, Chip	3.2; 3.6; 8.3
Steinhart, Carol	2.4; 2.13
Stephens, Robert	2.4; 2.13
Steppan, Linda	2.4; 2.13
Sterling, Tyson	N/A

TABLE Q-3 (Cont.)

Sternberg, Karin	2.4; 2.13
Stevens, Carol	2.4
Stevens, Gavi	N/A
Stevens, Lawrence (Grand Canyon Wildlands Council)	2.2; 2.5; 3.1; 7.4; 11.2
Stevens, Nike	N/A
Stevenson, Joey	N/A
Stewart, Mark	2.4; 2.13
Stewart, Sarah	2.4; 2.13
Stickel, Ann	N/A
Stieglitz, Joseph	2.4; 2.13
Stiles, Sarah	2.4; 2.13
Stillwell, Robert	3.2; 3.6; 8.3
Stoker, Cayley	N/A
Stoltenberg, John and Martha	N/A
Stone, Harry	2.4; 2.13
Stoner, Cynthia	2.4; 2.13
Stoner, Jon	2.12; 2.22
Stong, Stuart	N/A
Story, Don	2.4; 2.13
Strange, Marisa	N/A
Stratton, Jim	2.4; 2.13
Strauss, John	2.4
Streeter, Matthew	3.2; 3.6; 8.3
Strogen, Jim	2.9
Strong, Timothy	2.4
Struthers, Sue	N/A
Stuart, Michael	2.4; 2.13
Stucker, Melinda	2.4
Stump, David	2.4; 2.13
Sturm, Madeline	2.4; 2.13
Suarez, Joe	2.4; 2.13
Suda, Maryska	N/A
Sullivan, Gail	2.4; 2.13
Sullivan, Teresa	N/A
Summerville, Deborah	2.4; 2.13
Suniga, Michael	3.2; 3.6; 8.3
Sutkowski, John	2.4; 2.13
Sutton, Susan	2.4
Swan, Curtis	2.4; 2.13
Swanepoel, Karen	2.4; 2.13
Swanson, Cynthia	2.4; 2.13
Sweeney, John	N/A
Sweet, Harold	2.4
Sweet, Justin	2.4; 2.13
Sweetling, William	2.4; 2.13
Swift , Josh	3.2; 3.6; 8.3
Syapin, Peter	N/A
Sykes, Tom	N/A
Szof, Cheryl	2.4; 2.13
Szymanowski, Paul	2.4; 2.13

TABLE Q-3 (Cont.)

Tacker, Barbara	2.4
Tajdari, Amy	2.4; 2.13
Talbert, Aaron	3.2; 3.6; 8.3
Talbot, J	2.4; 2.13
Talbot, Thomas	2.4; 2.13
Talleagle, David	N/A
Tanner, Mary	2.4
Tao, Carol	2.4; 2.13
Tarallo, Mary	2.4
Taube, N/A	N/A
Taylor , Rocky	3.2; 3.6; 8.3
Taylor, Donald	N/A
Teed, Halcyon	2.4
Tendler, Marlene	2.4; 2.13
Terry, Thomas	2.4; 2.13
Tetarenko, Pamela	2.4; 2.13
Thelander, Donna	2.4; 2.13
Theriault, Laurence	N/A
Thiele, Jim	2.4; 2.13
Thomas , Ron	3.2; 3.6; 8.3
Thomas, Amy (American Public Power Association)	2.4; 2.10
Thomas, George	N/A
Thomas, Ron	N/A
Thomason, Michael	2.1; 2.2; 2.8; 2.14; 13.1
Thompson, Don	N/A
Thompson, Thurston	2.4; 2.13
Thomsen, Gary	2.4; 2.13
Thorn, Debbie	2.4; 2.13
Thornbloom, Gary	2.4
Thrailkill, James	2.4
Tibbets, Linda	N/A
Tibbitts, Connie	N/A
Tibbitts, Connie	2.4; 2.13
Tigerlily, Eliot	N/A
Tipton, James	3.6
Tobin, John (Pasadena Casting Club)	2.16; 3.6
Toler , Jean	N/A
Tomaselli, Susan	N/A
Tomlin, Curtis	2.4; 2.13
Tomlinson, Lynne	2.4
Tonks, Mary	2.4; 2.13
Torchenot, Ferold	N/A
Torgerson, Eric	2.4
Torres, Joseph	2.4; 2.13
Townsend, Darlene (Phoenix Institute for Human Development)	2.4; 2.13
Trafecanty, Chris	3.2; 3.6; 8.3
Travis, Donna Mae	N/A
Traweek, James	N/A
Trebbe, Dixie	2.4

