Chapter 3. Affected Environment and Environmental Consequences

3.1 Introduction

This chapter describes the existing conditions of the environmental resources (e.g., hydrologic, biologic, and socioeconomic) of the Basin, followed by an analysis of the extent and magnitude of potential effects on each resource from the alternatives described in **Chapter 2**. Only resources that could potentially be significantly affected by the alternatives are analyzed. Resources considered for analysis but determined not to be significantly affected include the following:

- **Transportation** – No impacts on transportation are anticipated in the analysis area, as the proposed changes are operational in nature. Impacts to the Lake Powell ferry are analyzed in the recreation section.
- **Minerals** – No impacts on minerals or mineral rights are anticipated because all proposed Lake Powell and Lake Mead operational changes and their associated releases and elevations would not affect minerals or mineral rights.
- **Noise** – No impacts on noise are anticipated in the analysis area, as existing noise conditions are expected to continue at the same level under all proposed Lake Powell and Lake Mead operational changes.
- **Light** – No impacts on light are anticipated in the analysis area, as existing light conditions are expected to remain unchanged under all proposed Lake Powell and Lake Mead operational changes.

Section 3.2, Analysis Methods, describes the approach used for assessing the environmental consequences, including the geographic and temporal scope, alternatives and a comparative baseline, and modeling. This is followed by the individual resource sections, which represent a summarized overview of the affected environment and environmental consequences. Further information for each resource section can be found in the corresponding technical appendices identified in each section.

3.2 Analysis Methods

3.2.1 Geographic Scope

Consistent with the geographic scope analyzed in the 2007 Interim Guidelines Final EIS, the geographic scope that would be affected by the proposed federal action begins at full pool of Lake Powell and extends downstream along the mainstream Colorado River floodplain to the SIB with Mexico. This proposed federal action would also potentially affect interests of water users in the Lower Division States in service areas that extend beyond the Colorado River floodplain. Additionally, numerous tribes hold Colorado River water entitlements and could be affected by water supply availability.

Although the proposed federal action is focused on Lake Powell and Lake Mead operations, management strategies that include activities upstream of Lake Powell are being analyzed in this Final EIS. These activities include Upper Basin conservation and, if warranted to protect critical reservoir elevations, operations at the CRSP Upper Initial Units (see **Map 1-1**). Operations at the CRSP Upper Initial Units specifically contemplated in the Final EIS alternatives are intended to remain within the scope of the existing Records of Decision (Reclamation 2006a, 2006b, 2012).[1 2] Accordingly, the Final EIS does not expand the geographic scope of analysis upstream of Lake Powell. With respect to Upper Basin conservation, the nexus to the proposed federal action is the storage and delivery of that conserved water in Lake Powell. The effects of this storage in and delivery from Lake Powell are within the scope of the EIS (see **Section 3.3**, Hydrologic Resources, and **TA 3**, Hydrologic Resources), while specific activities that may be undertaken in the Upper Basin to generate the conserved water are not within the scope of this EIS. Any such activities are unknown at this time and will not necessarily require federal decision making. Any federal decisions associated with these conservation activities will be assessed outside of this EIS.

For ease of discussion with respect to the geographic scope of this Final EIS and the affected areas and potential effects, the Colorado River has been divided into nine reaches, as shown on **Table 3-1** and **Map 3-1**. The geographic scope described in this section is a standard area of analysis; for some resource topics, the impact analysis area differs from this scope to account for the impacts on that specific resource. When different, the impact analysis area is defined in the resource's specific methodology section.

3.2.2 Temporal Scope

For purposes of analysis, the temporal scope of this EIS extends from 2027 through 2060, providing a framework for assessing short-term to long-term effects.

3.2.3 Alternatives Analyzed and Comparative Baseline

The analysis for each resource section focuses on specific issues identified during internal and public scoping (Reclamation 2023b). Impact analysis is provided for the Preferred Alternative, as represented by the Representative Alternative, described in **Chapter 2**, and all the "action alternatives" described in **Appendix S,** Additional Description of Alternatives (Basic Coordination Alternative, Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative [both LB Priority and LB Pro Rata approaches]), along with the No Action Alternative. A No Action Alternative typically serves as an extension of current operations to provide a benchmark to

[1] RODs for CRSP Upper Initial Units include those for Flaming Gorge, Blue Mesa (a component of the Aspinall Unit), and Navajo reservoirs.

[2] While the Secretary will consider and prioritize operations at these facilities that are consistent with existing RODs, the Secretary retains the authority to operate outside those RODs if necessary. The modeling assumptions regarding operation of the CRSP Upper Initial Units presented in this Final EIS are not intended to, and do not, limit the Secretary's ability to operate these facilities as necessary to respond to hydrologic conditions in accordance with applicable federal law, including operations for the authorized purposes as stated in the 1956 Colorado River Storage Project Act. See additional information regarding the modeling assumptions of the CRSP Upper Initial Units in **Appendix A,** CRSS Modeling Documentation **Section A.5.11**.

Map 3-1 Colorado River Reaches and Geographic Scope

Table 3-1
Colorado River Reaches and Reach Limits in the Geographic Scope

Reach	Reach Limits
Lake Powell and Glen Canyon Dam	Lake Powell at full pool to Glen Canyon Dam (RM -15.8)
Glen Canyon Dam to Lake Mead	Glen Canyon Dam (RM -15.8) to Separation Canyon (RM 240), including GCNP
Lake Mead and Hoover Dam[1]	Separation Canyon (RM 240) to Hoover Dam, including Lake Mead
Hoover Dam to Davis Dam	Hoover Dam (RM 342.2) to Davis Dam (RM 276), including Lake Mohave
Davis Dam to Parker Dam	Davis Dam (RM 276) to Parker Dam (RM 192.3), including Lake Havasu
Parker Dam to Cibola Gage (Adobe Ruin)	Parker Dam (RM 192.3) to Adobe Ruins and Reclamation's Cibola Gage near the terminus of Cibola Lake (RM 87.3)
Cibola Gage to Imperial Dam	Reclamation's Cibola Gage near the terminus of Cibola Lake (RM 87.3) to Imperial Dam (RM 49.2)
Imperial Dam to Northerly International Boundary (NIB)	Imperial Dam (RM 49.2) to the NIB (RM 23.1)
Northerly International Boundary (NIB) to Southerly International Boundary (SIB)	NIB (RM 23.1) to SIB (RM 0.0)

[1] For purposes of this EIS, RMs are measured differently along the length of the Colorado River in the Upper and Lower Basins. RMs in the Upper Basin begin at Glen Canyon Dam and increase from north to south. The Lower Basin RMs increase upstream (south to north), beginning at RM 0.0 at the SIB with Mexico and increasing to RM 342.2 at Hoover Dam. This system of identifying RMs is consistent with common practices within each Basin. Dam locations, reach limits, and other features are identified at their respective RM.

compare the extent and magnitude of the impacts from each action alternative. However, as described in **Chapter 2**, the expiration of current domestic and international implementing agreements means that the No Action Alternative represents a change in operations. As a result, the No Action Alternative does not serve as an appropriate baseline to compare impacts. Therefore, a CCS Comparative Baseline scenario is provided to assess the impacts if operations were to continue under the current direction and strategies.[3] While the CCS Comparative Baseline is not an action alternative, it is a contemporary set of operations that stakeholders are familiar with that can be used to comparatively evaluate the performance of the alternatives (including the No Action Alternative).

As discussed in **Chapter 2**, the Preferred Alternative is a multi-year decision framework that establishes the process and criteria that would govern development and adoption of operating guidelines through 2036. The decision framework is anticipated to be implemented in two-year operating intervals. Unlike other alternatives, the operating guidelines for each interval are not specified in this Final EIS. The sideboards provide a basis for assumptions included in the Representative

[3] This framework relies on strategies and agreements that expire in 2026, including the 2007 Interim Guidelines (as amended), the 2019 DCP, Minute 323 of the 1944 Water Treaty, and other agreements.

Preferred Alternative which captures the range of operating guidelines that may be adopted during each interval, but exact operations would be subject to the guidelines in place during each interval.

The key modeling assumptions for the CCS Comparative Baseline are summarized in **Table 3-2** and additional details are included in **Appendix A**, CRSS Model Documentation. These modeling assumptions were designed to reflect a continuation of the primary existing agreements for Colorado River management including the 2007 Interim Guidelines, the 2019 DCP, and Minute 323 of the 1944 Water Treaty.

3.2.4 Hydrologic Modeling

Hydrologic modeling of the Colorado River system was conducted to determine the potential hydrologic effects of the alternatives considered in this Final EIS. The hydrologic modeling provides projections of potential future Colorado River system conditions (such as reservoir elevations, reservoir releases, and river flows) under the No Action Alternative (and the CCS Comparative Baseline) for comparison with conditions simulated for the action alternatives. Due to uncertainties associated with future inflows, which are the largest driver of system outcomes under any given operation, hundreds of simulations were performed for each alternative to explore how each responds to a range of plausible future conditions. The simulations and analysis framework were designed to avoid reliance on narrow hydrologic assumptions, ensure meaningful comparison between alternatives, and provide reliable information about how the system would respond under each alternative. Hydrologic modeling is the driver for various resource impacts and is therefore the basis for analyzing potential effects on other environmental resources (e.g., recreation, biological resources, and energy). The potential effects on specific resource issues are identified for each alternative and compared with those under the No Action Alternative and CCS Comparative Baseline.

Hydrologic Model Description

Future Colorado River system conditions under the No Action Alternative, CCS Comparative Baseline, and the action alternatives were simulated using CRSS. CRSS, implemented through RiverWare™, is the core simulation tool, providing monthly and annual outputs of key variables, including reservoir storage, reservoir elevations, dam releases, and river flows. The simulation is based on a mass-balance calculation that accounts for water entering the system, water uses (diversions and consumptive use), water losses (evaporation), intervening gains and losses, and water movement through the system.

Input data for the model include monthly natural inflows, physical process parameters (e.g., evaporation rates for reservoirs), initial reservoir conditions, and future diversion and depletion schedules for the Basin States and for Mexico. The operating rules for the Colorado River system reservoirs (including Lake Powell and Lake Mead) are also considered inputs to the model. Detailed descriptions of CRSS and the hydrologic model process are included in **Appendix A**, CRSS Model Documentation.

Table 3-2
Summary of the CCS Comparative Baseline

Shortage Guidelines to Reduce Deliveries from Lake Mead[1]	Coordinated Reservoir Operations (Lake Powell and Lake Mead)	Storage and Delivery of Conserved System and Non-system Water (Lake Mead and/or Lake Powell)[1]	Surplus Guidelines to Increase Deliveries/Releases from Lake Mead[1]	Additional Activities Above Lake Powell
• Shortages determined based on Lake Mead elevation • Shortage volume of 400, 500, and 600 kaf at elevations 1,075, 1,050, and 1,025 feet, respectively • DCP and BWSCP contributions ranging from 241 kaf at elevation 1,090 feet to 750 kaf at elevation 1,025 feet • Shortages and DCP contributions distributed based on existing agreements	• Lake Powell releases are determined based on Lake Powell and Lake Mead elevations • 3 tiers of releases ranging from 9.5 to 7.0 maf with potential adjustments down to 6.0 maf for infrastructure protection • Equalization tier with higher releases possible at higher Lake Powell elevations	• Storage up to 4.2 maf in Lake Mead • Delivery of existing ICS assumed to continue through the analysis period (2027-2060) in accordance with existing agreements designed to reflect the historical range of use of the ICS mechanism • Creation of ICS assumed to continue through the analysis period (2027-2060) in accordance with existing agreements designed to reflect the historical range of use of the ICS mechanism	• Surplus determinations based on Lake Mead Elevation at or above 1,145 feet: Domestic Surplus, 70R (spill avoidance strategy), Flood Control Conditions, and increases in deliveries to Mexico per Minute 323	• Releases from CRSP Upper Initial Units within their respective RODs and contingent on hydrologic conditions to protect infrastructure at Glen Canyon Dam

[1]These operational elements contain modeling assumptions for water deliveries to Mexico. Shortage volumes include assumptions related to reductions in water deliveries to Mexico based on Minute 323. Lake Mead storage volumes for the Storage and Delivery of Conserved System and Non-system Water include assumptions related to storage available to Mexico. Surplus Guidelines include assumptions related to increased deliveries to Mexico based on Minute 323. **Appendix A** provides additional detail. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Assumptions

In addition to the specific operating rules necessary to model each alternative (discussed in **Chapter 2** and the associated appendices) and the CCS Comparative Baseline, modeling of Colorado River system operations requires assumptions about various aspects of inflows, water delivery, and system operations that are common to all alternatives and the CCS Comparative Baseline. These assumptions include:

- **Input Data Consistency:** All simulations use a common set of input data to isolate the effects of alternative operational guidelines.
- **Hydrologic Variability:** Simulations use 400 different hydrologic traces to capture the variability inherent in natural flows.
- **Initial Conditions:** In the Draft EIS, three sets of 2027 reservoir elevations were used to capture hydrologic uncertainty between 2025 and 2027. Since the Draft EIS was developed, the observed hydrology supports using the Low initial conditions only because they are similar to the likely starting point at the end of 2026.
- **Future Water Demands:** Upper Basin depletion schedules were developed from the Upper Colorado River Commission's updated 2016 Depletion Demand Schedule (**Appendix L**, Upper Division Depletion Schedules). The modeled Upper Basin use varies due to hydrologic conditions and alternative specific conservation assumptions. Lower Basin depletion schedules were developed by Reclamation (**Appendix M**, Lower Division Depletion Schedules). Lower Basin depletion schedules start at full apportionment and modeled use varies by alternative specific shortage, surplus, and conservation assumptions.
- **Physical Process Parameters:** Assumptions regarding evaporation, bank storage, and other processes are based on the most current measurements and modeling studies.
- **Infrastructure Constraints:** Modeled limitations on operations at high and very low reservoir elevations.

Detailed modeling assumptions and other aspects of the simulation are documented in **Appendix A**, CRSS Model Documentation. All results in **Chapter 3**, and the supporting technical appendices in **Volume III** are based on the single Upper Basin demand assumptions described above. **Appendix I**, Sensitivity Analysis – Effects of Alternate Upper Basin Demand Scenarios on Operations at Lake Powell and Lake Mead, presents a sensitivity analysis that evaluates how future Upper Basin demands assumptions influence modeled system conditions and vulnerabilities for select hydrologic and water delivery impact indicators.

3.2.5 Resource Model Description

In addition to CRSS, a suite of resource-specific models was used to evaluate potential effects of the alternatives on individual resource areas. These models build on CRSS outputs and provide finer-scale or specialized analyses tailored to individual resource areas. **Table 3-3** lists the primary models and the resources they support.

Table 3-3
Models and Supported Resources

Model/Owner	Primary Purpose	Resource Areas Supported
CRSS/RiverWare™ (Reclamation)	Core system operations model; simulates reservoir elevations, releases, river flows, and salinity.	Hydrologic Resources; Water Deliveries; Dams and Electrical Resources, Water Quality; Visual Resources; Vegetation; Terrestrial Wildlife; Geomorphology and Sediment; Air Quality; Fish and other Aquatic Species; Tribal; Recreation; Population and Land Use; Indian Trus Assets
SAM / Alternative Distribution Model(s) (ADM) (Reclamation)	Emulates a distribution of Colorado River water shortage among entitlement holders under shortage tiers and allocation assumptions; translates tiers into volumes for specific users/jurisdictions.	Water Deliveries; Socioeconomics; Indian Trust Assets (ITAs); Lands and Population
High-Flow Experiment (HFE) / Sediment models (Grand Canyon Monitoring and Research Center [GCMRC] / U.S. Geological Survey [USGS])	Simulates sediment transport and geomorphic response to HFEs (sand mobilization, sandbar building, channel budgets). Evaluates whether and how often HFEs rebuild sandbars.	Geomorphology and Sediment
CRSP Python model (CRiSPPy)/WAPA	An advanced hydropower scheduling tool that projects annual electricity production and powerplant firm capacity. The hourly release data generated by this model is used as an input for many of the GCMRC models listed below.	Dams and Electrical Power Resources
GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry and Grand Canyon (Reclamation/ GCMRC/USGS)	Evaluates thermal stratification, interflows, and downstream release water temperatures and dissolved oxygen conditions, especially important for aquatic resource (humpback chub, trout) impacts and selective withdrawal scenarios.	Water Quality; Fish and Aquatic

Model/Owner	Primary Purpose	Resource Areas Supported
Glen Canyon National Recreation Area (NRA) Exposed Shoreline Model (Lake Powell) (subaerially exposed sand model) (USGS/GCMRC/ Southwest Biological Science Center)	Predicts exposed sand and shoreline area as reservoir levels change; used to estimate aeolian sand availability and cultural/paleo exposure.	Air Quality; Cultural Resources; Paleontological Resources
Lake Mead Dust Model (USGS/GCMRC)	Predicts potential dust emissions from newly exposed shoreline and estimates human-health/air-quality impacts under drawdown scenarios.	Air Quality
Preservation Risk Model (USGS/GCMRC)	Ranks Lake Powell and Lake Mead (1–5) based on the potential for cultural and paleontological resource preservation to be affected by reservoir levels. Combines a resource distribution model with a preservation hazard model.	Cultural Resources; Paleontological Resources
Joint Cultural/Paleo Models (Sand Area, Vegetation, and Sandbar Models) (USGS/GCMRC)	Integrates the aeolian sand availability model, vegetation habitat suitability model, and sandbar volume model. Together, these evaluate sand supply, vegetation cover, and sandbar dynamics as key drivers of cultural and paleontological resource preservation in the Grand Canyon.	Cultural Resources; Paleontological Resources
Smallmouth Bass Model (entrainment and population growth proxies) (GCMRC)	Estimates entrainment rates of smallmouth bass through Glen Canyon Dam, thermal suitability downstream, and consequent population establishment/growth (λ proxies).	Fish and Aquatic
Whitewater and Angling Economic Model (USGS/GCMRC)	Estimates changes in recreation value (rafting in Grand Canyon, angling in Glen Canyon) under varying flow and condition scenarios.	Recreation
Socioeconomic IMPLAN (Impact Analysis for Planning) commercial regional input-output model	Assesses community-level socioeconomic outcomes (employment, income, tax base, social vulnerability) from water delivery and recreation/hydropower impacts. Converts changes in agricultural output (or other direct effects) into regional economic impacts.	Socioeconomics

Additional specialty models that add layers of analysis to the above models are introduced in their respective resource sections.

3.2.6 Decision Making under Deep Uncertainty

To help inform the impact analysis, a DMDU approach, drawn from a well-established branch of decision science, was implemented to evaluate how each alternative performs across a wide range of plausible future hydrologic and operational conditions. As described in Smith et al. (2022), this approach is appropriate because of extreme uncertainty in future hydrology, the inability to accurately assess the probability distribution of future inflows, and the desire to avoid overconfidence in probabilistic predictions that will vary depending on model inputs.

The DMDU approach is a non-probabilistic evaluation framework that compares alternatives based on their ability to meet specific performance criteria in many potential future conditions and analyzes how the alternatives respond to specific hydrologic conditions. Importantly, the DMDU approach does not assume the likelihood of any future conditions *before* the quantitative analysis is performed. Instead, it first evaluates a broad range of future conditions and then, *after the analysis is presented*, it provides the opportunity to consider whether specific impacts are reasonably foreseeable based on individual and/or expert judgment. Essentially, since there is no way to confidently state the probabilities of different conditions or outcomes occurring, DMDU focuses on applying knowledge and experience at the end of the analysis to assess whether it is reasonable to plan for the specific conditions that result in negative consequences.

Additional background and technical details about the DMDU framework are provided in **Appendix E**, DMDU Overview and Approach.

Note, certain analysis thresholds, such as historic minimum elevations and minimum average flows, were based on observations through June 2026.

Overview of the DMDU Analysis Framework

The key to successful DMDU-style analysis is structured model inputs that capture a range and variety of conditions related to the key factors that drive the uncertainties in the model outputs. For this EIS process, the most impactful uncertainty is future hydrology. Four hundred hydrology sequences (traces) were selected from a suite of data sources that include observed flows, reconstructions of historical flows based on tree ring analysis, statistical models that combine information about recent trends, historical patterns, projected variability, and projections derived from climate models. The traces capture a wide range of potential future conditions and a variety of streamflow statistics. This ensures that the alternatives are thoroughly tested and enables targeted analysis to understand how each alternative responds to specific hydrologic conditions. In the Draft EIS, three sets of 2027 reservoir elevations (High, Mid and Low initial conditions) were used to capture hydrologic uncertainty between 2025 and 2027. Since the Draft EIS was developed, the observed hydrology supports using the Low initial conditions only since they are similar to the projected conditions at the end of 2026. The Low initial conditions are combined with the 400 different hydrology (streamflow) traces. Each alternative is simulated in all 400 futures using CRSS and subsequent resource-specific models. For more information about the hydrology used in this analysis, refer to **Appendix F**, Approach to Hydrologic Uncertainty, and for more information on the initial reservoir condition used in the analysis, refer to **Appendix G**, CRSS Initial Conditions.

Overview of DMDU Figures and Terminology Included in this Analysis

Throughout the resource analysis there are three standard figures: conditional boxplots, robustness heatmaps, and vulnerability bar plots. Each type of figure explains key information regarding performance. When taken together, the figures provide a full picture of how the alternatives compare and whether significant negative impacts are reasonably foreseeable under each alternative. The following sections introduce these figures and provide annotated examples to assist with understanding the resource analysis.

DMDU enables readers to apply individual judgment about the likelihood of specific impacts: The quantitative analysis underpinning this document tests alternatives in a wide range of conditions to identify relationships between hydrologic conditions and system impacts. The DMDU-oriented figures can be combined with historical hydrologic context and future projections to understand whether impacts of concern are reasonably foreseeable. These connections will be demonstrated as each figure is introduced.

Conditional Boxplots

The conditional boxplot figures show how the alternatives respond to different categories of preceding hydrology and enable a comparison of alternatives in specific hydrologic conditions (e.g., average conditions or dry conditions). To create these figures, all 34 years (2027–2060) from all 400 simulated futures (13,600 data points per alternative) are separated into five categories based on their preceding 3-year average Lees Ferry natural flow.[4,5] Then, the resource outcomes for each year are sorted into their respective categories, resulting in a range of potential system outcomes that could occur given the preceding hydrologic conditions. The range of values is presented as a boxplot to summarize the statistical distribution of outcomes.

The flow categories were defined based on how they compare to historical conditions and stakeholders' understanding of different historical periods, as presented in **Table 3-4**, Colorado River Flow Categories. **Figure 3-1**, Preceding 3-Year Average Lees Ferry Natural Flow, 2000 to 2024, shows how the preceding 3-year average Lees Ferry natural flow varied from 2000 to 2024 and demonstrates the relevance of these categories in recent history.

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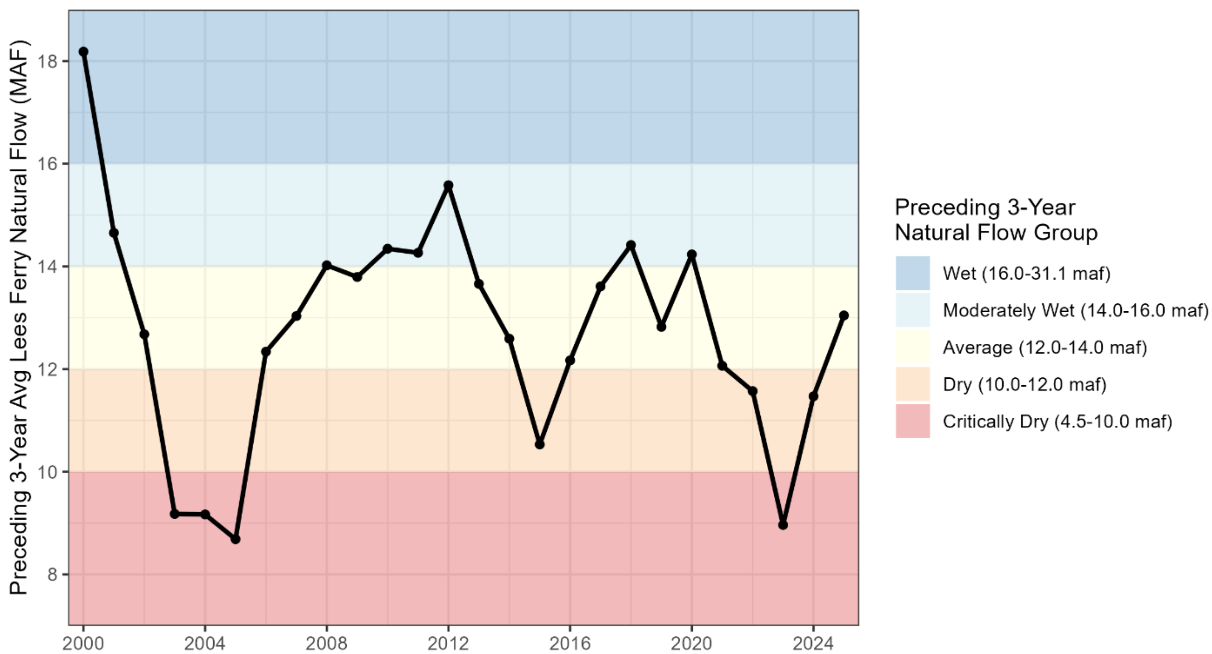
[4] Natural flow at Lees Ferry is a calculated estimate of the flow at that point in the river undepleted by human activities upstream (e.g., reservoir evaporation and regulation, consumptive use). Given that over 90 percent of the total water in the system originates upstream of Lees Ferry, it is a good proxy for the amount of water available to the system overall. This makes it a useful way to categorize hydrology traces.

[5] The 3-year average is used because it is long enough to show impacts from multiple years of moderately challenging hydrology yet short enough to capture the impacts of annual extremes.

Table 3-4
Colorado River Flow Categories

Flow Category Name	Range of Preceding 3-Year Average Lees Ferry Natural Flows (maf)	Percent of Modeled Years in Flow Category	Number of Observed Years in Flow Category, 2000–2025
Wet	16.0–31.1	17	1
Moderately Wet	14.0–16.0	20	7
Average	12.0–14.0	25	11
Dry	10.0–12.0	21	3
Critically Dry	4.5–10.0	17	4

Figure 3-1
Preceding 3-Year Average Lees Ferry Natural Flow, 2000 to 2024



A sample conditional boxplot figure with annotations for guidance is provided in **Figure 3-2,** Sample Conditional Boxplot for WY Minimum Combined Storage of Lake Powell and Lake Mead. **Figure 3-2** has numbered annotations to describe the features of the figure and provide an example summary of what the figure shows about the comparison between the No Action Alternative and the CCS Comparative Baseline. Reading the text in numerical order will provide the clearest understanding.

Conditional boxplots in the impacts analysis will show these two operations alongside the action alternatives. Additionally, reference lines representing values of interest (e.g., historical values or critical thresholds) will be shown with dashed lines. Conditional boxplots will be accompanied by tables of values captured in the boxplots to ensure that precise statistics are communicated.

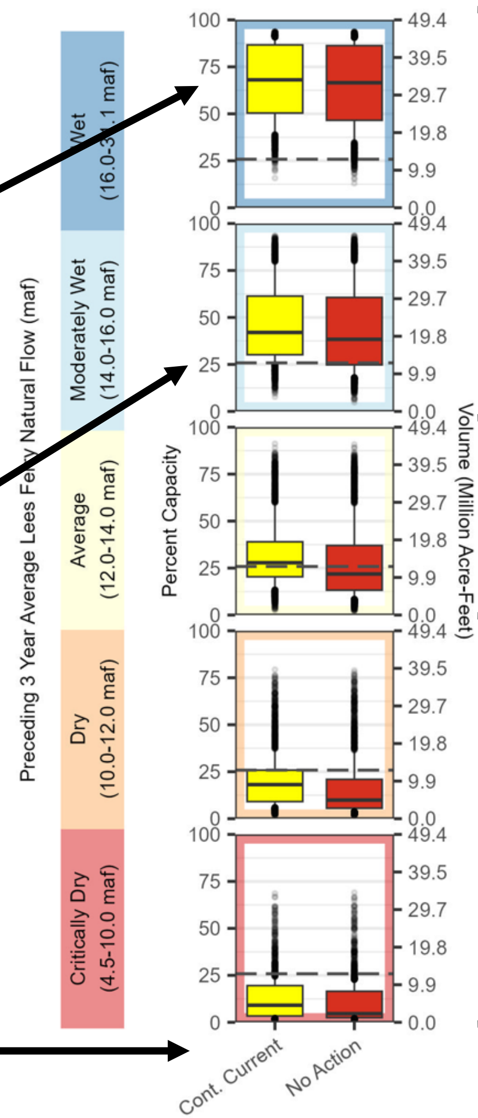
Figure 3-2
Sample Conditional Boxplot for WY Minimum Combined Storage of Lake Powell and Lake Mead

1. The flow categories are assigned a color and the range of volumes in each category is shown.

3. Because there are many data points in each category, their distributions are presented as boxplots. See the boxplot legend in the bottom right corner of this page.

4. A reference line of 12.77 maf (25.84%), which is the minimum observed combined Lake Powell and Lake Mead storage since both reservoirs filled (observed in March 2023) is shown on each panel.

2. Each alternative and the CCS Comparative Baseline is represented by a series of colored boxplots.

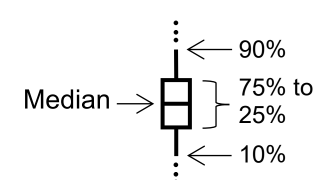


5. The No Action Alternative and CCS Comparative Baseline perform similarly when the preceding 3-year average annual flow was Moderately Wet or Wet.

6. In the Average flow category, both operations have a significant number of years falling below the reference line, but the No Action Alternative performs worse, with more than 50% of years below the threshold.

7. The No Action Alternative continues to perform worse than the CCS Comparative Baseline in both the Dry and Critically Dry categories, but under the driest conditions the difference is small because both result in about 90% of years falling below the reference line.

Boxplot Legend: Percentages of Data



The connection between system outcomes and hydrologic conditions is clear in the conditional boxplots because the data is sorted by the preceding 3-year average hydrology. To determine which hydrologic categories to focus on and which impacts to contemplate as reasonably foreseeable, the recently observed conditions presented in **Figure 3-1** and **Table 3-4** offer useful context. The Average category is the most common since 2000, while the Wet category is the least common. There have been as many combined instances of Dry and Critically Dry conditions (seven) as there have been instances of Moderately Wet (though, notably, most of the Moderately Wet instances were close to being Average). Recent history combined with the increasing temperature trend, which is associated with lower streamflow, suggests that focusing more on the Average and Dry categories is warranted. However, Critically Dry conditions have been observed and could become more common.

Within each flow category, the distribution of data provides a connection to conditions that occurred before the 3 years used to sort the data into categories: the higher end of a distribution is likely the result of wetter conditions preceding the 3 years, and the lower end of a distribution is likely the result of drier conditions preceding the 3 years. Considering that 20 out of 24 years since 2000 have fallen in the Moderately Wet, Average, and Dry flow categories, it is prudent to focus on specific portions of the distribution within each flow category: the 25th to 75th percentiles (the colored portions of the boxes) are most relevant, since the high and low ends of the distributions are representative of extreme conditions occurring before the 3 years used to sort the data into the flow categories.

Robustness Heatmaps

A robust alternative achieves the preferred minimum performance level under a wide range of future conditions. Robustness heatmaps show the alternatives' ability to meet different levels of performance over one or more decades in the wide range of potential future conditions used in the analysis. Since there are many ways to analyze performance for each resource, there are many opportunities to define meaningful levels of performance. A definition for a single level of performance requires three components: the modeled outcome of a system variable over a time period (i.e., a timeseries), a threshold, and a frequency of meeting the threshold over the specified period.

When a simulated (or modeled) future meets the specified level of performance, it is considered a "successful future." Under each alternative, the percentage of futures (out of 400 modeled futures) that are successful provides information about how robust the alternative is. A large percentage of successful futures (i.e., a high robustness score) means that the alternative is robust (i.e., it performs well) with respect to the specified level of performance; a low percentage of successful futures means that the alternative is not robust with respect to the specified level of performance.

The data that was sorted into categories for the conditional boxplots in **Figure 3-2** can be used in an example robustness heatmap. Performance levels are defined using the annual timeseries of minimum WY combined storage in Lake Powell and Lake Mead (i.e., the minimum storage recorded in each WY from 2027 through 2060) and comparing the timeseries to the threshold of the minimum observed storage (12.77 maf), where staying above this value is better. The final component of defining a level of performance is the frequency of staying above the minimum observed combined storage (100 percent of years, 90 percent of years, etc.).

Figure 3-3 compares the robustness of the No Action Alternative to the CCS Comparative Baseline with respect to their ability to maintain different levels of performance in combined Lake Powell and

Lake Mead storage. It is annotated using numbered descriptions as a guide to the features of the figure and a summary of findings. Reading the text in numerical order will provide the clearest understanding.

In **Figure 3-3**, each row represents a different level of performance. This is useful because individuals can have different opinions about what level of performance is necessary for a given resource. In this case, they could focus on the row that best aligns with their preference. At the same time, it is useful for resource experts to identify a 'preferred minimum level of performance,' which is identified in **Figure 3-3** by the purple box. In this example, the preferred minimum performance level is for the combined storage of Lake Powell and Lake Mead to stay above 12.77 maf in at least 90 percent of years. The preferred minimum performance level is also the basis for vulnerability analysis, as described in the next section.

This type of figure is referred to as a "heatmap" because clusters of colors provide an easy way to identify regions of robustness or lack of robustness across the alternatives. Robustness heatmaps contain a large amount of information, but a quick scan of the rows and columns can reveal key conclusions about robustness. The analysis in this chapter and in the technical appendices uses heatmaps covering four different modeling periods: the full 34-year modeling period (2027-2060) and three approximately equal sub periods. This provides insight into how different alternatives perform in smaller timespans. Importantly, the early sub period (2027-2039) captures how the dry conditions leading up to 2027 affect robustness and corresponds approximately to the length of the Preferred Alternative.

Key visual tips to quickly interpret robustness heatmaps: Every column of colors represents the robustness of an alternative across different levels of performance in a given resource. The more blue there is in a column, and the darker the blue, the more robust an alternative is; a large amount of orange or red, and especially dark red, means an alternative is not robust with respect to a specific type of performance.

For all modeling periods (the full modeling period and individual sub periods), approximately 75 percent of the 400 hydrology traces had an average annual flow lower than the 1906–2025 average of 14.6 maf. Across all periods, approximately 50 percent of traces had an annual average flow lower than the 1988–2024 average, and more than 25 percent of traces had an average that is lower than the 2000–2024 average. Over the subperiods, the 25th percentiles, 10th percentiles, and the driest traces became drier.

The distributions of these statistics can be roughly mapped to robustness percentiles to understand the average conditions associated with unsuccessful futures. For example: over the full modeling period, if a resource is sensitive to drier conditions and an alternative has a robustness score of 90 percent, it is unsuccessful in 10 percent of futures and it is reasonable to map this unsuccessful percentage to the driest 10 percent of the average flows, meaning that the failures are most likely occurring in futures where the 34-year average flow is 11 maf or lower. Readers can determine whether these average conditions are reasonably likely to occur, in which case a 90 percent robustness score may not be adequate to avoid negative impacts on the resource. For resources that are sensitive to wet conditions, the higher end of the distribution of average flows should be referenced. Note that these comparisons are only approximations but are useful for providing context to robustness scores.

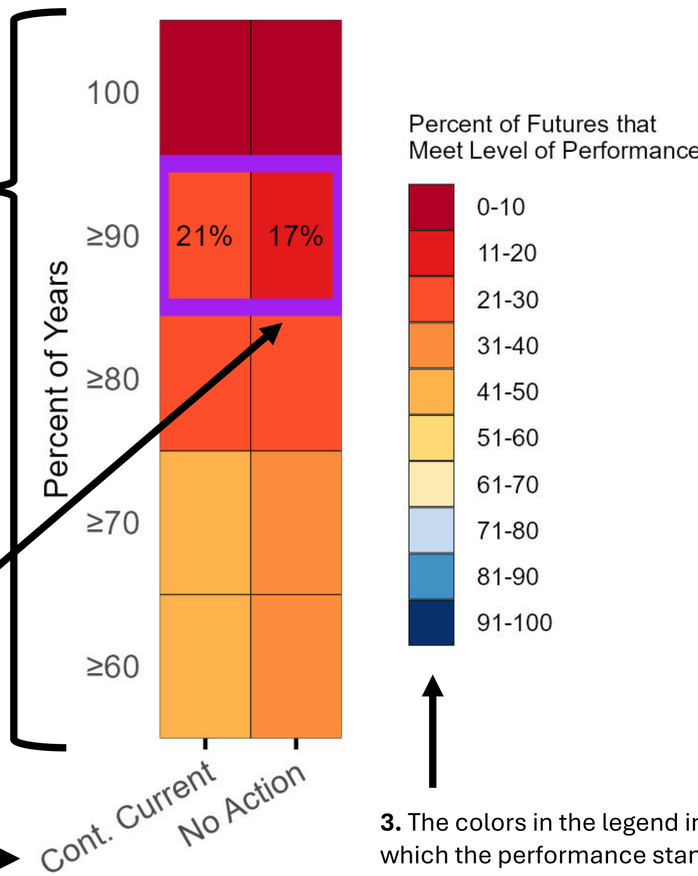
Figure 3-3
Sample Robustness Heatmap for WY Minimum Combined Storage of Lake Powell and Lake Mead.
Percent of futures in which the WY minimum combined storage stays above the historical minimum (12.77 maf) in the percent of years specified by each row

1. The subtitle describes the time-series, threshold, and frequency used to calculate *robustness* (i.e., the percentage of 400 futures that meet the performance requirement).

4. The rows in the heatmap capture different levels of performance. The highest row is the hardest level of performance to achieve (colors are more likely to be red, orange or yellow) and the lowest row is the easiest (colors are more likely to be blue). In this example, each row represents a frequency of keeping combined Lake Powell and Lake Mead storage above the observed minimum.

5. The purple highlighted row denotes the *preferred minimum performance*. This row is the focus for figure descriptions and is the performance level used in vulnerability bar plots.

2. Each alternative and the CCS Comparative Baseline has a column of “cells” that are colored based on the legend.



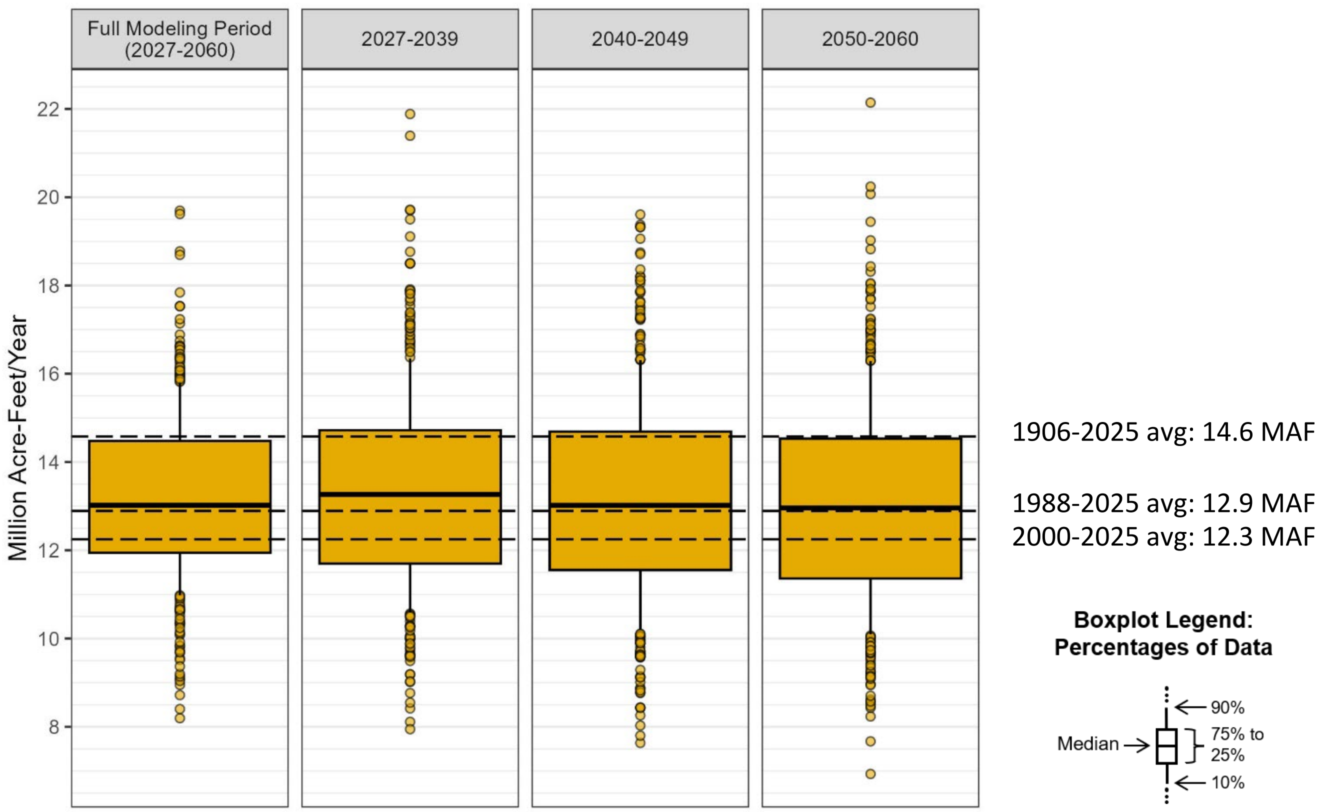
6. The ability of different alternatives to maintain a reasonable minimum amount of storage in Lake Powell and Lake Mead is an important consideration when evaluating their performance. Here, the observed minimum volume of 12.77 maf is taken as a significant threshold, and the preferred minimum performance is to stay above that threshold in at least 90% of years across the 34-year simulation period (purple highlighted row). The CCS Comparative Baseline achieves this level of performance in 17% of futures, so it is slightly more robust than the No Action Alternative which only achieves it in 21% of futures. Both increase in robustness as the performance standard is lowered (looking down the rows), with CCS Comparative Baseline achieving above 40% robustness (light orange cell) when the frequency of staying above the observed minimum storage is relaxed to 60% of years (bottom row).