TABLE Q-3 (Cont.)

Trevillian , Linda	N/A
Trice, Tina	2.4; 2.13
Trinkle, Heidi	2.4; 2.13
Trout, Larry	2.4; 2.13
Trujillo, Tanya (Colorado River Board of California)	2.2; 2.4; 3.5; 3.8; 5.1; 5.2; 6.1.3; 6.7; 8.12
Tuch, Christopher	2.4; 2.13
Tudor, Geoffrey	2.4
Tuke, Carla	2.1; 2.2; 2.8; 2.14; 13.1
Turley, Steven	2.1; 2.2; 2.8; 2.14; 13.1
Turner , James	3.2; 3.6; 8.3
Turner, Dawn	2.4; 2.13
Turner, Doris	2.4; 2.13
Turner, Julie	2.4; 2.13
Turner, Kathleen	2.4; 2.13
Turner, Phyllis	2.4; 2.13
Turner, Tamara	2.4
Tuttle, Jeffrey	2.4
Twickler, Carrie	N/A
Tyrrell, Patrick (Wyoming State Engineer's Office)	2.5; 2.19; 8.7, 8.12
Tyson, Kathleen	N/A
Upp, Heidi	N/A
Uribe, Esmeralda	2.4; 2.13
Utley, Chad	3.2; 3.6; 8.3
Utter, Mark	3.2; 3.6; 8.3
Utzig, Albert	2.4; 2.13
Uyetanaka, Steven	N/A
Vacek, Radko	2.4
Vachula, William	2.4; 2.13
Vail, Mark	2.4; 2.13
Valdez, Richard	N/A
Valentino, David	2.4; 2.13
Van Buren, Kenneth	N/A
Van Kampen, Art	N/A
Van Kolken, Robert	2.4; 2.13
Van Leekwijck, Natalie	2.4; 2.13
Van Pelt, Jason	2.4
Van Tassell, Bruce	N/A
Van Velson, Nathan	2.4; 2.13
van Wijk, Melissa	2.4; 2.13
Vanderhill, Margo	N/A
VanderLaan, Harold	2.4; 2.13
VanWinkle, Jean Marie	2.4; 2.13
Varanitsa, Oleg	2.4; 2.13
Varnon, Dee	2.4; 2.13
Vatter, Sherry	2.4; 2.13
Vecchiotti, Dorothea	2.4; 2.13
Veltkamp, Robert	2.4; 2.13
Vermeulen, Mary	N/A
Vermeulen, Mary	N/A
Vernon, Gerald	2.4; 2.13

TABLE Q-3 (Cont.)