3. The colors in the legend indicate the percentage of futures out of 400 in which the performance standard in each row is met across the time period 2027 to 2060. Each cell in the heatmap has a color corresponding to the robustness of an alternative with respect to the performance standard in that row. Higher percentages (darker blues) indicate higher robustness.

Assessing which alternatives are in shades of blue (generally robust) and which are in shades of yellow, orange, or red (generally not robust) for a given level of performance provides a basic level of information that is sufficient for comparison. To apply judgment about what robustness score is adequate, it is beneficial to understand the statistical distribution of the underlying hydrology.

Figure 3-4 shows annual average flows by trace for the full 400-trace hydrology ensemble over different time periods and compares them to historical averages. In the first subperiod (second panel from the left) the distribution is slightly higher at the median and 75th percentiles. This is a statistical artifact from several of the constituent ensembles, not a prediction that supply could increase between 2027 and 2039.

Figure 3-4
Average Annual Lees Ferry Natural Flow by Trace for 400-Trace Hydrology Ensemble over Different Time Periods



Vulnerability Bar Plots

Vulnerability bar plots provide complementary analysis to the robustness heatmaps by identifying the specific hydrologic conditions in which each alternative is likely to succeed or fail the preferred minimum performance level[6] (recall, the preferred minimum performance is shown by the purple-

[6] Vulnerability analysis considers if the performance levels are violated any time during the 34-year modeling period. Using the full modeling is preferred such that one hydrology statistic can accurately predict if an alternative will meet the performance level. A decadal-based analysis (like what is included in some robustness heatmaps) would require a multi-dimensional prediction accounting for reservoir storage at the start of each decade, which varies by alternative and hydrology, making it difficult to compare alternatives.

outlined row of the heatmap). For example, the heatmap in **Figure 3-3** shows that the CCS Comparative Baseline successfully meets the preferred minimum performance level in 21 percent of futures, meaning that the CCS Comparative Baseline is unsuccessful in the remainder of the futures (79 percent of futures). Vulnerability analysis uses information about both the successful and the unsuccessful futures to identify hydrologic conditions (via statistical characteristics) that are most skillful at predicting the different outcomes. The hydrologic statistical characteristics tested are:

- the driest 10-year average Lees Ferry flow over a 34-year hydrology trace
- the median 10-year average Lees Ferry flow over a 34-year hydrology trace
- the wettest 10-year average Lees Ferry flow over a 34-year hydrology trace

Statistics based on 10-year averages were determined to be highly accurate at separating successful from unsuccessful futures and provide information on a time-scale relevant to the Preferred Alternative (which is a 10-year decision framework). The driest 10-year average is most frequently the most skillful predictor because it is highly correlated with the undesirable resource outcomes that occur due to dry hydrology. For information about other predictors and how they are tested, refer to **Appendix E**, DMDU Overview and Approach.

Once a skillful predictor is identified, the alternatives can be described in terms of the hydrology conditions associated with undesirable performance (i.e., the conditions in which an alternative is vulnerable). Alternatives will have different vulnerabilities because of their different approaches to operating the reservoirs. Conditions associated with vulnerability can then be compared to conditions that have occurred in the past and a range of conditions that could potentially occur in the future; if conditions that have already occurred are similar to those associated with vulnerability under an alternative, the conclusion is that the undesirable impacts are reasonably likely to occur in the future.

Figure 3-5 compares the vulnerability of the No Action Alternative and the CCS Comparative Baseline with respect to avoiding undesirable performance in combined Lake Powell and Lake Mead storage (i.e., falling below the historical minimum in more than 10 percent of years). The figure also shows how each alternative's vulnerability compares to conditions that have occurred in the past or could potentially occur in the future. It is annotated using numbered descriptions as a guide to the features of the figure and a summary of findings. Reading the text in numerical order will provide the clearest understanding.

Vulnerability bar plots capture complex information, but a brief visual inspection can provide the key conclusions about whether undesirable impacts could be reasonably expected under a given alternative.

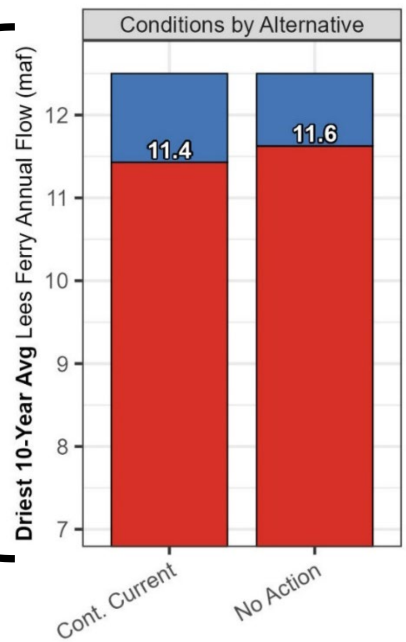
Key visual tips to quickly interpret vulnerability bar plots: Every alternative is linked to a bar that is divided into blue and red; the larger the red portion, the wider the range of hydrology conditions in which the alternative is vulnerable. If the red portion of the bar encompasses, or is close to, conditions that have already occurred according to the reference hydrology panel, undesirable performance in that resource is likely to occur. (If a bar is completely blue, none of the conditions tested caused vulnerability and the alternative is robust.)

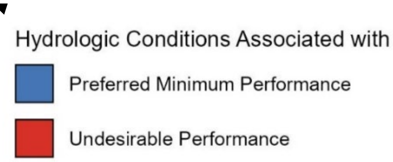
Figure 3-5
Sample Vulnerability Bar Plot for WY Minimum Combined Storage of Lake Powell and Lake Mead.
Conditions that could cause Combined Lake Powell and Lake Mead storage to fall below the historical minimum in more than 10 percent of years

1. The subtitle provides a definition of undesirable performance adapted from the purple preferred minimum performance row in the heatmap.

3. The vertical axis is based on the streamflow statistic that is a skillful predictor of the alternatives' ability to meet the preferred minimum performance. In this case, the driest 10-year average Lees Ferry annual flow was a good predictor. The range of the axis captures the full range of worst 10-year droughts tested.

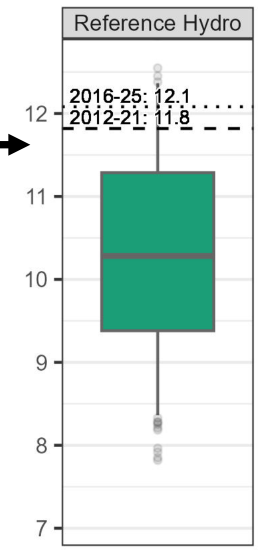
2. Each alternative and the CCS Comparative Baseline have a vertical bar divided into conditions associated with meeting the minimum preferred performance (blue region) and conditions that are associated with undesirable performance (red region).

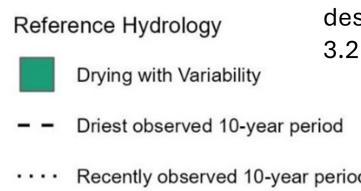




6. The vertical axis is the same on both panels, so the values in each panel can be compared across the figure.

4. The height of the red region (and the value of the white number) indicate the hydrologic conditions associated with causing undesirable performance; an alternative is likely to be vulnerable if these conditions occur in the future.





5. The Reference Hydro panel provides two types of context for the height of the red region for each alternative. First, there are two historical reference lines: the statistics for the most recent period and the statistics for the worst observation in the relevant statistic. The second type of context shows the distribution of this streamflow statistic represented in the Drying-with-Variability ensemble, which is a set of 100 hydrology traces whose significance is described in Section 3.2.6 and Appendix F.

7. The No Action Alternative is likely to be vulnerable to undesirable performance if the future includes a 10-year drought averaging 11.6 maf or less; conditions similar to these have already occurred in the observed record. The CCS Comparative Baseline is likely to be vulnerable if the future includes a 10-year drought averaging 11.4 maf or lower, which is close to conditions that have already occurred. About 90 percent of the hydrology sequences in the Drying-with-Variability ensemble have drier droughts than those likely to cause vulnerability under these two operations.

The "reference hydrology" panel introduced in **Figure 3-5** is included in every vulnerability bar plot to provide context for interpreting the likelihood of the conditions associated with vulnerability. The historical reference lines are the first component of the context, and anytime an alternative is vulnerable to conditions that have already been observed, it is reasonable to assume these conditions can occur again.

The second component of the context is the boxplot that shows projections about potential future conditions. These projections are based on the "Drying-with-Variability" ensemble, which is a 100-trace statistically generated ensemble that represents conditions that may occur in the future.[7] Long-term planning in the Basin must consider the significant potential for a future with more frequent, sustained, and/or severe dry periods and a downward trend in average flows, but this does not preclude the occurrence of wet years. The Drying-with-Variability ensemble was designed to capture this by combining information about the observed temperature trend, temperature's impact on the translation of precipitation into streamflow, and the sequencing of wet and dry periods from paleo reconstructed data while preserving the potential for infrequent but significant wet years.

For every vulnerability bar plot, the two sources of hydrologic context – observed hydrology and the Drying with Variability ensemble – are used to make a summary statement about whether the Representative Preferred Alternative is reasonably likely or unlikely to be vulnerable absent additional action. This statement combines objective analysis of conditions likely to cause failure and Reclamation's expert judgment considering how those conditions compare to the past and to a reasonable expectation of future hydrology given current trends.

Figure 3-6 provides the distribution of statistics across the 100 traces in the Drying-with-Variability ensemble and compares them to the worst statistic in the observed record (1906–2025). For the driest 1-year flow, over 50 percent of Drying-with-Variability traces have a drier year than the lowest observed flow, with the lowest single-year flow in the ensemble falling below 5 maf. In the 2-to-10-year windows, 60 percent of traces or more are drier than the worst observed statistic; for the driest 10-year volume, approximately 85 percent of traces contain drier decades than the worst observed decade, which occurred from 2012 to 2021.

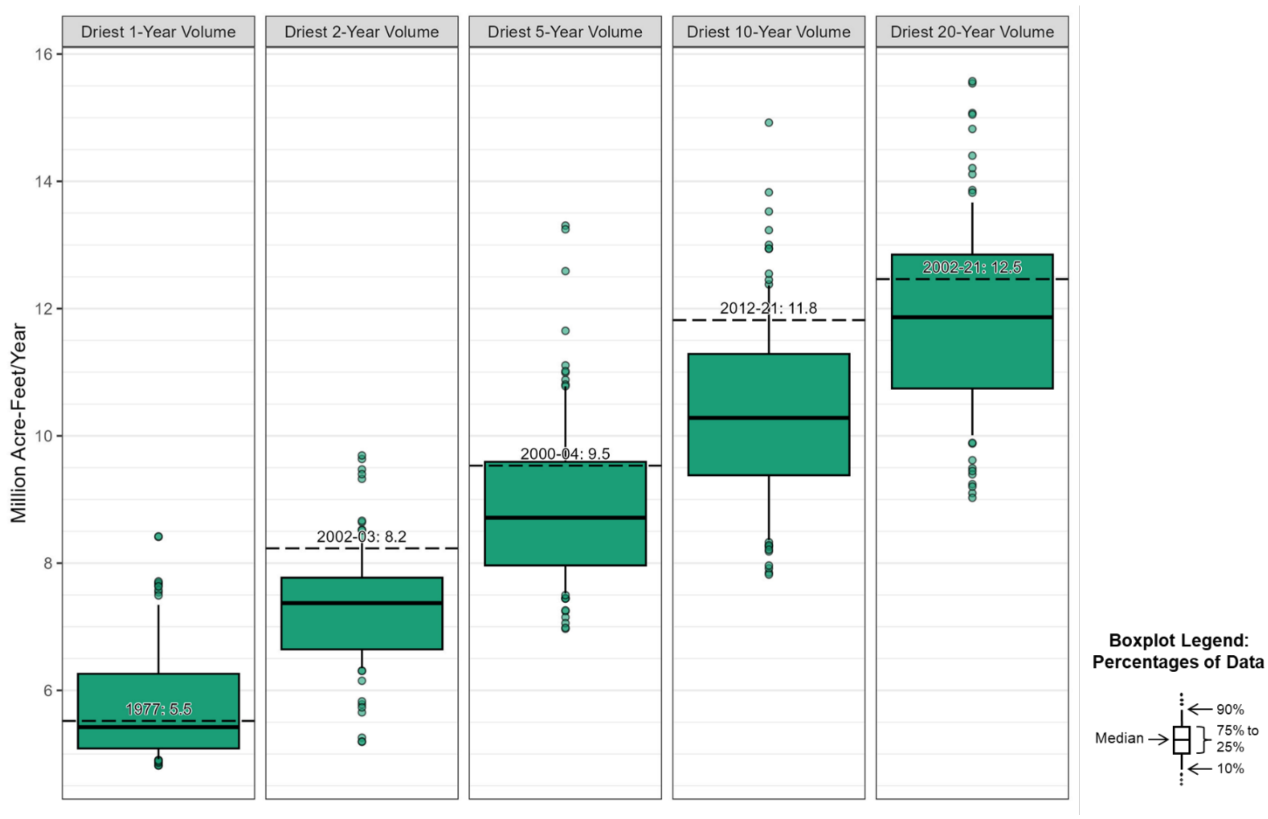
The purpose of describing the narrative, underlying data, and statistics of the Drying with Variability ensemble in the introduction to DMDU figures is to highlight that vulnerability bar plots provide a large amount of information that allows readers to use their judgment in determining the likelihood of negative resource impacts. The vulnerability bar plots combine information about the conditions in which each alternative is vulnerable, historical context, and the potential for a drier future.

3.2.7 Salton Sea

During scoping and public review of the Draft EIS, Reclamation received comments requesting analysis of impacts to the Salton Sea. The Salton Sea is a terminal lake in Riverside and Imperial Counties, California. Lake levels are influenced by runoff from the surrounding Imperial Valley and Coachella Valley watersheds, as well as agricultural drainage from the IID and CVWD. As explained below, analysis of impacts to the Salton Sea is not included in this EIS.

[7] For additional information about this ensemble, refer to **Appendix F**, Approach to Hydrologic Uncertainty.

Figure 3-6
Key Statistics for the Drying with Variability Ensemble



The Salton Sea acts as a terminal sump for agricultural drainage; therefore, reductions in agricultural runoff could impact Salton Sea elevations, which, in turn, could impact air quality and shoreline wildlife habitat. Agriculture in the IID and CVWD service areas, as well as smaller non-agricultural uses, are sustained by Colorado River water diverted at the Imperial Dam and delivered via the All American and Coachella Canals. In recent years, total diversions of Colorado River water were approximately 2.8 mafy at the Imperial Dam (California Natural Resources Agency 2024).

Over the past 20 years, inflows to the Salton Sea have declined from 1.3 mafy to approximately 1.1 mafy (California Natural Resources Agency 2024), primarily related to California's reduced usage of Colorado River water due to the prolonged drought in the Basin and changing agricultural practices, including implementation of water conservation programs.

The California Natural Resources Agency established the Salton Sea Management Program (SSMP) to oversee restoration efforts at the Salton Sea. Currently, the SSMP is working with local, state, tribal, and federal partners to implement the first phase of habitat restoration projects to establish at least 14,900 acres of aquatic habitat and up to 14,900 acres of vegetated habitat by the year 2028 (USACE 2024). Additionally, the SSMP released a long-range plan to address future recession of the Salton Sea beyond the year 2028 (California Natural Resources Agency 2024). The goal of the plan is to protect or improve air quality, water quality, and wildlife habitat to prevent or reduce health and environmental consequences anticipated from the long-term recession of the Salton Sea shoreline (California Natural Resources Agency 2024).

Given that inflows into the Salton Sea depend on a highly managed system, subject to growing water demands, and uncertain weather patterns and water polices, the SSMP used a range of projected annual net inflows to the Salton Sea as baselines for analysis: (1) high probability of inflow at 889,000 af, (2) low probability inflow at 684,000 af, and (3) very low probability at 444,000 af. These flows are used to project the future baseline of the Salton Sea and the restoration needs. The SSMP's long-range plan specifically acknowledges the uncertainty around policy decisions on this Colorado River Post-2026 process and is a reason for using a range of net inflows.

The SSMP's long-range plan is informing the scope of the Imperial Streams and Salton Sea Ecosystem Restoration Feasibility Study and NEPA compliance that the USACE is currently preparing. Once that process is complete, state and federal funding will be pursued to support the resultant design and construction of restoration projects, beginning around 2028.

For this Post-2026 process, Reclamation's action is to develop operational guidelines for the storage and release of water through Lake Powell at Glen Canyon Dam and Lake Mead at Hoover Dam. Reclamation's contracts with IID and CVWD do not provide Reclamation with the discretion to determine how individual water users within these districts use or allocate their water resources, including user decisions to participate or not participate in conservation programs.

Any reductions of Colorado River water available for diversion at the Imperial Dam for use by IID and CVWD could result in less available water for agriculture and, depending on the conservation activity or how the reduction would be implemented, subsequent drainage to the Salton Sea. While Reclamation cannot control Basin hydrology, there could be policy decisions that result in shortages.

In summary, analysis of impacts to the Salton Sea are not included in this EIS for the following reasons:

1. Any resultant impacts are within the scope and range of inflows being considered as part of the baseline in the SSMP's long-range plan and the USACE's ongoing NEPA process. While any resultant impacts to the Salton Sea may be accelerated by Post-2026 policies, the overall magnitude of impacts would not change.
2. Reclamation does not manage or control the end use of water after the point of delivery. As such, Reclamation has no management authority over the distribution of end use or allocation by these water districts and individual users, including user decisions to participate in conservation programs. The State of California oversees management of the Salton Sea, and Reclamation has no management or enforcement authority over inputs to the Sea. Reclamation would need new authorities and compliance to implement any policies that change how water shortages are distributed to IID and CVWD.[8]

[8] Reclamation's potential contribution of funds through contribution agreements does not affect the enforcement mechanisms of those state and local authorities.

3.3 Hydrologic Resources

3.3.1 Affected Environment

Overview and Study Area

This section summarizes the Basin's hydrology from the full pool elevation of Lake Powell to the SIB with Mexico. It also includes groundwater under direct influence of the Colorado River and the Lower Basin reservoirs. For a more detailed account of the affected environment for the hydrologic resources, please see **TA 3**, Hydrologic Resources.

Key Drivers and Trends

Worsening drought conditions have been a major driver for changes to hydrologic resources in the Basin. Since 2000, the Basin has experienced persistent drought conditions, exacerbated by higher temperatures, resulting in increased evapotranspiration, reduced soil moisture, and ultimately reduced runoff (Lukas and Payton 2020). The flow in the Colorado River is highly variable from year to year because of variations in precipitation in the Basin. However, the Basin is currently experiencing a prolonged period of drought; 2000 to 2024 was the driest 25-year period in more than a century. A paleo reconstruction of Colorado River streamflow at Lee Ferry, Arizona, back to 762 current era (CE), indicates that the recent 25-year period has lower streamflow than any other period in the last 1,200 years (Meko et al. 2007). These conditions have led to a cumulative streamflow deficit of about 70.0 maf relative to twentieth-century conditions (Reclamation 2025b).

Operational Impacts

The overall characteristics and connectivity of the Basin remain unchanged from when the 2007 Final EIS was issued. However, since 2007, key operational changes have affected hydrologic resources. Domestic agreements specifying such operations include the 2007 Interim Guidelines (supplemented in 2024), the 2016 Glen Canyon Dam LTEMP (supplemented in 2024), and the 2019 DCP. More details on operational changes since 2007 can be found in **Section 1.8.2.1**, The Law of the River.