Vernon, Margaret	2.4; 2.13
Veynar, Vance	3.2; 3.6; 8.3
Viacrucis, John	2.4; 2.13
Vick, Margaret (Havasupai Tribe)	3.2; 10.7; 10.8
Vilkin, Jeffrey	3.2; 3.6
Villalobos, Lydia	N/A
Villanova , Carolyn	N/A
Vincent, Joseph	N/A
Voelker, Paul	3.6
Vogel, Steven	2.4; 2.13
Vogelsong, Patrick	2.4; 2.13
von Eberstein, Lesli	2.4; 2.13
Von Tobel, Jefffrey	3.2; 3.6
Von tobel, William	N/A
Vorachek, Mary	2.4; 2.13
Vrymoed, John	2.1; 2.11
Waddell, Christine	N/A
Wagner, Robert	2.4
Wagner, Vickie	2.4
Wagoner, Douglas	2.4; 2.13
Waite, Paul	3.2; 3.6; 8.3
Walchak, Shelley	2.4; 2.13
Walker, Jim (Zane Grey Trout Unlimited)	2.5; 3.2; 3.3; 3.4; 3.6; 8.3; 12.2
Wallace, John (Grand Canyon State Electric Cooperative Association, Inc.)	2.6; 2.11
Wallis, Tracy	2.4; 2.13
Walls, Mary	2.4
Walsh, Gary	N/A
Walsh, Justin	2.4
Walsh, Tom	N/A
Walters, Robyn	2.4; 2.13
Walters, Sandra	2.4
Walton, John	2.4; 2.13
Walz, Kenneth	N/A
Ward, Everett	2.1; 2.2; 2.8; 2.14; 13.1
Ward, Ken	2.4; 2.13
Ward, Marvin	2.4; 2.13
Warner, Charles	N/A
Warwick, Maureen	2.4
Washburn, Thomas	2.4
Washington, Martin	N/A
Waskey, Susan	2.4; 2.13
Wasser, Nancy	2.4; 2.13
Watanabe, Wayne	3.2; 3.6; 8.3
Watland, Bob	N/A
Watt, Celeste	2.4
Watters, Whitney	2.4; 2.13
Watts II, Howard	3.2; 3.6; 8.3
Weales, Ron	2.1; 2.2; 2.8
Weaver, Larry	3.2; 3.6; 8.3

TABLE Q-3 (Cont.)

Weber, Carol	2.4; 2.13
Wechter, Michael	N/A
Weeks, Ken	2.4
Weihrauch, Gary	3.2; 3.6; 8.3
Weinberger, Deborah	N/A
Weiner, Jeffrey	3.2; 3.6; 8.3
Weinstein, Elyette	2.4; 2.13
Weisheit, John (Living Rivers & Colorado Riverkeeper)	2.8; 2.9; 2.14; 2.18; 5.1; 6.1.1; 6.1.4; 6.1.6; 6.1.7; 11.5
Weiss, Leslie	2.4
Weiss, Stuart	2.4
Weisz, Russell	2.4; 2.13
Wellin, Paul	N/A
Wells, J.	2.4; 2.13
Wells, Michael	2.4
Welty, Walter	3.2; 3.6; 8.3
Wemer, Kim	2.4; 2.13
Wen, William	3.2; 3.6
Wendt, George (O.A.R.S.)	2.12
Wenzel, Quentin and Jacquelyn	N/A
Werner, Katherine	2.4; 2.13
Westfall, Brian	N/A
Westfall, Sara	N/A
Wheadon, Rick	N/A
Wheeler, Dorothy	N/A
Wheeless, Erin	2.4; 2.13
Whitaker, Howard	2.4; 2.13
White, Bryson	N/A
White, Diane	N/A
White, Eugene	N/A
White, Howard	2.4; 2.13
White, Michael	N/A
White, Scott	2.4; 2.13
Whitehouse, Charlie	3.2; 3.6; 8.3
Whitehouse, Katy	2.4; 2.13
Whiteside, Catherine	2.4; 2.13
Whitlock, Glen	12.4
Whitman, Rick	2.4; 2.13
Whitmire, Donna	N/A
Whitmore, Thomas	N/A
Whitney, Ellen	2.4; 2.13
Whitney, James	2.4; 2.13
Whittick, Vard	2.4; 2.13
Whitton, Erika	2.4; 2.13
Whorley, R	N/A
Wichman, Michael	2.4; 2.13
Wick, Jodi	2.4; 2.13
Wicks, Alicia	N/A
Widen, Alyson	2.4
Wieduwilt, Trudi	2.4; 2.13
Wieland, Charles	2.4; 2.13

TABLE Q-3 (Cont.)