Reservoirs and River Reaches Overview

Upper Basin – CRSP Upper Initial Units

The 1956 CRSPA created four major Upper Basin reservoirs to support Colorado River Compact compliance: Flaming Gorge in Utah, Navajo in New Mexico, Blue Mesa in Colorado, and Lake Powell in Utah and Arizona. The CRSP Upper Initial Unit reservoirs include Flaming Gorge, Navajo, and Blue Mesa. Total live storage volume of the CRSP Upper Initial Units is 6.15 maf. Prolonged drought and low runoff conditions prompted the 2019 DROA (a component of the 2019 DCP) to allow strategic releases from the CRSP Upper Initial Units reservoirs to protect elevations at Lake Powell. As described in **Section 3.2.1**, operations at the CRSP Upper Initial Units specifically contemplated in the Final EIS alternatives are intended to remain within the scope of the existing RODs. Accordingly, the Final EIS does not expand the geographic scope of analysis upstream of Lake Powell.

Lake Powell and Glen Canyon Dam

Lake Powell is a reservoir located in southern Utah and northern Arizona. The water surface operating range of Lake Powell is between 3,490 feet (corresponding to the minimum power pool) and 3,700 feet (corresponding to the top of Glen Canyon Dam spillway). The total live storage capacity of Lake

Powell at the full pool elevation of 3,700 feet is 23.31 maf (excluding 1.9 maf of flood control space). Due to persistent drought, storage levels in Lake Powell have declined, particularly in the early 2000s and from 2020 to 2022, when elevations were at an all-time low since filling. Should elevations drop below 3,490 feet, routine operations of Glen Canyon Dam would be discontinued, and hydropower could no longer be produced. Releases can be made through the river outlet works down to elevation 3,370 feet (corresponding to dead pool) below which water cannot be delivered downstream. However, the outlet works are not designed nor intended for long-term use at low reservoir levels. The infrastructure at Glen Canyon Dam is described further in **Section TA 3.1.3**, Lake Powell and Glen Canyon Dam.

Unregulated inflows to Lake Powell from the Upper Basin vary year to year based on hydrologic conditions. A period of drought that began in 2000, exacerbated by increasing temperatures, has led to a 20 percent decrease in average annual Upper Basin (at Lees Ferry) natural flows (Reclamation 2025a). This continued dry period and decrease in inflows in recent years have resulted in Lake Powell approaching critically low elevations. Drought conditions from 2020 to 2022 triggered the need to supplement the 2007 Interim Guidelines with near-term provisions for addressing extremely low reservoir levels. The result was the 2024 ROD, providing for lower releases from Lake Powell. Since the implementation of the 2007 Interim Guidelines, the water surface operating range of Lake Powell has been between a low of 3,519.92 feet (occurring in 2023), and a high of 3,660.9 feet (occurring in 2011). Historical low and high elevations in Lake Powell are shown in **Figure TA 3-1** in **TA 3**, Hydrologic Resources. Annual Glen Canyon Dam releases from Lake Powell averaged 9.75 maf from 1996 through 2007, but have since averaged 8.62 maf (ranging from 7.00 maf to 12.52 maf from 2008 through 2025).

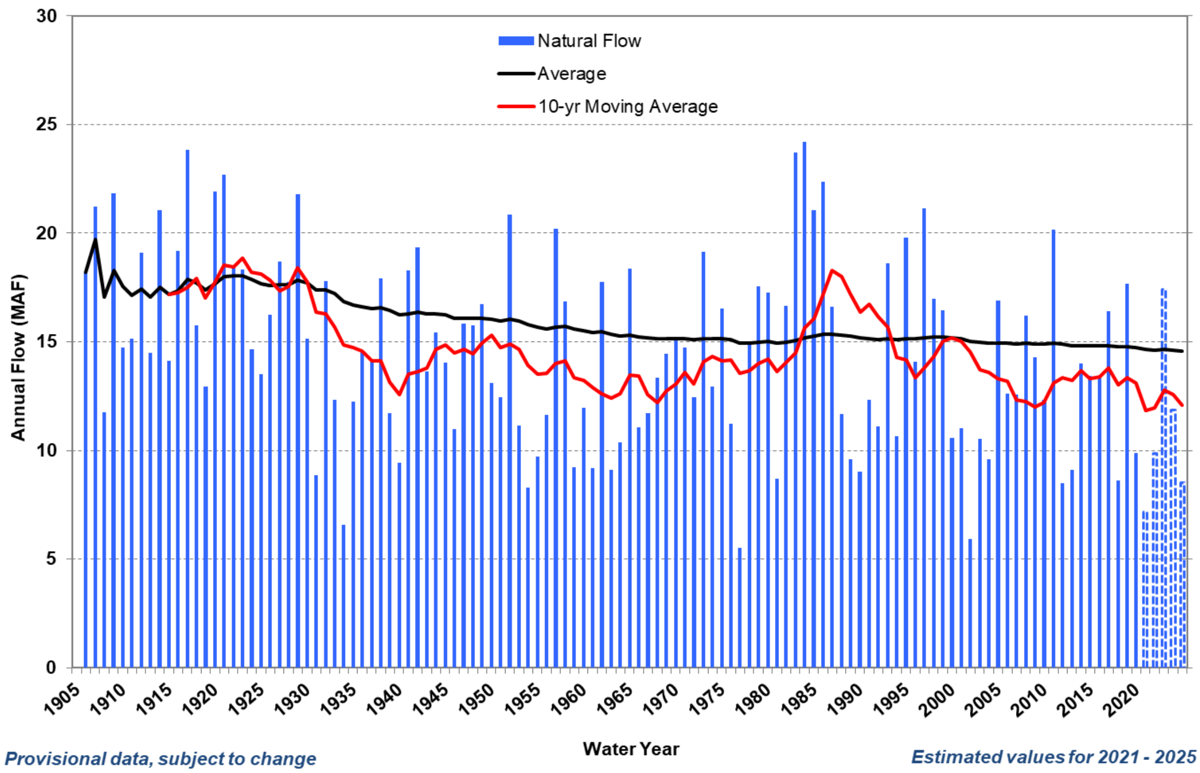
Lees Ferry Gaging Station and Lee Ferry Compact Point

The Lees Ferry Gaging Station is located in Arizona, approximately 15.9 river miles (RMs) downstream of Glen Canyon Dam. This differs from the Lee Ferry Compact Point, which is the division point between the Upper Basin and Lower Basin as established by the 1922 Colorado River Compact. The Lee Ferry Compact Point is located a few miles downstream of the Lees Ferry Gaging Station and the confluences with the Paria River. **Figure TA 3-2** in **TA 3**, Hydrologic Resources shows the difference between the two locations.

From 1906 to 2007, the average annual natural flow at the Lees Ferry Gaging Station was calculated to be 14.9 maf and ranged from 5.4 maf to 24.4 maf. Since the implementation of the 2007 ROD (2008 to 2025), the annual natural flow at the Lees Ferry Gaging Station averaged 12.7 maf and has ranged from a low of 6.7 maf (2021) to 20.3 maf (2011). **Figure 3-7** below shows the WY natural flows calculated at the Lees Ferry Gaging Station for 1906 through 2025.

Natural flows at Lees Ferry Gaging Station are calculated based on observed (gage) flow and corrected by Reclamation for upstream reservoir changes in storage and release, losses including evaporation, and depletions due to agriculture and domestic uses.

Figure 3-7
Colorado River Natural Flow at Lees Ferry Gaging Station, Arizona (1906-2025)



Source: Reclamation 2025f

Lake Mead, Lake Mohave, Lake Havasu, Cibola Gage, Imperial Dam, Northerly and Southerly International Boundaries

Approximately 292 miles downstream of Glen Canyon Dam is Lake Mead, formed by Hoover Dam. This reach of the Colorado River includes the Grand Canyon, which is approximately 277 miles long. Flows in this reach primarily consist of flow from Glen Canyon Dam releases but do include minor contributions from perennial tributaries. The two largest tributaries in this reach are the Paria River and the Little Colorado River, which make up approximately 3 percent of the total flows in the Colorado River in this reach (USGS 2025a).

Lake Mead is located in the Black Canyon, on both sides of the Arizona-Nevada state line near Las Vegas. The water surface elevation operating range for Lake Mead is between 895 feet (corresponding to dead pool) and 1,229 feet (corresponding to the top of the Hoover Dam spillway). The total live storage capacity of Lake Mead at the full pool elevation of 1,219.6 feet is 26.12 maf (excluding approximately 1.5 maf of flood control space). Lake Mead has a minimum power pool elevation of 950 feet, below which releases occur only through the river outlet works and hydropower cannot be generated. When elevations drop below 895 feet, water is no longer able to be delivered downstream from Hoover Dam.

Since 2007, water surface elevations at Lake Mead have generally declined. Since the implementation of the 2007 ROD, the water surface operating range of Lake Mead has been between a low of 1,040.6

feet (occurring in 2022) and a high of 1,134.5 feet (occurring in 2012). Historical low and high elevations in Lake Mead are shown in **Figure TA 3-5** in **TA 3**, Hydrologic Resources. Annual Hoover Dam releases from Lake Mead ranged from 8.275 maf to 12.781 maf (averaging 10.199 maf) from 1996 through 2007, but have since ranged from 8.515 maf to 9.615 maf (averaging 9.185 maf) from 2008 through 2024.

The 67-mile reach from Hoover Dam to Davis Dam forms Lake Mohave. Lake Mohave is located on both sides of the Arizona-Nevada state line near Bullhead City, Arizona. Flows in this reach are almost entirely comprised of releases from Hoover Dam. The average storage in Lake Mohave has remained constant, at approximately 1.6 maf over the past few decades. Lake Mohave is operated under an existing rule curve that determines specific target elevations at the end of each month. This rule curve was not affected by the 2007 Interim Guidelines, so the average annual water surface elevation at Lake Mohave was approximately 640.8 feet from 1996 to 2007 and 640.9 feet since 2008.

The 84-mile reach from Davis Dam to Parker Dam forms Lake Havasu, which is located on both sides of the California-Arizona state line near Lake Havasu City, Arizona. Flows in this reach primarily consist of releases from Davis Dam, although contributions from the Bill Williams River make up approximately 1 percent of the total flows (USGS 2025b). Lake Havasu provides a forebay and desilting basin that pumps water for delivery to the MWD and CAP service areas. Similar to Lake Mohave, Lake Havasu is operated under an existing rule curve that determines specific target elevations at the end of each month. This rule curve was not changed by the 2007 Interim Guidelines and maintains Lake Havasu's water surface elevation between 445 and 450 feet. While the 2007 Interim Guidelines did not explicitly target Parker Dam operations, decreased inflows to Lake Havasu (as a result of decreased releases from upstream Lake Powell and Lake Mead) have resulted in decreased annual release rates. Since the implementation of the 2007 Interim Guidelines, the average annual releases from Parker Dam have decreased by 1.0 maf.

One hundred five miles downstream of Parker Dam is Reclamation's Cibola Gage. Flows in this reach primarily consist of releases from Parker Dam. Decreased releases from Parker Dam in the last 20 years have resulted in decreased flows in this 105-mile reach. Two major diversion dams are located in this reach: Headgate Rock Dam and Palo Verde Diversion Dam. The impoundments of these dams facilitate the diversion of water for the Colorado River Indian Tribes and the Palo Verde Irrigation District. Current operations keep these reservoirs at constant elevations. Thirty-eight miles downstream from the Cibola Gage is Imperial Reservoir, formed by Imperial Dam. Flows in this reach primarily consist of releases from Parker Dam. Imperial Dam was constructed to raise the water surface elevation enough to provide gravity-controlled flow to meet water deliveries to California via the AAC and to Arizona via the Gila Main Canal. The AAC diverts water for the IID, the CVWD, the Yuma Project, and the City of Yuma. The Gila Gravity Main Canal diverts water for Gila Valley, Yuma Mesa, and the Wellton-Mohawk area. Imperial Dam also regulates deliveries to Mexico.

Five miles downstream of Imperial Dam is Laguna Dam. Originally, Laguna Dam diverted water to the Yuma Project area but then the Imperial Dam was built. The Laguna Dam is now used as a regulating structure for sluicing flows from Imperial Dam and also provides downstream toe protection for Imperial Dam. Flows in this reach primarily consist of releases from Imperial Dam and contributions from the Gila River. Twenty-six miles downstream of Imperial Dam is the NIB between the U.S. and Mexico.

The Morelos Diversion Dam is 1.1 miles downstream of the NIB and impounds the majority of the water supply that is diverted by Mexico into the Reforma Canal. The dam is owned, operated, and maintained by Mexico per the 1944 Water Treaty. To ensure the annual 1.5 maf water delivery under Normal Conditions per the 1944 Water Treaty, the Morelos Diversion Dam operations have not changed as a result of the 2007 ROD. Refer to **Appendix N**, International Border Region of the Colorado River, for more details related to previous binational coordination efforts. Since most of the water is diverted at Morelos Diversion Dam into the Reforma Canal, flows in the Colorado River limitrophe downstream of Morelos Diversion Dam are infrequent. Flows downstream of Morelos Diversion Dam in the limitrophe to the SIB only occur due to Flood Control operations at Hoover Dam, seepage from Morelos Diversion Dam, irrigation return flows, groundwater inflow, and any water released for environmental purposes in the Colorado River Delta. The upper portion of the limitrophe is a gaining reach due to high groundwater levels in adjacent irrigated fields; however, in the southern portions of the limitrophe, groundwater elevations decrease, and it becomes a losing reach.

3.3.2 Environmental Consequences

Methodology

CRSS was used to simulate Basin conditions and account for hydrologic uncertainty through the full analysis period (2060) on a monthly time-step. Reservoir elevations, reservoir releases, and river flows are outputs to the model and are used directly for the results presented in this resource section. To help visualize the different states of modeled futures, results from CRSS are framed using five potential flow condition categories that range from wet hydrologic conditions to critically dry hydrologic conditions. For background and guidance related to figures used in the analysis below (conditional boxplots, robustness heatmaps, and vulnerability bar plots), see **Section 3.2**, Analysis Methods.

Impact Analysis Area

The geographic scope of the hydrologic resources analysis is the Colorado River corridor from the upstream limits of full pool elevation of Lake Powell to the downstream limits of the SIB. Reservoirs upstream of Lake Powell are operated pursuant to their own RODs, which are not altered by the proposed alternatives.

Assumptions

The hydrologic resources results are direct outputs from CRSS. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation. All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell and/or Lake Mead (refer to **Appendix S**, Additional Description of Alternatives). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

Impact Indicators

Five impact indicators were used to assess impacts on hydrologic resources due to operational activities: reservoir elevations, system storage, reservoir releases, river flows, and qualitative (descriptive, non-modeled) impacts on groundwater adjacent to reservoirs and river reaches.

Issue 1: Reservoir Elevation

Water surface elevations at Lake Powell and Lake Mead are anticipated to be affected by the various alternatives as a result of changes to operational activities. Water surface elevations at Lake Mohave and Lake Havasu are not anticipated to be affected. The impacts on water surface elevations at each reservoir are summarized below. Refer to **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources, for details regarding impacts on water surface elevations at Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu.

Under the Average Flow Category, all action alternatives generally maintain reservoir elevations above critical thresholds, but performance diverges significantly as conditions become drier.

Lake Powell Reservoir Elevations

Refer to **Table TA 3-2** in **TA 3** for a list of critical elevations at Lake Powell. A statistical breakdown of CRSS modeling results for end of water year (EOWY) elevations and minimum WY elevations at Lake Powell can be found in **Table TA 3-3** and **Table TA 3-4** in **TA 3**, respectively.

Figure 3-8 below looks at the response of Lake Powell WY minimum elevations and storage volumes, and EOWY elevations and storage volumes, to different hydrologic conditions under different alternatives by looking at the preceding 3-year average of Lees Ferry natural flow. The figure visualizes the same data that is included in **Table TA 3-3** and **Table TA 3-4** in two side by side conditional box plot panels.

At Lake Powell, the critical elevations of 3,500 feet and 3,525 feet, shown as dashed lines, frame the analysis. These elevations are important because they provide a 10-foot and a 35-foot buffer above 3,490 feet—the elevation below which water can only be released through the river outlet works. Operating below 3,490 feet limits the volume of water that can be released, since water can only pass through the river outlet works. As described in **Section 1.8.4.1**, there are infrastructure concerns associated with the uncertainty of extended operations through the river outlet works as the sole means of sustained water releases from Glen Canyon Dam that could compromise the reliability and operational flexibility of Glen Canyon Dam and affect the ability to meet critical downstream water supply needs. There are additional impacts to hydropower associated with operating below 3,490 feet as this is minimum power pool.

Under the Average Flow Category, all alternatives keep median EOWY elevations well above these thresholds. As conditions dry, the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best, maintaining median EOWY elevations of 3,557 and 3,546 feet respectively even under the Critically Dry Flow Category, while the No Action Alternative (3,478 feet) and Basic Coordination Alternative (3,487 feet) drop below the 3,500-foot threshold.

Figure 3-8
WY Minimum and EOWY Elevations and Storage Volumes of Lake Powell

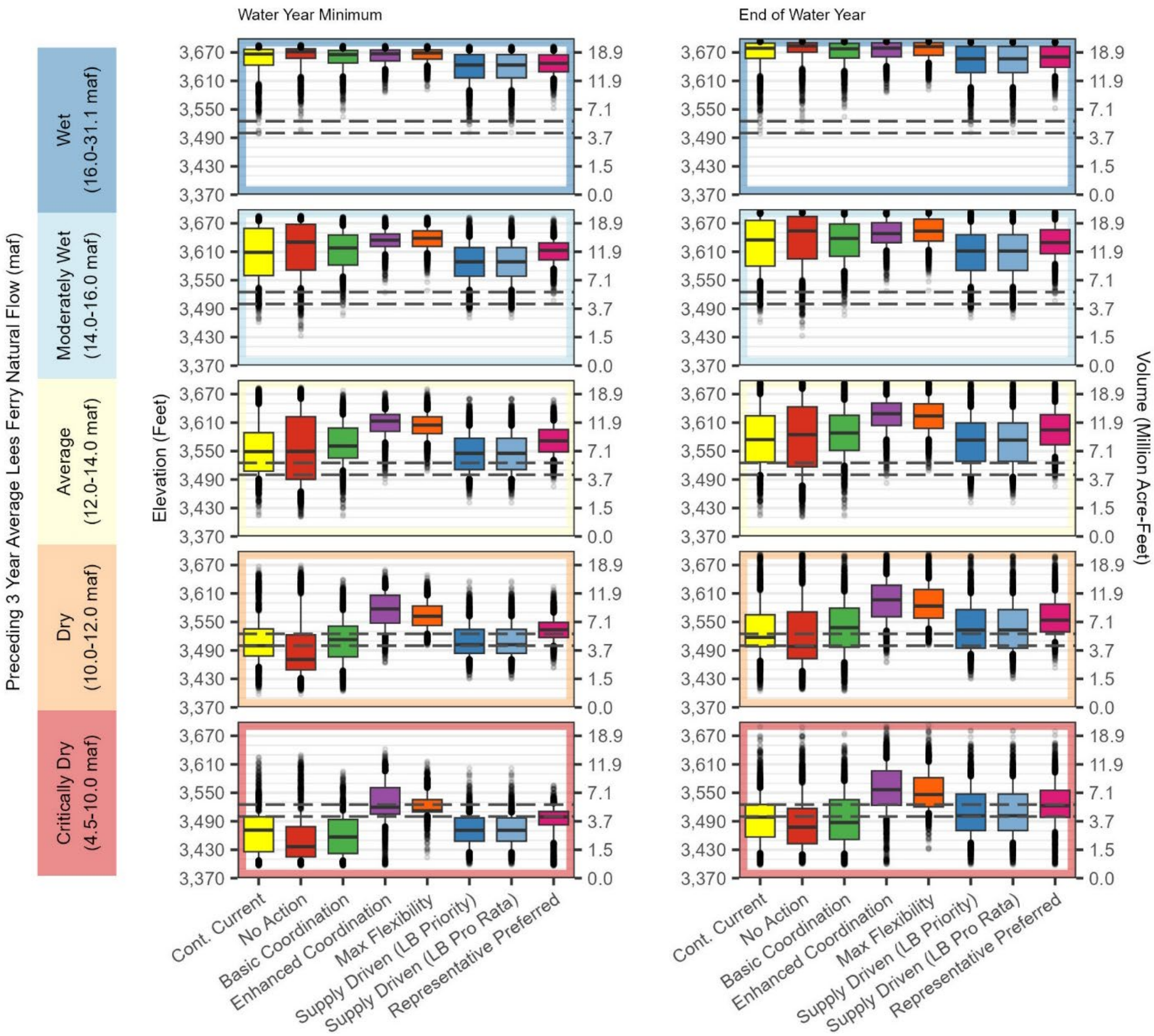
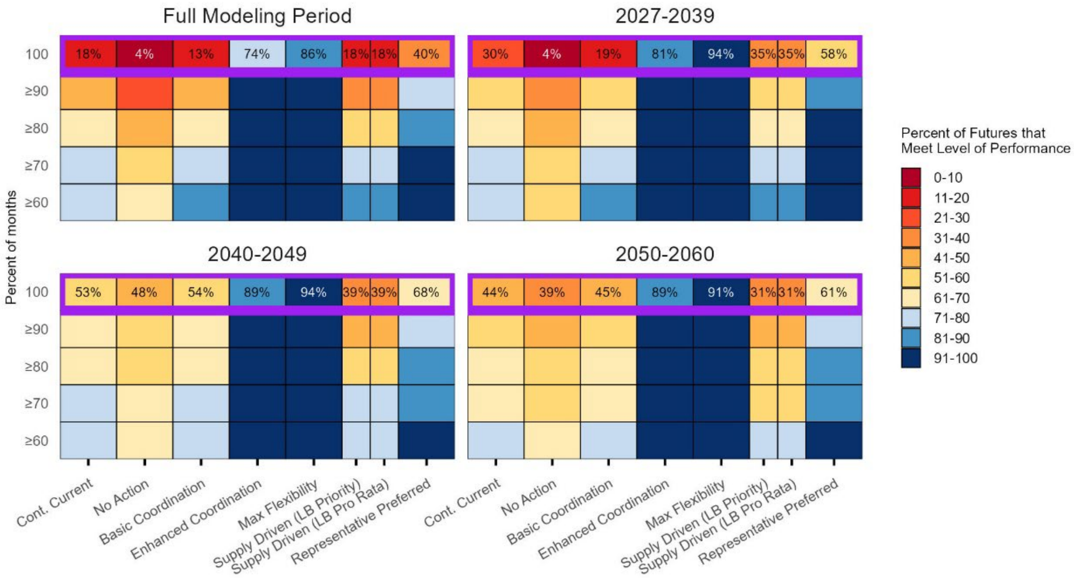


Figure 3-9 compares alternatives with respect to keeping Lake Powell above an elevation of 3,500 feet. As described above, this elevation is important because it provides a 10-foot buffer to protect critical infrastructure, water supply, and hydropower, which are critically impacted at an elevation of 3,490 feet. Over the full 34-year modeling period, the Maximum Operational Flexibility Alternative keeps Lake Powell above 3,500 feet in 100 percent of months in 86 percent of futures, and the Enhanced Coordination Alternative does so in 74 percent of futures. The Representative Preferred Alternative achieves this in 40 percent of futures overall and 58 percent in the critical first decade (2027–2039), ranking third among alternatives. The No Action Alternative is least robust at just 4 percent of futures.

Figure 3-9
Lake Powell 3,500 Feet: Robustness.
Percent of futures in which Lake Powell elevation stays above 3,500 feet in the percent of months specified by each row



Lake Mead Reservoir Elevations

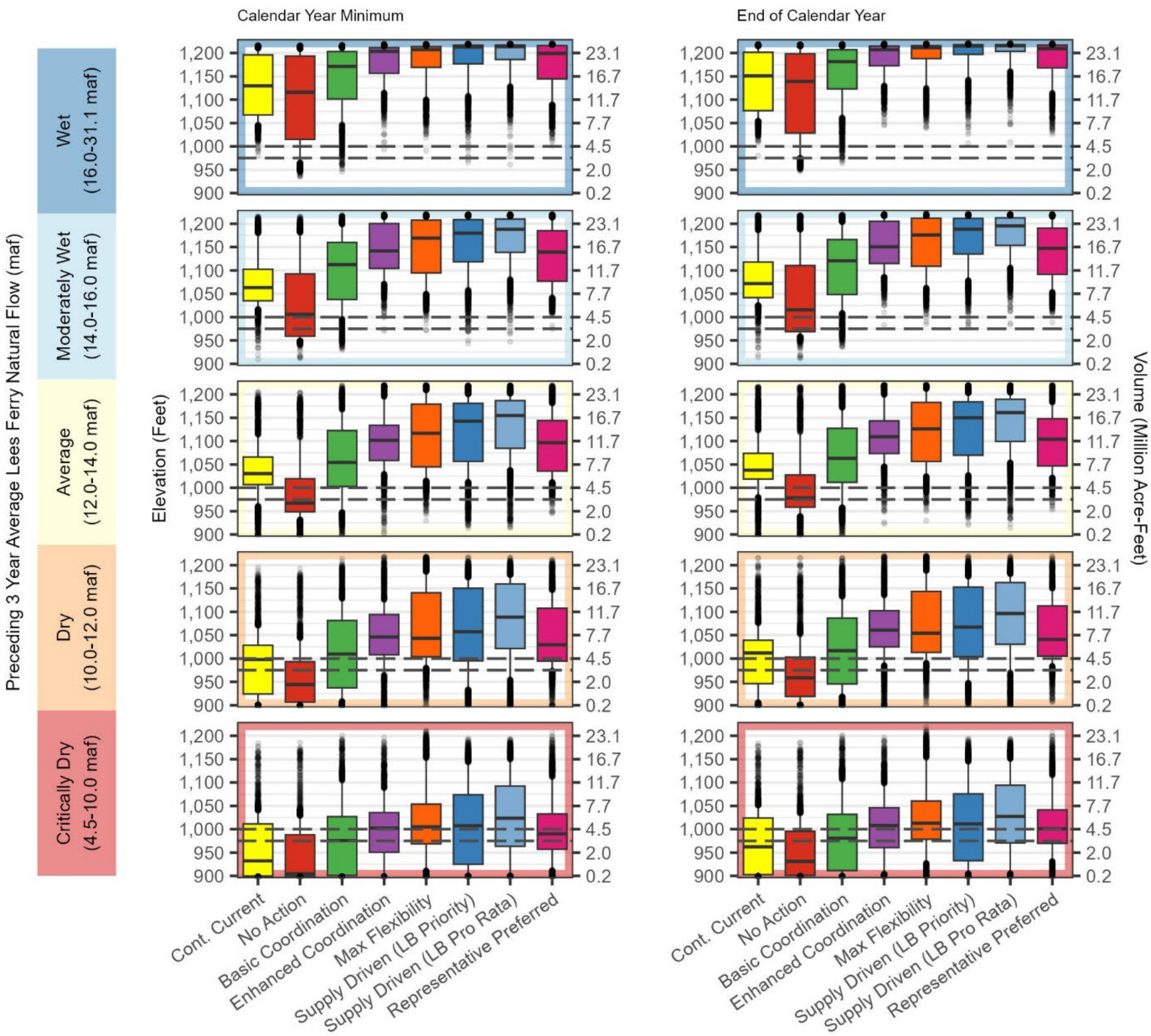
Refer to **Table TA 3-5** in **TA 3**, Hydrologic Resources, for a list of critical elevations at Lake Mead. A statistical breakdown of CRSS modeling results for end of calendar year (EOCY) elevations and minimum CY elevations at Lake Mead can be found in **Table TA 3-6** and **Table TA 3-7** in **TA 3**, Hydrologic Resources, respectively.

Figure 3-10 below looks at the response of Lake Mead CY minimum elevations, and EOCY elevations and storage volumes to different hydrologic conditions under different alternatives by looking at the preceding three-year average of Lees Ferry natural flow. The figure visualizes the same data that is included in **Table TA 3-6** and **Table TA 3-7** in two side by side conditional box plot panels. In each flow category shown in the box plots, the key elevations of 1,000 feet and 975 feet are identified with dashed lines. These elevations are important because they provide a 50-foot and a 25-foot buffer from 950 feet—the elevation below which water can only be released through the intake towers, constraining both the volume of water able to be released as well as the ability to generate power. Lake Mead requires larger buffers above the hydropower and critical infrastructure elevations than Lake Powell because Reclamation is required to deliver water orders that have already been approved. As a result, there is generally less flexibility to adjust releases from Hoover Dam than from Glen Canyon Dam.

Under the Average Flow Category, the No Action Alternative already performs poorly, with a median EOCY elevation of just 978 feet, which is between the two critical thresholds, while all action alternatives maintain medians above 1,000 feet. Under the Critically Dry Flow Category, the No Action Alternative and CCS Comparative Baseline fall to medians of 931 and 962 feet respectively, well below both thresholds, while the Enhanced Coordination, Maximum Operational Flexibility, and Supply

Driven (both LB Priority and LB Pro Rata approaches) Alternatives maintain medians above 1,000 feet. The Representative Preferred Alternative achieves a median EOCY elevation of 1,041 feet under the Dry Flow Category and 1,001 feet under the Critically Dry Flow Category, remaining above 975 feet in close to 75 percent of Critically Dry Flow Category years.

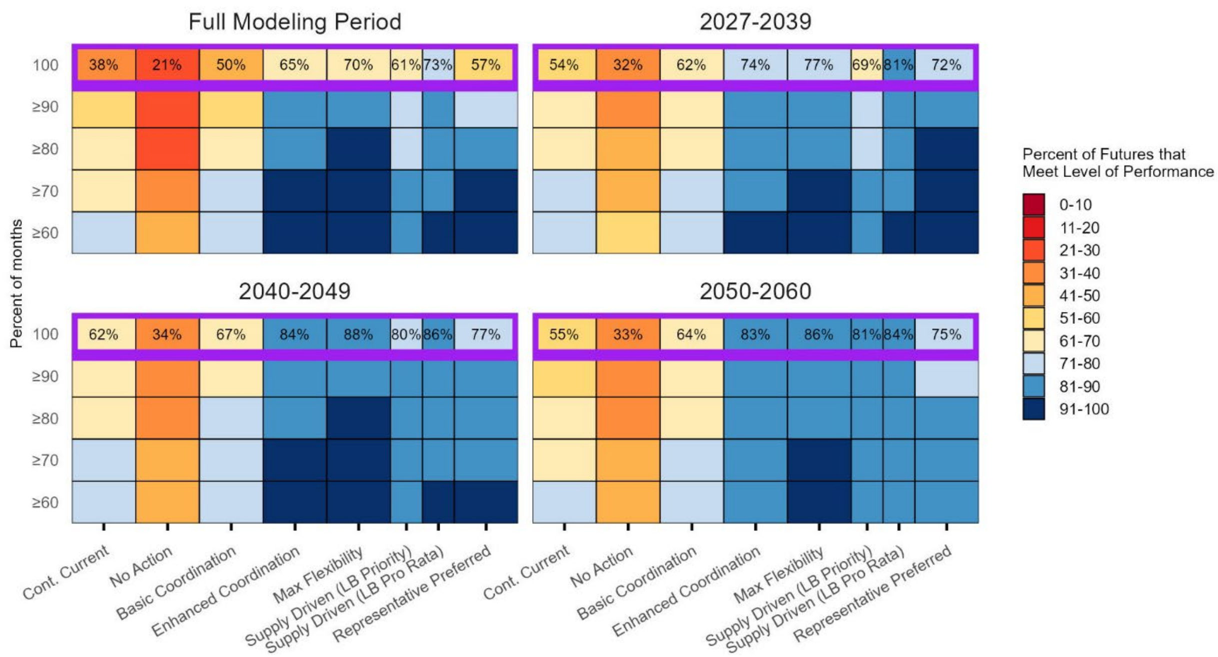
Figure 3-10
CY Minimum and EOCY Elevations and Storage Volumes of Lake Mead



The CY minimum elevations panel follows the same pattern as the EOCY elevations panel, but some median elevations are slightly lower.

Figure 3-11 compares alternatives with respect to keeping Lake Mead above elevation 975 feet in 100 percent of months. This critical threshold is important because it provides a 25-foot buffer to protect critical infrastructure and hydropower, which can no longer be produced at elevation 950 feet.

Figure 3-11
Lake Mead 975 Feet: Robustness.
Percent of futures in which Lake Mead elevation stays above 975 feet in the percent of months specified by each row



For the 975-foot robustness metric over the Full Modeling Period, the Maximum Operational Flexibility and Supply Driven (LB Pro Rata approach) Alternatives lead, meeting the preferred minimum performance in 70 percent and 73 percent of futures respectively, the Representative Preferred Alternative achieves the preferred minimum performance in 57 percent of futures over the Full Modeling Period (72 percent in the first decade), and the No Action Alternative performs worst meeting the preferred minimum performance in only 21 percent of futures.

Lake Mohave and Lake Havasu Elevations

Lake Mohave and Lake Havasu are operated under existing rule curves that determine specific target elevations at the end of each month. The existing rule curves were used in CRSS and applied to operations for all alternatives and the CCS Comparative Baseline. As such, water surface elevations at Lake Mohave and Lake Havasu are not affected.

Conservation Activity

Conservation activity modestly improves reservoir elevations for most action alternatives. For the Representative Preferred Alternative, enabling conservation raises median Lake Powell EOWY elevations by approximately 1.2 feet under the Dry Flow Category and 0.8 feet under the Critically Dry Flow Category. The effect is more pronounced at Lake Mead, where conservation raises the median EOCY elevation by 11.8 feet under the Dry Flow Category and 5.6 feet under the Critically Dry Flow Category.

Issue 2: System Storage

System storage is anticipated to be affected by the various alternatives as the result of changes to operational activities. The impacts on various combinations of system storage are summarized below. Refer to **Section TA 3.2.2**, Issue 2: System Storage, in **TA 3**, Hydrologic Resources, for details regarding impacts.

Combined system storage is evaluated across three reservoir groupings, each providing a different perspective on overall system conditions. Across all three groupings, storage declines with drying hydrology and the ranking of alternatives is generally consistent, with the Maximum Operational Flexibility and Enhanced Coordination Alternatives consistently producing the highest combined storage and the No Action Alternative producing the lowest.

Combined System Storage at Lake Powell and Lake Mead

Analysis of the combined storage across Lake Powell and Lake Mead helps to understand the overall condition of the Colorado River system. Based on this analysis, the primary drivers of Colorado River system conditions are related to assumptions for shortage operations and conservation activities. Refer to **Table TA 3-11** in **TA 3**, Hydrologic Resources, for a statistical breakdown of CRSS modeling results for EOWY combined system storage at Lake Powell and Lake Mead as a percentage of the total storage capacity. Refer to **Figure TA 3-18** in **TA 3** for the box plot representation of the combined system storage of Lake Powell and Lake Mead.

The combined live storage capacity of Lake Powell and Lake Mead is 49.43 maf. Under the Average Flow Category, the Maximum Operational Flexibility and Enhanced Coordination Alternatives maintain median combined storage above 50 percent of total capacity, while the No Action Alternative has the lowest median storage (27 percent) with nearly half of modeled years falling below the September 2022 historic low of 26.55 percent full.

Under the Critically Dry Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives have median combined storages near the lowest observed EOWY storage reference of 26.55 percent, while under the CCS Comparative Baseline and No Action and Basic Coordination Alternatives, more than 75 percent of modeled years are below the 2022 historic low.

The Representative Preferred Alternative ranks fifth among alternatives, maintaining a median combined storage of 32 percent under the Dry Flow Category and 21 percent under the Critically Dry Flow Category, with roughly 75 percent of years in the Critically Dry Flow Category falling below the 2022 historic low.

Combined System Storage at CRSP Reservoirs

Analysis of the combined storage across CRSP reservoirs helps to understand the overall status of Lake Powell and the CRSP Upper Initial Units (Flaming Gorge, Navajo, and Blue Mesa reservoirs). Lake Powell makes up approximately 80 percent of the total CRSP storage capacity, so trends in combined storage capacity are primarily controlled by Lake Powell operations. The CRSP Upper Initial Unit reservoirs can be operated (within their RODs) so that releases help bolster elevations in Lake Powell and protect Glen Canyon Dam infrastructure. Refer to **Table TA 3-12** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY combined system storage at CRSP reservoirs as a percentage of the total storage capacity. Refer to **Figure TA 3-19** in **TA 3** for the box plot representation of the combined system storage at CRSP reservoirs.

Because the Upper Initial Unit reservoirs vary minimally across alternatives, CRSP median combined storage trends closely mirror Lake Powell elevation performance described in **Issue 1**. Under the Average Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives lead with median combined storage of 63 and 62 percent of capacity respectively, while other alternatives cluster near 50 percent. Under the Critically Dry Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain the highest median combined storage at 41 and 38 percent respectively, while remaining alternatives fall to 21-26 percent.

The Representative Preferred Alternative ranks third overall with a median combined storage of 37 percent under the Dry Flow Category and 27 percent under the Critically Dry Flow Category.

Combined System Storage at Seven Reservoirs

Analysis of the seven-reservoir system storage (CRSP Upper Initial Units of Flaming Gorge, Navajo, and Blue Mesa Reservoirs, as well as Lake Powell, Lake Mead, Lake Mohave, and Lake Havasu) volumes over time can be used to better understand overall system conditions. Refer to **Table TA 3-13** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY combined system storage of the seven reservoirs as a percentage of the total storage capacity. Refer to **Figure TA 3-20** in **TA-3** for the box plot representation of the combined system storage of the seven reservoirs.

Under the Average Flow Category, the Maximum Operational Flexibility Alternative has the highest median combined storage (60 percent), followed by the Enhanced Coordination Alternative at 59 percent, while the No Action Alternative (35 percent) and the CCS Comparative Baseline (38 percent) have the lowest median combined storages.

The Representative Preferred Alternative achieves median combined storage of 37 percent under the Dry Flow Category and 27 percent under the Critically Dry Flow Category, ranking fifth among all alternatives which is consistent with its ranking in the Powell-Mead and CRSP groupings.

Issue 3: Reservoir Releases

Releases from reservoirs are anticipated to be affected by the various alternatives as the result of changes to operational activities. The impacts on reservoir releases are summarized below. Refer to **Section TA 3.2.3**, Issue 3: Reservoir Releases, **TA 3**, Hydrologic Resources, for details regarding impacts on reservoir releases.

Glen Canyon Dam (Lake Powell) Releases

Generally, alternatives that prioritize higher elevations in Lake Powell result in lower median annual releases from Glen Canyon Dam. This trend demonstrates the tradeoffs between maintaining reservoir elevations to protect critical infrastructure and annual releases from reservoirs. Refer to **Table TA 3-14** in **TA 3** for a statistical breakdown of CRSS modeling results for EOWY releases from Glen Canyon Dam. Refer to **Figure TA 3-21** in **TA 3** for the box plot representation of the EOWY releases from Glen Canyon Dam. In addition to annual releases, 10-year releases from Glen Canyon Dam are also considered. Refer to **Table TA 3-15** and **Figure TA 3-22** in **TA 3** for modeled results for the 10-year Glen Canyon Dam releases.

Under the Average Flow Category, median annual releases cluster near 8.23 maf for most alternatives. Under the Critically Dry Flow Category, releases diverge significantly: the No Action Alternative and

CCS Baseline release the most (6.36 and 6.41 maf respectively) partly due to infrastructure-constrained variability below 3,490 feet, while the Enhanced Coordination Alternative releases the least (5.11 maf).

The Representative Preferred Alternative has a median annual release of 7.20 maf under the Dry Flow Category and 6.0 maf under the Critically Dry Flow Category and has the least variability in Glen Canyon Dam releases under Critically Dry conditions.

At the Lee Ferry Compact Point median 10-year cumulative flows are highest under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) (84.6 maf), followed by the No Action Alternative (83.6 maf) and the CCS Comparative Baseline (83.3 maf), with the Enhanced Coordination Alternative having the lowest cumulative flows (81.3 maf).

The Representative Preferred Alternative achieves a median 10-year flow of 76.4 maf under the Dry Flow Category, exceeding the 75.0 maf threshold in over 50 percent of Dry Flow Category years, but surpassing the 82.5 maf threshold in fewer than 25 percent of Dry Flow Category years.

Hoover Dam (Lake Mead) Releases

Generally, alternatives with higher Lake Mead elevations correspond to lower releases from Hoover Dam, especially in the Average Flow Category (12.0–14.0 maf). However, the range of interquartile variability for releases from Hoover Dam is wide, especially in the Wet Flow Category (16.0–31.11 maf) and the Critically Dry Flow Category (4.46–10.0 maf), indicating more variability in releases as flow conditions get more extreme (in both directions). Refer to **Table TA 3-17** in **TA 3** for a statistical breakdown of CRSS modeling results for EOCY releases from Hoover Dam. Refer to **Figure TA 3-24** in **TA 3** for the box plot representation of the EOCY releases from Hoover Dam.

Under the Average Flow Category, the No Action Alternative releases the most from Hoover Dam (median of 8.63 maf), while Enhanced Coordination releases the least (7.58 maf). In the Critically Dry Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives have the lowest median releases (6.48 and 6.40 maf respectively). All alternatives except the Enhanced Coordination and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives have more variability under Critically Dry than Average conditions.

The Representative Preferred Alternative falls near the middle across all flow categories, with Hoover Dam median releases of 7.61 maf under the Dry Flow Category and 6.94 maf under the Critically Dry Flow Category and average variability compared to other alternatives.