Wiener, William	2.4
Wightman, Kevin	2.4; 2.13
Wilding, Michael	N/A
Wilkerson, Colleen	2.4
Wilkins, Marcelle	N/A
Wilkins, Rose	2.4; 2.13
Williams, Catherine	2.4; 2.13
Williams, Judd	N/A
Williams, Lee	N/A
Williams, Mara	N/A
Williams, Marilyn	2.4; 2.13
Williams, Mitch	2.4
Williams, Pat	N/A
Williams, Patti	2.4; 2.13
Williams, Patty	2.4; 2.13
Williams, William	2.4; 2.13
Williamson, Gay	N/A
Williamson, Kiyoshi	N/A
Willson, Clyde	2.4; 2.13
Wilp, Ludger	N/A
Wilson, Angela	2.4
Wilson, David	2.4; 2.13
Wilson, Ken	3.2; 3.6; 8.3
Wilson, Kim	2.4; 2.13
Wilson, M Wayne	2.4; 2.13
Wilson, Michael	3.2; 3.6; 8.3
Wilson, Sharon	2.4; 2.13
Wine, Jordann	2.4; 2.13
Winstead, Annie	2.4
Winter, Lindsay	2.12
Wirth, Mark	2.4
Wisboro, Judy	N/A
Wise, Barbara	2.4; 2.13
Witchner, Beverly	N/A
Wittorp, Lauren	3.2; 3.6; 8.3
Wittorp, Terry	3.2; 3.6; 8.3
Wockner, Gary (Save the Colorado)	1.6; 2.8; 2.14; 5.2
Woelk, Barbara	2.4; 2.13
Wolenter, Richard	2.4; 2.13; 12.3
Wolf, Karen	N/A
Wolf, Martin	3.2; 3.6; 8.3
Wolf, Wesley	2.1; 2.2; 2.8; 2.14; 13.1
Wolongevicz, Patricia	2.4
Wong, Steve	3.6
Wood, Jon	N/A
Wood, Peter	2.4; 2.13
Wood, Sara	2.4; 2.13
Woodall, Greg	2.4; 2.8
Woodward, Ellis, Jr	2.4; 2.13

TABLE Q-3 (Cont.)

Woolridge, Nancy	2.4; 2.11; 2.13
Worley, Robert	2.4
Worth, Daniel	3.6
Worthy, Crista	2.8; 2.14; 13.1
Wostenberg, Darren	2.4
Wright III, Trigg	2.4; 2.13
Wright, Steven	2.4; 2.13
Wurtz, Betty	N/A
Wyatt, Cathy	2.4; 2.13
Wyatt, Jennifer	N/A
Wykstra, Kyle	2.13; 4.1.2;7.3.1; 11.3
Wylie, Mary	2.4; 2.13
Wyse, Margo	N/A
Xavier, Marjorie	2.4
Yarger, Andrea	2.4; 2.13
Yasgur, Eleanor	2.4
Yost, Gaylord	2.4; 2.13
Young, Dennis	N/A
Young, Jo Ellen	2.4
Yount, Madeline	N/A
Yount, Robin	3.2; 3.6; 8.3
Yun, Allen	2.4; 2.13
Zagona, Helen	3.6
Zanger, Manfred	N/A
Zastrow, Lila and Hendrickson, Dave	2.4; 2.13
Zei, Wayne	3.2; 3.6; 8.3
Zerr, Laura	2.4; 2.13
Zerzan, Paula	2.4; 2.13
Zeutenhorst, Dennis	2.4; 2.13
Zick, Edward	N/A
Zieber, Thomas	2.4; 2.13
Ziegler, Russell	N/A
Ziegler, russell	N/A
Zielinski, Virginia	2.4; 2.13
Zirasri, Ran	2.4; 2.13
Zornesky, Jerome	2.4; 2.13
Zoupas, Robbin	N/A
Zuckerman, Ben	2.1; 2.2; 2.8; 2.14; 13.1

[a] For individuals or organizations that entered comments to the PEPC online database, names and affiliations shown here are as provided in those entries. Occasionally, hard copies of the same comments were mailed to DOI with a different signatory.

[b] N/A = Not applicable; only editorial or non-substantive comments were provided.

[c] NA -= Not available; first or last name was not available in the comment submittal to PEPC