Davis Dam (Lake Mohave), Parker Dam (Lake Havasu) Releases, and Morelos Diversion Dam

Releases from Davis Dam and Parker Dam are based on target elevations defined by the existing rule curves. Inflows into Lake Mohave vary across alternatives, so releases from Davis Dam and Parker Dam subsequently vary across alternatives to maintain target elevation ranges. These releases follow similar trends to Hoover Dam releases

Issue 4: River Flows

River flows throughout the seven analyzed reaches of the Colorado River, from Glen Canyon Dam to the SIB, largely reflect upstream reservoir releases, with tributary contributions and return flows accounting for only a small fraction of total flow. All alternatives show declining median flows with drier hydrology across all reaches. Refer to **Section TA 3.2.4**, Issue 4: River Flows, in **TA 3**, Hydrologic Resources, for details regarding impacts on river flows within specific reaches of the Colorado River.

Downstream of Glen Canyon Dam

Reach 1 of the river extends 292 miles from Glen Canyon Dam, through GCNP, to Lake Mead. Flows in this reach are dominated by releases from Lake Powell plus smaller inflows from the Paria and Little Colorado rivers (3 percent of total flow).

Annual flow patterns in this reach generally follow the Glen Canyon Dam release patterns summarized in Issue 3. Tributary inflows are modeled identically across all alternatives. The Representative Preferred Alternative produces median Water Year releases of 8.23 maf under the Average Flow Category, consistent with the No Action and the Basic Coordination Alternatives, and the CCS Comparative Baseline, and 6.0 maf under the Critically Dry Flow Category; it is the least variable of any alternative under the driest conditions.

Downstream of Hoover Dam to Imperial Dam (Reaches 2–5)

Reaches 2 through 5 are primarily influenced by releases from Hoover, Davis, and Parker Dams, with additional localized effects from one major tributary (Bill Williams River), diversions, and return flows.

Flows through these reaches are driven almost entirely by upstream dam releases, declining progressively with drying hydrology across all alternatives. The Enhanced Coordination Alternative consistently produces the lowest median flows while the No Action and Basic Coordination Alternatives produce the highest flows under dry conditions. The Representative Preferred Alternative performs near the middle of all alternatives throughout these reaches, with median annual flows of 7.89 maf below Hoover Dam, 7.8 maf below Davis Dam, 6.2 maf below Parker Dam, and 5.3 maf at Imperial Dam under the Dry Flow Category, declining to 6.94, 6.9, 5.9, and 5.0 maf respectively under the Critically Dry Flow Category.

Downstream of Imperial Dam (Reaches 6–7)

Below Imperial Dam, flows are primarily driven by delivery requirements and remain relatively stable across alternatives, ranging from 0.8 to 1.1 maf median under most flow categories. Below the Morelos Diversion Dam in the limitrophe, flows are infrequent across all alternatives, occurring in fewer than 10 percent of years under the Average, Dry, and Critically Dry Flow Categories. The Representative Preferred Alternative produces median flows of approximately 0.9 maf below Imperial Dam across both the Dry and Critically Dry Flow Categories, which is on the low end compared to other alternatives, and sees flows in the limitrophe in greater than 25 percent of years only under the Wet Flow Category.

Issue 5: Groundwater

Groundwater elevations adjacent to reservoirs and within specific reaches along the Colorado River may be affected by the various alternatives, depending on the hydraulic connectivity and geotechnical characteristics of the area. In reaches of the Colorado River that have a direct connection to groundwater, changes in river flows and changes in reservoir elevations are anticipated to affect groundwater elevations. The reaches that are anticipated to have impacts on groundwater as the result of changes to operational activities are summarized below. Refer to **Section TA 3.2.5**, Issue 5:

Groundwater, in **TA 3**, Hydrologic Resources, for details regarding impacts on groundwater within specific reaches of the Colorado River.

Reaches Anticipated to Have Impacts

Adjacent to Lake Powell, groundwater elevations are expected to track reservoir pool elevations. The Representative Preferred is third most robust at maintaining Lake Powell elevations above critical thresholds yielding adjacent groundwater elevations lower than the Enhanced Coordination and Maximum Operational Flexibility Alternative and comparable to the CCS Comparative Baseline and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). The No Action Alternative is least robust at maintaining Lake Powell elevations and is therefore expected to result in the lowest adjacent groundwater elevations.

Reaches 3 through 5 of the Colorado River are made up of alluvial fill groundwater basins and impacts on groundwater elevations mirror trends seen for river flows in Issue 4, where higher flows result in higher groundwater elevations. Under the Dry and Critically Dry Flow Categories, the Basic Coordination Alternative produces the highest flows in these reaches and is therefore expected to yield the highest groundwater elevations. The Representative Preferred Alternative falls near the middle of all alternatives and is likely to result in groundwater elevations that are higher than the Enhanced Coordination and Supply Driven Alternative (LB Pro Rata approach) but lower than the Basic Coordination, and Supply Driven (LB Priority approach) Alternatives, and the CCS Comparative Baseline in the Critically Dry Flow Category. The Enhanced Coordination Alternative is anticipated to result in the lowest groundwater elevations in these reaches due to its consistently lower river flows.

The downstream portion of Reach 7 is considered a losing reach where the river recharges groundwater. Groundwater elevations are likely to continue to decline under dry conditions.

Reaches Not Anticipated to Have Impacts

Reaches of the Colorado River that contain bedrock, that consist of lined canals, or which otherwise have limited hydraulic connectivity to groundwater are not anticipated to have impacts on groundwater associated with changes to operational activities. These portions of the analysis area include the Grand Canyon, Lake Mead, Reach 2 within the Black Canyon, and Reach 6 which diverts Colorado River water into lined canals. Likewise, reservoirs that maintain the same water surface elevation regardless of alternative are not anticipated to affect groundwater levels. These reservoirs include Lake Mohave and Lake Havasu, which will continue to be operated under their existing release rule curves, which keeps reservoir elevations within a tight range. The upstream portion of Reach 7 has high groundwater elevations from nearby irrigated fields, and the alternatives are not anticipated to impact groundwater elevations in this reach.

Summary Comparison of Alternatives

Beginning with reservoir elevations, performance differences among alternatives increase under drier conditions. The Representative Preferred Alternative meets the preferred minimum performance in 40 to 50 percent of futures over the Full Modeling Period and 52 to 58 percent in the first decade for Lake Powell, and 57 to 63 percent of futures over the Full Modeling Period and 62 to 72 percent in the first decade for Lake Mead. Absent additional action, the Representative Preferred Alternative is reasonably likely to be vulnerable to elevations below key thresholds within the next 10 years.

System storage declines under drier conditions across all alternatives and reservoir groupings, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives generally maintaining the highest median storage. Under the Representative Preferred Alternative, median combined storage in the Dry Flow Category is 32 percent for Powell-Mead, 37 percent for CRSP, and 37 percent for the seven-reservoir system, declining to 21, 27, and 27 percent respectively in the Critically Dry Flow Category. More than 25 percent of Dry Flow Category years and nearly 75 percent of Critically Dry Flow Category years fall below the lowest observed historical Powell-Mead combined storage.

Alternatives that prioritize higher reservoir elevations generally release less water, demonstrating the operational tradeoff between maintaining reservoir elevations to protect critical infrastructure and annual releases from reservoirs. Releases generally decrease under drier conditions, with greater variability for most alternatives. Under the Representative Preferred Alternative, median Glen Canyon Dam releases decline from 7.20 maf in the Dry Flow Category to 6.0 maf in the Critically Dry Flow Category, remaining the least variable among alternatives under the Critically Dry Flow Category. At the Lee Ferry Compact Point, median 10-year volumes are 76.4 maf under the Dry Flow Category and 73.9 maf under the Critically Dry Flow Category. Releases under the Representative Preferred Alternative from Hoover, Davis, and Parker Dams are generally in the middle range of alternatives, decreasing as conditions dry.

For most reaches of the Colorado River, flows mostly comprise releases from upstream reservoirs and overall trends for river flows mirror those seen for reservoir releases. Inflows from perennial tributaries are minor and do not change between alternatives. River flows generally decrease with drying hydrology across all reaches and alternatives. Under the Representative Preferred Alternative, annual flow volumes are generally in the middle of the range of alternatives below Hoover and Davis Dams, and similar to most alternatives below Parker Dam. At Imperial Dam, median annual flow is 5.3 maf in the Dry Flow Category and 5.0 maf in the Critically Dry Flow Category. Below Imperial Dam, median annual flow is 0.9 maf in both categories, on the low end of all alternatives. Flows below Morelos Diversion Dam are infrequent across all alternatives in the Average, Dry, and Critically Dry Flow Categories.

Groundwater effects are qualitative, complex, and most likely near Lake Powell and in alluvial river reaches with hydraulic connectivity. Under the Representative Preferred Alternative, groundwater elevations near Lake Powell are anticipated to be lower than under the Maximum Operational Flexibility and Enhanced Coordination Alternatives but higher than under the CCS Comparative Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata) Alternatives. Across river reaches, the Representative Preferred Alternative is generally not identified as producing either the highest or lowest anticipated groundwater elevations where flow-related effects are possible.

3.4 Water Deliveries

3.4.1 Affected Environment

Water from the Colorado River is delivered to entities in the Lower Division States and Mexico for domestic and agricultural use, in accordance with the Law of the River. Colorado River water is also used to serve many purposes in the Upper Basin. The geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact on Upper Basin water users. With respect to Upper Basin conservation, the nexus to the proposed federal action is the storage and delivery of that conserved water in Lake Powell. The effects of this storage in and delivery from Lake Powell are within the scope of the EIS (see **Section 3.3**, Hydrologic Resources, and **TA 3**, Hydrologic Resources), while specific activities that may be undertaken in the Upper Basin to generate the conserved water are not within the scope of this EIS. Any such activities are unknown at this time and will not necessarily require federal decision making. Any federal decisions associated with these conservation activities will be assessed outside of this EIS.

Legal and Policy Framework

The Law of the River is an umbrella term for the collection of laws, compacts, decrees, court decisions, contracts, and regulatory guidelines that govern management and operation of the Colorado River. Notable documents that define the Law of the River are identified and further explained in **TA-4**, Water Deliveries.

Apportionments

The Colorado River Compact apportions 7.5 million acre-feet (maf) of water per year to the Upper Colorado River Basin (Upper Basin), and 7.5 maf to the Lower Basin with division of the two basins occurring at Lee Ferry, Arizona. Water is distributed among the Upper Division States by the 1948 Upper Colorado River Basin Compact as a percentage of the total amount available for consumptive use each year after the deduction of Arizona's 50 thousand acre-feet (kaf) apportionment of Upper Basin water. The water is distributed among Colorado (51.75 percent), Utah (23 percent), Wyoming (14 percent), and New Mexico (11.25 percent). The Upper Division State apportionments have not yet been fully developed. Water apportionments to the Lower Division States total 7.5 maf for consumptive use, subject to annual increases or reductions pursuant to Secretarial determinations of a Surplus or a Shortage condition. Lower Division State apportionments are set by the BCPA as follows: California (4.4 maf), Arizona (2.8 maf), and Nevada (0.3 maf). See **Section 1.8** for a description of historical water use across the Upper and Lower Basins.

Rights to use Colorado River water within the Lower Division States, known as entitlements, are established in accordance with the BCPA and the Consolidated Decree. All of the water apportioned to the Lower Division States is allocated in accordance with these documents. For users in the Lower Division States, entitlements arise through (i) a decreed right, (ii) a Section 5 water delivery contract, or (iii) a Secretarial reservation. According to Section 5 of the BCPA, the Secretary is authorized as the contracting authority for the Lower Colorado River, and any user of Colorado River water in the Lower Basin is required to have a contract with the Secretary acting through the Bureau of Reclamation. The Consolidated Decree lists and quantifies all PPRs in the Lower Division States. PPRs are the highest priority Lower Basin mainstream Colorado River water entitlements that were perfected before June 25, 1929. The Consolidated Decree also lists federal reserved water rights for five Indian reservations. PPRs are satisfied first in order of priority in years when less than 7.5 maf of water is available from the Colorado River for consumptive use in the Lower Division States before other entitlements are fulfilled.

Storage & Delivery of Conserved and Non-System Water and Treatment of Pre-2027 Intentionally Created Surplus

As outlined in the 2007 Interim Guidelines, Lower Basin entitlement holders can store conserved water in Lake Mead, provided they have an ICS exhibit and an approved ICS creation plan. ICS may only be created in a given year via approved conservation actions and a reduction in consumptive use. Beginning in 2027, guidelines regarding the delivery and creation of ICS will change in accordance with the 2007 ROD and Lower Basin DCP to incorporate additional thresholds and repayment timelines. Additional information is available in **TA-4**, Water Deliveries.

Lower Basin Water Supply Determination

Annually, the Secretary determines the water supply condition for the Lower Division as Normal, Surplus, or Shortage Condition based on Lake Mead's projected elevation on January 1, as modeled by the prior year's August 24-Month Study. The 2007 ROD provides objective criteria used to make annual water supply determinations. The guidance provides supply thresholds under which consumptive use from Lake Mead would be Normal, Surplus, or Shortage Condition, and outlines coordinated reservoir management strategies between Lake Powell and Lake Mead. From 2008 to 2021, Lake Mead operated under Normal/ICS Surplus Conditions, shifting to Shortage Conditions from 2022 through 2025. Further historical information is available in **TA-4**, Water Deliveries.

Mexico's Allotment

Mexico's allotment of Colorado River water is described under Article 10 of the 1944 Water Treaty. The 1944 Water Treaty guarantees that 1.5 maf will be delivered to Mexico annually. Additionally, it outlines Surplus Conditions such that no greater than 1.7 maf shall be delivered to Mexico in a given year, and Extraordinary Drought such that deliveries are reduced in proportion to reductions of U.S. consumptive uses. Minute 242 provides guidance for the geographic locations where deliveries from the U.S. will be made. Minute 323 adjusts how and under what conditions deliveries occur but does not change Mexico's allotment. For further information regarding Mexico's allotment and pertinent policy, refer to **Appendix N**, International Border Region of the Colorado River.

Distribution of Shortages and Reductions to and within the Lower Division States

The 2007 Interim Guidelines, the 2019 DCP and Minute 323 to the 1944 Water Treaty provide for a maximum of 1.375 maf of shortages and reductions (including DCP Contributions and BWSCP savings). Beyond these required activities, Reservoir Protection Conservation implemented through the 2024 ROD resulted in additional Lower Basin conservation from 2023 to 2026. The Reservoir Protection Conservation may vary year to year but is designed to achieve a collective total volume of 3.0 maf. A summary of the 2007 Interim Guidelines Shortages, 2019 DCP contributions, and 2024 ROD conservation is shown in **Table TA-4-6** in **TA-4**, Water Deliveries.

Apportionment is allocated for Arizona, California, and Nevada as outlined in **Tables TA-4-7** through **TA-4-9** in **TA-4**, Water Deliveries.

3.4.2 Environmental Consequences

Methodology

Reclamation uses CRSS for long-term planning studies. CRSS simulates Basin conditions decades into the future (the full analysis period is through 2060) and can be used to account for hydrologic uncertainty. Refer to **Appendix A**, CRSS Model Documentation for more details related to model documentation. For background and guidance related to figures used in the full analysis, see **Section 3.2**, Analysis Methods. Additionally, the SAMs and ADMs were used to analyze potential impacts of the alternatives on individual water users within each Lower Division State under varying levels of shortage. Modeling assumptions for the SAMs and ADMs are summarized in **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation.

Reclamation uses CRSS for long-term planning studies. CRSS simulates Basin conditions decades into the future (the full analysis period is through 2060) and can be used to account for hydrologic uncertainty. Refer to **Appendix A**, CRSS Model Documentation for more details related to model documentation. Additionally, the SAMs and ADMs were used to analyze potential impacts to individual water users within each Lower Division State under varying levels of shortage. Modeling assumptions are summarized in **Appendix C**, and additional details on the DMDU framework and figure interpretation are provided in **Appendix E** and **Section 3.2.6**.

Impact Analysis Area

The geographic scope of the water deliveries analysis is the Colorado River corridor from the upstream limit of full pool elevation of Lake Powell to the downstream limit of the Southerly International Boundary. The geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact on Upper Basin water users. Although assumptions about Upper Basin conservation are included in various alternatives, no assumptions are made with respect to where conserved water is generated nor about the specific activities that produce it (see **Appendix B** for more information).

Assumptions

CRSS was used to analyze shortage volumes and Lower Basin water deliveries, and the SAMs and ADMs were used to analyze shortage impacts to specific groups of water users. CRSS also includes assumptions regarding Upper Basin conservation activities but does not make assumptions with respect to conservation by different entities or via specific activities. Refer to their respective appendices for more details related to model assumptions and documentation. All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell and/or Lake Mead (see **Appendix S**, Additional Description of Alternatives). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

Impact Indicators

The following indicators were used to assess impacts on water deliveries due to operational activities: magnitude of shortage volumes, distribution of shortages, and depletions among and within the Lower Division States.

Issue 1: Apportionments to the Upper Division States

The alternatives would not affect apportionments to the Upper Division States. Therefore, no impact analysis is warranted.

Issue 2: Lower Division States Apportionments and Water Entitlements

The approaches to distributing shortages incorporated in all alternatives are designed to explore a wide range of potential concepts and impacts; they do not reflect an intention by Reclamation to alter apportionments or water entitlements. However, because the concepts would affect a range of users, impacts on deliveries to different entities are analyzed in Issues 3, 5, and 7, and addressed in **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation. Once an alternative is selected, the Department will supplement the analysis if necessary.

Issue 3: Lower Division States Water Supply Determinations and Total Water Deliveries

Issue 3 addresses how operational activities affect water deliveries for the Lower Division States and Mexico. This is analyzed through the following key metrics: shortage versus dead pool–related reductions, conservation modeling assumption effects, shortage, annual depletions, and surplus.

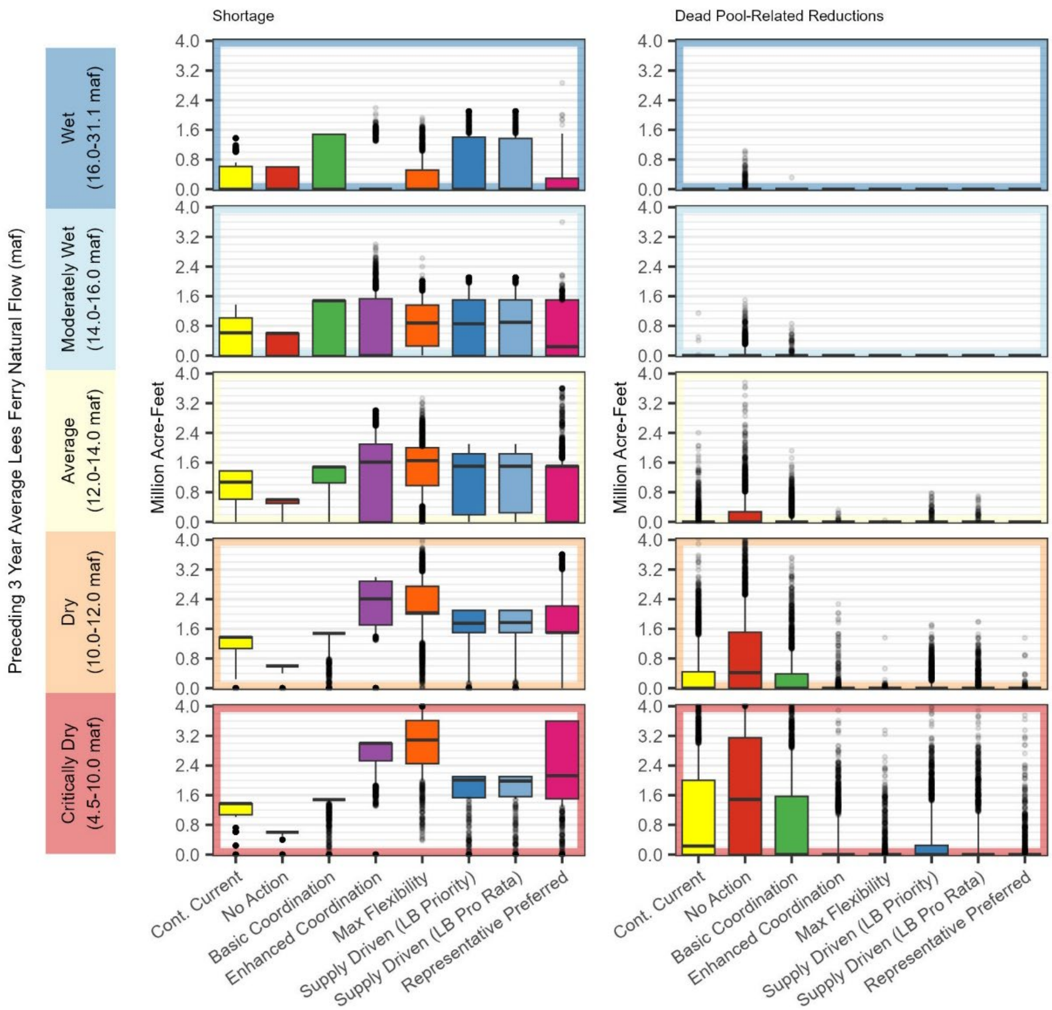
Shortage versus Dead Pool–Related Reductions: Comparison for Full Lower Basin

Shortage refers to delivery reductions at the Basin, state, or individual apportionment level that are defined and distributed as part of an alternative's shortage operations. Volumes and distributions of shortage are described in **Chapter 2**. Dead pool–related reductions occur when there is not enough water in Lake Mead to fully meet downstream demands and/or when Hoover Dam infrastructure constraints result in releases below the demand volume. In some cases, these unplanned reductions occur because Lake Mead is approaching dead pool (elevation 895 feet) and in some cases they occur higher (up to elevation 950 feet).

Annual Lower Basin Reductions

Figure 3-12 compares modeled annual Lower Basin shortages and dead pool-related reductions across alternatives and flow categories, including modeling assumptions for reductions in deliveries to Mexico. Overall, alternatives with lower maximum shortage volumes tend to have more frequent or larger dead pool-related reductions, most notably the No Action Alternative. Under the Average Flow Category, median shortages are 2.1 maf or less. The Maximum Operational Flexibility and Enhanced Coordination Alternatives have the highest median shortages at 1.7 and 1.6 maf, while the CCS Comparative Baseline and No Action Alternative are lower at 1.1 and 0.6 maf. Dead pool-related reductions are generally infrequent for action alternatives under the Average Flow Category, except under the Basic Coordination Alternative, while the No Action Alternative has the most frequent and highest-magnitude reductions. Differences are greatest under the Critically Dry Flow Category, where most action alternatives have higher median shortages but lower dead pool-related reductions than the CCS Comparative Baseline and No Action Alternative. For the Representative Preferred Alternative, the Dry Flow Category shows a median shortage of 1.5 maf, median dead pool-related reductions of 0.0 maf, and dead pool-related reductions only in outlier years. Under the Critically Dry Flow Category, its median shortage is 2.1 maf, median dead pool-related reductions remain 0.0 maf, and 10 percent of years have dead pool-related reductions.

Figure 3-12
Annual Lower Basin Reductions

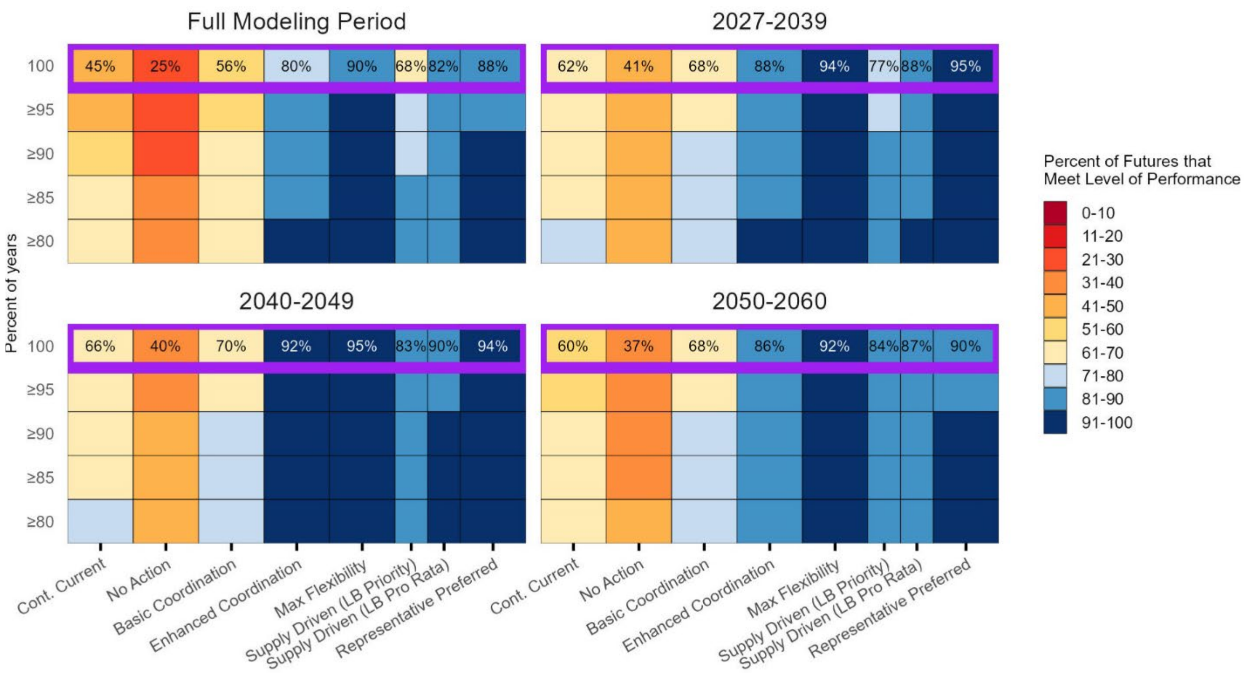


Note: Shortage and dead pool-related reduction volumes include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Lake Mead Dead Pool-Related Reductions

Figure 3-13 compares the robustness of each alternative in avoiding dead pool-related reductions at Lake Mead across the full modeling period and three subperiods. The preferred minimum performance is shown in the purple highlighted row, which represents the percentage of futures that an alternative avoids dead pool-related reductions in 100 percent of years. Over the full modeling period, the Maximum Operational Flexibility Alternative is the most robust, avoiding dead pool-related reductions in 90 percent of futures, followed by the Representative Preferred Alternative at 88 percent, Supply Driven Alternative (LB Pro Rata approach) at 82 percent, and Enhanced Coordination Alternative at 80 percent. These alternatives perform better than the Basic Coordination Alternative, CCS Comparative Baseline, and No Action Alternative, which avoid dead pool-related reductions in 56, 45, and 25 percent of futures, respectively. For 2027-2039, the Representative Preferred and Maximum Operational Flexibility Alternatives are the most robust, meeting the preferred minimum performance in 95 and 94 percent of futures, respectively. The Representative Preferred Alternative performs among the best alternatives in both the full modeling period and the 2027-2039 period.

Figure 3-13
Lake Mead Dead Pool–Related Reductions: Robustness.
Percent of futures in which dead pool-related reductions are avoided in the percent of years specified by each row



Note: Dead pool-related reduction volumes include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

The Lake Mead dead pool vulnerability analysis shows what flow conditions are likely to cause dead pool-related reductions from Lake Mead in any year. Undesirable performance is based on the highlighted row in **Figure 3-13**, above. The driest 10-year average Lees Ferry annual flow was determined to be skillful at predicting undesirable performance. The No Action Alternative is vulnerable at 11.6 maf, which is near the driest observed 10-year average flow of 11.8 maf, while the Basic Coordination Alternative and the CCS Comparative Baseline are vulnerable at 10.4 and 10.9 maf, respectively. Other action alternatives are not likely vulnerable unless flows are much drier than observed conditions. The Representative Preferred Alternative is likely vulnerable at a 10-year average flow of 8.0 maf, a condition not observed and present in fewer than 10 percent of Drying with Variability Ensemble traces. Further information and detailed figures can be found in **Figure TA 4-3** in **TA-4**, Water Deliveries.

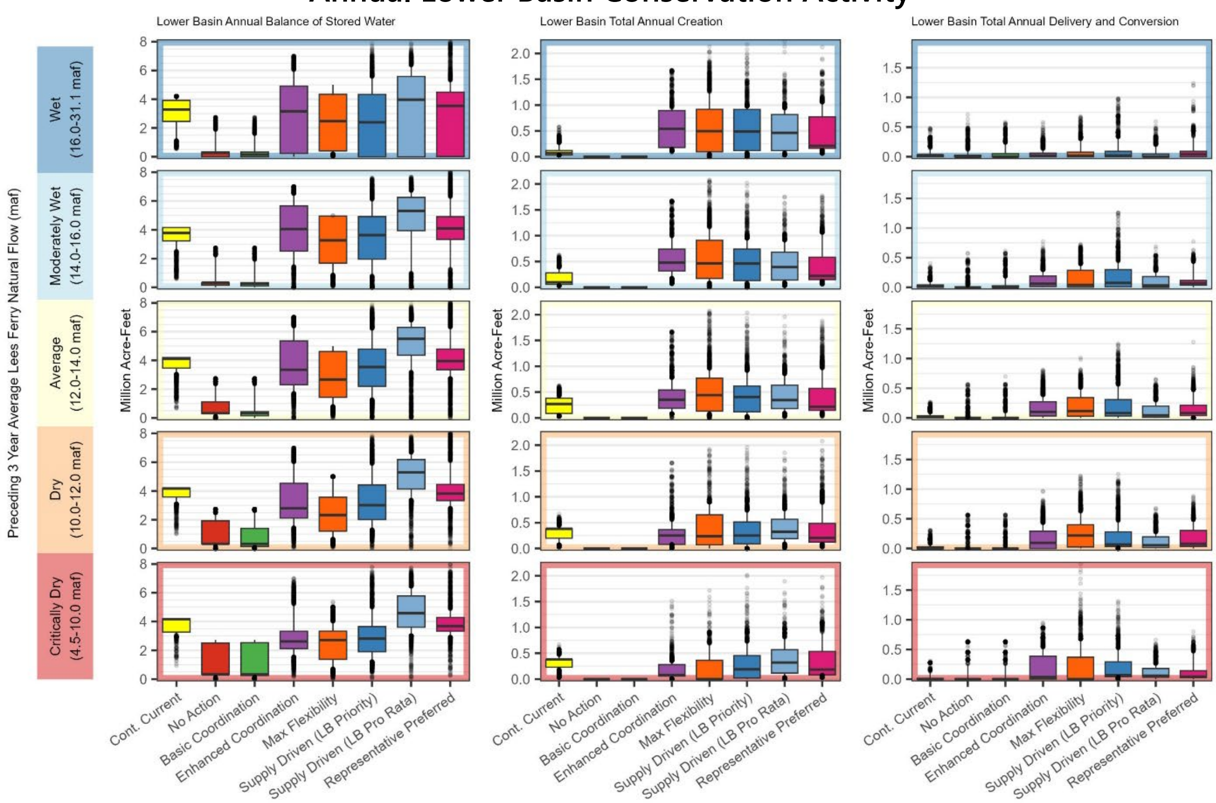
Conservation Activity

All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell and Lake Mead. **Table TA 4-12** in **TA-4**, Water Deliveries summarizes the various conservation mechanisms for each action alternative.

Lower Basin Conservation Activity

Figure 3-14 shows Lower Basin conservation activity by alternative using conditional boxplots for stored water balance, annual conservation creation, and annual delivery and conversion. Stored water balances generally decline in the Dry and Critically Dry Flow Categories as annual creation decreases. Delivery and conversion volumes increase from the Average Flow Category to the Dry Flow Category, then stay the same or decrease in the Critically Dry Flow Category due to lower available stored water and/or low Lake Mead elevations. The No Action and Basic Coordination Alternatives have small balances because they do not include new conservation mechanisms. For the Representative Preferred Alternative, median stored water balances are 3.8 maf in the Dry Flow Category and 3.7 maf in the Critically Dry Flow Category. Median annual creation is 0.2 maf in both categories, while median delivery and conversion is 0.1 maf in the Dry Flow Category and 0.0 maf in the Critically Dry Flow Category.

Figure 3-14
Annual Lower Basin Conservation Activity



Note: Lower Basin conservation activity includes assumptions related to the storage available to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Effects of Modeling Assumptions for Total Basin Conservation Activity on Lower Basin Shortages and Deliveries

Modeling assumptions for conservation activity do not substantially affect median Lower Basin shortages or depletions, but they can influence variability across flow categories. These assumptions can also affect the frequency or magnitude of Lake Mead dead pool-related reductions, particularly in drier flow categories. Further information and detailed figures can be found in **TA-4**, Water Deliveries.

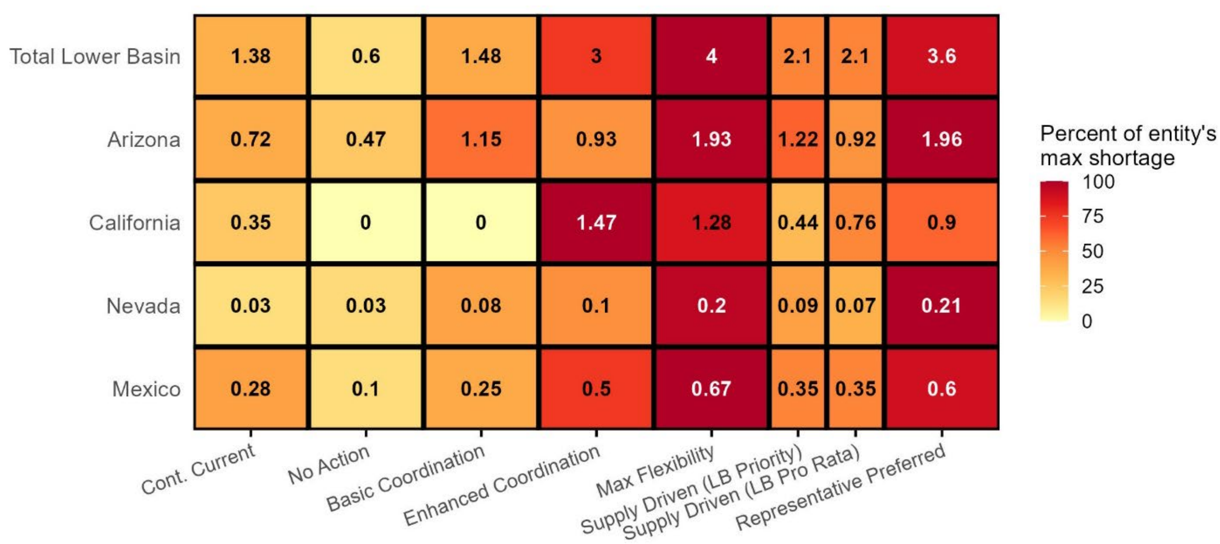
Shortage

This section compares all the alternatives and the CCS Comparative Baseline with respect to shortages to each of the Lower Division States and Mexico.

Maximum Shortage

Figure 3-15 compares maximum modeled shortages for the total Lower Basin and for each state and Mexico. Because the alternatives have different maximum volumes and also different distributions of shortage, each row has an independent color scale to facilitate identifying the maximum shortage to each entity. For all entities except California, either the Maximum Operational Flexibility Alternative or Representative Preferred Alternative produces the largest maximum shortage. The Enhanced Coordination Alternative produces California's largest maximum shortage due to its pro rata distribution and large total shortage volumes. The No Action Alternative produces the lowest, or tied-lowest, maximum shortage for all entities. Under the Representative Preferred Alternative, actual shortage distributions under specific operating guidelines may differ from the representative approach shown here.

Figure 3-15
Maximum Shortage (maf)



Note: Lower Basin shortage volumes include modeling assumptions for reductions in water deliveries to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Shortage by State

Shortage under different hydrologic conditions categorized by the preceding 3-year average of Lees Ferry natural flow is compared across alternatives in **Figure 3-16**. There is a column for each Lower Division State and Mexico. The vertical axis for each state's column is scaled based on its respective volume of apportionment; the percent apportionment is shown on the left side of each column, and the absolute volume of shortage is shown on the right. A summary by state for Arizona, California, and Nevada follows.

Arizona

In Arizona, all alternatives impose shortages on Priority 4 users. Shortages to more senior users occur only under alternatives that use pro rata-based shortage distribution or when total Lower Basin shortages are large enough to extend beyond Priority 4 users. The Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives affect Priorities 1, 2 and 3 through pro rata-based distribution. The Maximum Operational Flexibility and Representative Preferred Alternatives affect Priority 2 and 3 users when shortages are large enough. Under the Representative Preferred Alternative, Priority 4 median shortages are 1,167.1 kaf in the Dry Flow Category and 1,442.6 kaf in the Critically Dry Flow Category. Priority 1 users do not take shortage. The sum of the shortages across priority groups is shown in **Figure 3-16**, below. Shortage is also displayed by priority in **Figure TA 4-11** in **TA-4**, Water Deliveries.

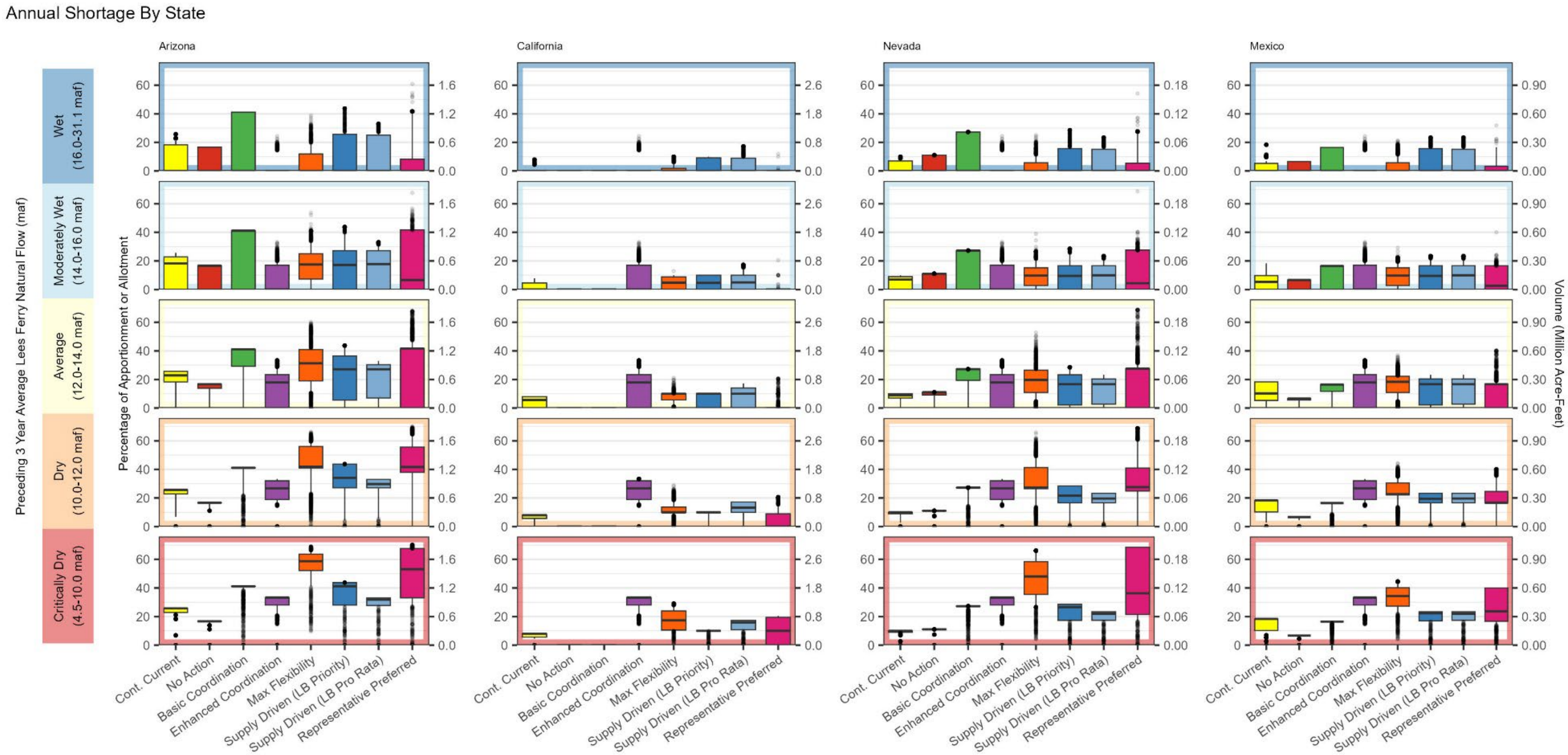
California

In California, the No Action and Basic Coordination Alternatives do not apply shortages to water users because they combine low maximum Lower Basin shortages with priority-based shortage distribution. However, low maximum Lower Basin shortages correspond to higher dead pool-related reductions. The Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives apply shortages to senior priority groups through pro rata-based distribution. The Maximum Operational Flexibility Alternative also affects Priorities 1 and 2 and PPRs in a small number of years in the Dry and Critically Dry Flow Categories. Priority 4 users are the most junior and experience the largest shortage volumes relative to their total rights. Under the Representative Preferred Alternative, Priority 4 median shortages are 0.0 kaf in the Dry Flow Category and 255.7 kaf in the Critically Dry Flow Category. Priorities 3a and 3b median shortages are 0.0 kaf and 100.4 kaf, respectively. The sum of the shortages across priority groups is shown in **Figure 3-16**. Shortage is also displayed by priority in **Figure TA 4-12** in **TA-4**, Water Deliveries.

Nevada

In Nevada, modeled shortages are primarily associated with Priority 8 users, who represent the vast majority of Nevada water rights. Other priority groups receive shortages only under the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives because those alternatives use pro rata-based shortage distribution. Most action alternatives have higher median shortages as conditions become drier, while the Basic Coordination Alternative remains at 81.7 kaf because its maximum shortage is already applied in the Average Flow Category. Under the Representative Preferred Alternative, Priority 8 median shortages are 82.8 kaf in the Dry Flow Category and 108.9 kaf in the Critically Dry Flow Category. No other priority groups take shortage under this alternative. The sum of the shortages across priority groups is shown in **Figure 3-16**. Shortage is also displayed by priority in **Figure TA 4-13** in **TA-4**, Water Deliveries.

Figure 3-16
Calendar Year Shortage by State and Water Delivery Reductions to Mexico



Note: The modeled annual delivery reductions in Mexico include modeling assumptions for reductions in water deliveries to Mexico and storage available to Mexico. Reclamation's modeling assumptions are not intended to constitute an interpretation or application of the 1944 Water Treaty or to represent current U.S. policy or a determination of future U.S. policy regarding deliveries to Mexico. The U.S. will conduct all necessary and appropriate discussions regarding the proposed federal action and implementation of the 1944 Water Treaty with Mexico through the IBWC in consultation with the Department of State.

Annual Depletions

Depletion, also referred to as total consumptive use or the net amount of water used, is defined as the amount of water diverted from the river minus return flow. Return flow is the portion of water diverted for use that is not consumed and returns to the river for subsequent downstream use. Across entities, alternatives, and the CCS Comparative Baseline, median depletions do not uniformly decrease as conditions become drier, but the percentage of years affected by dead pool-related reductions increases.

Arizona

In Arizona, modeled depletions are below 100 percent of apportionment in most years because shortages are applied frequently and conservation activity does not fully offset them. Depletions change little from the Average Flow Category to the Dry Flow Category, but years affected by dead pool-related reductions increase. In the Critically Dry Flow Category, median and lower-percentile depletions decrease for most alternatives due to larger shortages and limited availability of, or access to, conserved water. Under the Representative Preferred Alternative, median Arizona depletions are 58.5 percent in the Dry Flow Category and 51.8 percent in the Critically Dry Flow Category, with dead pool-related effects in some outlier years and approximately 10 percent of years, respectively. The full range of annual depletions in Arizona across the different alternatives can be viewed in **Figure TA 4-14** in **TA-4**, Water Deliveries.

California

California's modeled depletions are below 100 percent of apportionment in most years under alternatives that apply shortages to the state. Under the No Action and Basic Coordination Alternatives, depletions below 100 percent are associated with dead pool-related reductions. Except under the Enhanced Coordination Alternative, median depletions change little from the Average Flow Category to the Critically Dry Flow Category, although years affected by dead pool-related reductions increase. Under the Representative Preferred Alternative, median California depletions are 95.8 percent in the Dry Flow Category and 86.0 percent in the Critically Dry Flow Category, with dead pool-related effects in some outlier years and fewer than 10 percent of years, respectively. The full range of annual depletions in California across the different alternatives can be viewed in **Figure TA 4-15** in **TA-4**, Water Deliveries.

Nevada

In Nevada, modeled depletions change little from the Average Flow Category to the Dry Flow Category, while years affected by dead pool-related reductions increase. In the Critically Dry Flow Category, median and lower-percentile depletions decrease for most alternatives due to larger shortages and limited availability of, or access to, conserved water. Under the Representative Preferred Alternative, median Nevada depletions are 89.7 percent in the Dry Flow Category and 73.3 percent in the Critically Dry Flow Category. Dead pool-related effects occur in some outlier years in the Dry Flow Category and approximately 10 percent of years in the Critically Dry Flow Category. The full range of annual depletions in Nevada across the different alternatives can be viewed in F**igure TA 4-16** in **TA-4**, Water Deliveries.

Surplus

Surplus deliveries become more frequent as flow conditions become wetter. In the Average Flow Category, the Representative Preferred Alternative has the highest frequency of surplus deliveries at

18.0 percent of years, followed by the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) at about 15 percent. All alternatives have surplus deliveries in fewer than 10 percent of years in the Dry Flow Category. In the Critically Dry Flow Category, only the CCS Comparative Baseline and the Supply Driven (both LB Priority and LB Pro Rata approaches) and Representative Preferred Alternatives have any surplus deliveries, at fewer than 3 percent of years. The full range of frequency of surplus across the different alternatives can be viewed in **Figure TA 4-17** in **TA-4**, Water Deliveries.

Issue 4: Deliveries to Mexico

Issue 4 addresses how operational activities affect deliveries to Mexico. Refer to **TA-4**, Water Deliveries for greater details regarding the analysis of impacts as well as **Appendix N**, International Border Region of the Colorado River for additional information regarding water deliveries to the International Border Region.

Annual Reductions

For Mexico, modeled water delivery reductions generally increase as conditions become drier, with higher median reductions in the Dry and Critically Dry Flow Categories than in the Average Flow Category. In the Average Flow Category, the CCS Comparative Baseline and No Action Alternative have among the lowest median reductions, while the Maximum Operational Flexibility and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are around 20 percent. Under the Representative Preferred Alternative, Mexico's median water delivery reduction is 16.7 percent in the Dry Flow Category and 23.6 percent in the Critically Dry Flow Category. Refer to **Figure 3-16,** above, and the tables and figures in **TA-4,** Water Deliveries for further information.

Annual Depletions

Mexico's modeled depletions are below 100 percent of allotment in most years because delivery reductions are applied frequently and conservation activity does not fully offset them. Median depletions change little from the Average Flow Category to the Dry Flow Category, while years affected by dead pool-related reductions increase. In the Critically Dry Flow Category, median and lower-percentile depletions decrease for most alternatives. Under the Representative Preferred Alternative, median Mexico depletions are 83.3 percent in the Dry Flow Category and 81.5 percent in the Critically Dry Flow Category, with dead pool-related effects in some outlier years and approximately 25 percent of years, respectively. Refer to **Figure TA 4-18** in **TA-4**, Water Deliveries for further information.

Issue 5: Lower Division States Combined Shortages

Issue 5 addresses how operational activities affect modeled distribution of combined shortages for the Lower Division States. As discussed in **Chapter 2**, the alternatives considered evaluate a distribution of shortages via priority and pro rata. Lower Division States' shortage distributions discussed under this issue were modeled with the SAM and ADM to estimate the volume of available water to entitlement holders or water users under Shortage Conditions over a specified range of shortage volumes. Refer to **TA-4**, Water Deliveries for greater details regarding the analysis of impacts as well as the **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation for additional information.

Tribal, Domestic, and Irrigation Shortage Impacts

For tribal users, priority-based alternatives result in greater shortage impacts than pro rata-based alternatives when comparing the same total shortage volume. Shortage impacts range from 209 to 582 kaf for priority-based alternatives and from 76 to 378 kaf for pro rata-based alternatives. Under the Representative Preferred Alternative, maximum 2027 and 2028 shortage impacts would be 346 kaf unless critical elevations at Lake Mead prompt consultation, while 2029-2060 modeling assumptions show a maximum potential impact of over 574 kaf.

For domestic users, priority-based alternatives result in greater shortage impacts than pro rata-based alternatives when comparing the same total shortage volume. Shortage impacts range from 277 to 1,501 kaf for priority-based alternatives and from 109 to 546 kaf for pro rata-based alternatives. Under the Representative Preferred Alternative, maximum 2027 and 2028 shortage impacts would be 858 kaf unless critical elevations at Lake Mead prompt consultation, while 2029-2060 modeling assumptions show a maximum potential impact of over 1,472 kaf.

For non-tribal irrigation users, pro rata-based alternatives result in greater shortage impacts than priority-based alternatives when comparing the same total shortage volume. Shortage impacts range from 2 to 1,211 kaf for priority-based alternatives and from 206 to 1,578 kaf for pro rata-based alternatives. Under the Representative Preferred Alternative, maximum 2027 and 2028 shortage impacts would be 70 kaf unless critical elevations at Lake Mead prompt consultation, while 2029-2060 modeling assumptions show a maximum potential impact of over 829 kaf.

Volumes of Shortage by State (Arizona, California, Nevada)

State specific distribution of shortages can be viewed in **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation.

Issue 6: Upper Basin Conservation

This section describes how alternatives perform in terms of annual Upper Basin conservation activity. **Figure 3-17** shows three components of Upper Basin conservation activity.[9] The first column shows the annual total volume of conserved water accumulated by Upper Basin conservation. The second column reports the annual volume of conserved water that is created. The third column reports the annual volume that is converted to system water.

There is zero accumulation, creation, or conversion under the CCS Comparative Baseline or the No Action and Basic Coordination Alternatives, so the remainder of the discussion on **Figure 3-17** focuses on Enhanced Coordination, Maximum Operational Flexibility, Representative Preferred, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives.[10]

Among alternatives with Upper Basin conservation, the Maximum Operational Flexibility Alternative has the highest median accumulation in the Average and Critically Dry Flow Categories and also has the highest median creation in those categories. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) does not convert conserved water because conservation is created as system

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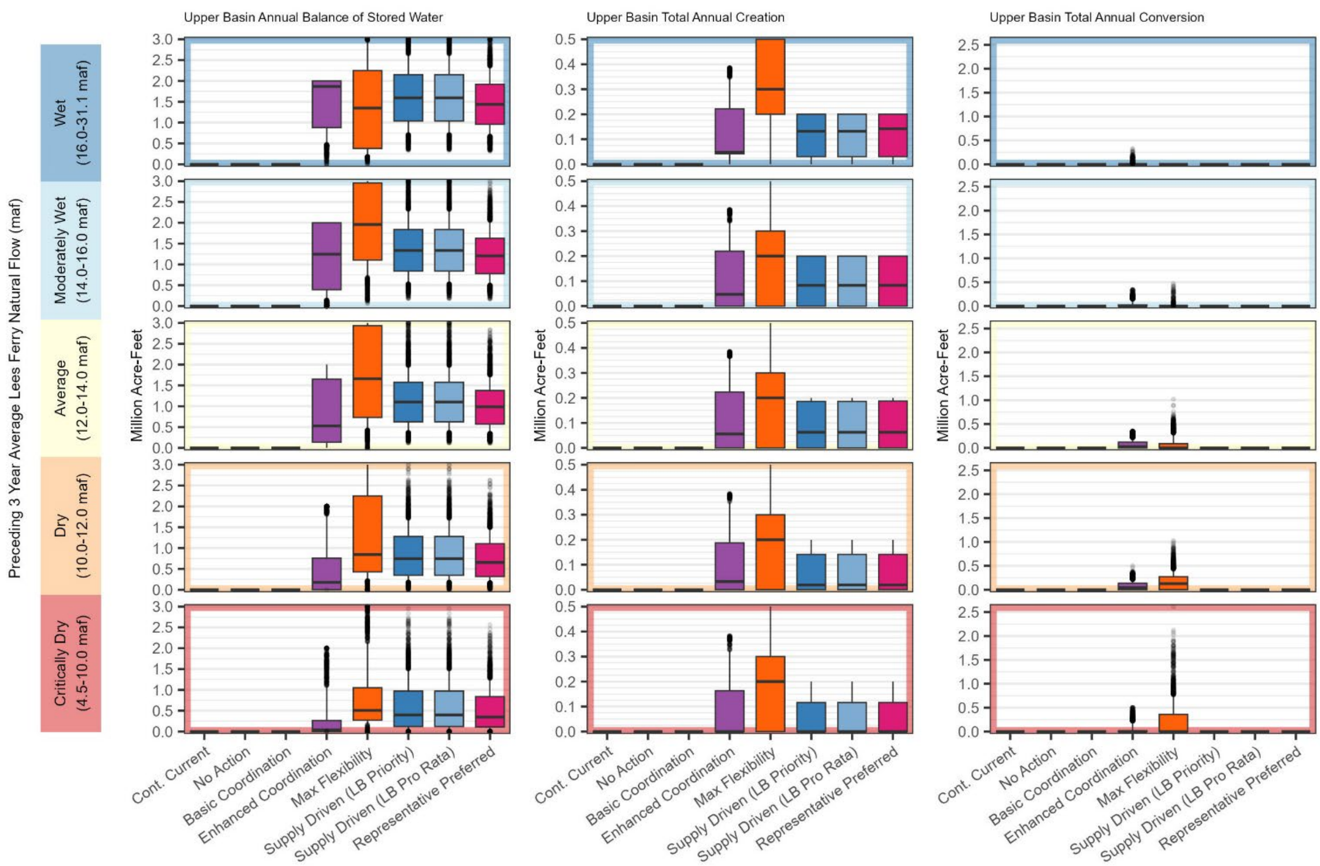
[9] For all alternatives except the Maximum Operational Flexibility Alternative, Lower Basin conserved water is stored in Lake Mead. For the Maximum Operational Flexibility Alternative, this water can be stored in Lake Mead, Lake Powell, or both.

[10] UB conservation activity is the same for both the LB Priority and LB Pro Rata approaches under the Supply Driven Alternative.

water. For the Representative Preferred Alternative, median accumulation is 1.0 maf in the Average Flow Category and 0.3 maf in the Critically Dry Flow Category. Median creation is about 0.1 maf in the Average Flow Category and 0.0 maf in the Critically Dry Flow Category.

Figure 3-17
Annual Upper Basin Conservation Activity



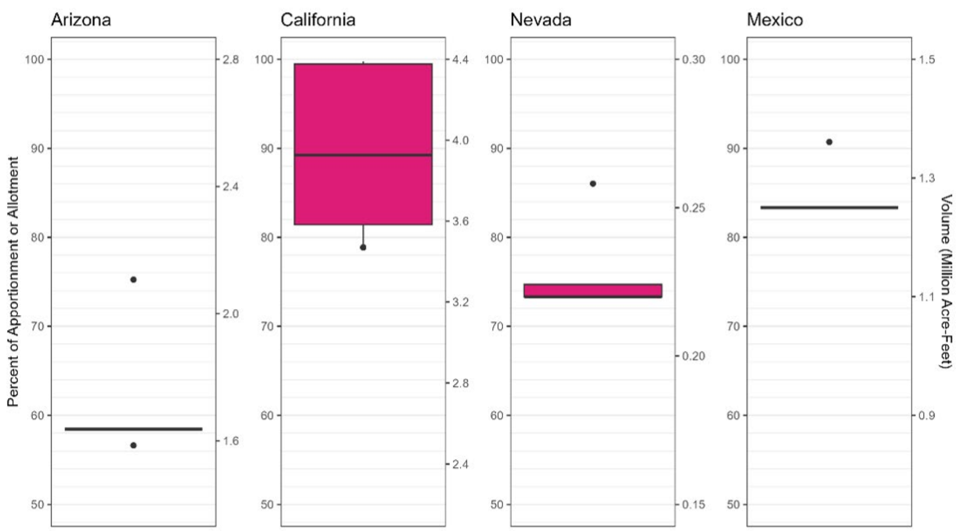
Note: In addition to the conservation volumes, the Supply Driven Alternative also includes “gap water” (see EIS **A**ppendix S, Additional Description of Alternatives, and **Appendix A,** CRSS Model Documentation). The modeled gap water volume increases with higher natural flow release percentages and drier hydrologic conditions. The median is 0.0 maf for the 60 and 65 percent natural flow release scenarios in the Average and Critically Dry flow categories, and increases to slightly over 0.1 maf and 0.8 maf, respectively, for the 70 percent scenario; the maximum gap water volume across all flow categories is approximately 1.1 maf. **Appendix D**, Sensitivity Analysis – Effects of Natural Flow Percentage Used for the Supply Driven Alternative, includes additional information on the modeled volumes of gap water.

Issue 7: Lower Division States’ 2027-2028 Water Supply Determinations in the Representative Preferred Alternative

Under the Preferred Alternative decision framework, specific operating guidelines, including shortage volumes and distributions, will be developed and adopted periodically. It is anticipated that the first set of operating guidelines will cover 2027 and 2028. The Lower Division States’ proposal for distributing shortages up to 1.5 maf on May 1, 2026, was incorporated in the Representative Preferred Alternative for 2027 and 2028, as described in **Chapter 2**.

In the Representative Preferred Alternative modeling, all 400 traces show a 1.5-maf Lower Basin shortage in 2027. In 2028, 148 traces remain at 1.5 maf, while 252 traces show larger shortages, with up to 3.0 maf in 3 traces. It is anticipated that volumes and distribution of shortages above 1.5 maf, should they be deemed necessary, would be developed based on consultation and are not analyzed in this Issue. **Figure 3-18**, below, shows the distribution of annual depletions for each state in 2027 and 2028 in the Representative Preferred Alternative. Median 2027-2028 depletions are approximately 1.6 maf for Arizona, 3.9 maf for California, 0.2 maf for Nevada, and 1.3 maf for Mexico. As a percent of apportionment or allotment, they are 58.5 percent for Arizona, 89.2 percent for California, 73.3 percent for Nevada, and 83.3 percent for Mexico.

Figure 3-18
Distribution of 2027-2028 Annual Depletions by State in the Representative Preferred Alternative



Summary Comparison of Alternatives

A summary of each issue is provided below, with additional information and details provided in **TA-4**, Water Deliveries**.**

Issue 1 considered whether the alternatives could affect apportionments to the Upper Division States. Because no changes to those apportionments are expected, no further impact analysis was needed.

Issue 2 assessed whether the alternatives could affect the Lower Division States' apportionments or water entitlements. The shortage distribution approaches were evaluated to explore potential concepts and impacts and not to change existing apportionments or entitlements. Related delivery effects are addressed under Issues 3, 5 and 7, and further summarized below.

Issue 3 evaluates effects on water supplies for the Lower Division States and Mexico, including shortages, Lake Mead dead pool-related reductions, conservation activity, depletions, delivery reductions, and surplus deliveries. Across alternatives, lower planned shortages tend to leave Lake Mead more vulnerable to dead pool-related reductions, while larger or more responsive shortages tend to provide stronger protection against those reductions. Differences among alternatives become more pronounced under drier hydrology, and outcomes vary based on shortage volume, shortage distribution, conservation assumptions, and dead pool-related constraints. Under the Representative Preferred Alternative, modeled shortages are higher in the Critically Dry Flow Category than in the Dry Flow Category, which helps limit the frequency of Lake Mead dead pool-related reductions. Dead pool-related reductions remain limited in the Dry Flow Category and occur more often under Critically Dry conditions. The vulnerability analysis indicates that this alternative would likely become vulnerable to at least one dead pool-related reduction only under hydrologic conditions much drier than the observed record.

Issue 4 evaluates effects on Colorado River deliveries to Mexico, including annual delivery reductions and depletions. Across alternatives, Mexico generally receives its full allotment infrequently, and Lake Mead dead pool-related reductions occur more often under No Action and Basic Coordination than under several other alternatives. Under the Representative Preferred Alternative, Mexico's median depletions are similar in Dry and Critically Dry conditions, at 83.3 percent and 81.5 percent of allotment, respectively. Dead pool-related reductions affect about 25 percent of Critically Dry years, which is less frequent than under No Action but more common than under Maximum Operational Flexibility and the Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives.

Issue 5 considered how action alternatives would affect the distribution of combined shortages among Lower Division States water users. Modeled outcomes vary by distribution approach, with priority-based methods generally increasing shortages for tribal and domestic users, while pro rata methods tend to increase impacts to non-tribal irrigation users. Assuming a maximum shortage volume of 1.5 maf distributed based on the Lower Division States' May 1, 2026, proposal, the Representative Preferred Alternative, maximum modeled shortages in 2027 and 2028 would be 346 kaf for tribal users, 858 kaf for domestic users, and 70 kaf for non-tribal irrigation users[11]. For 2029 through 2060, the Representative Preferred Alternative assumes shortages up to 3.6 maf distributed by priority and potential for larger impacts, but actual shortage distributions would depend on the operating guidelines adopted under the Preferred Alternative framework.

Issue 6 examined how alternatives perform in terms of annual Upper Basin conservation activity. Upper Basin conservation activity occurs only under Enhanced Coordination, Maximum Operational Flexibility, Supply Driven (both LB Priority and LB Pro Rata approaches), and the Representative Preferred Alternatives. No accumulation, creation, or conversion occurs under the CCS Comparative Baseline, and the No Action or Basic Coordination Alternatives. The Maximum Operational Flexibility Alternative generally has the highest annual accumulation and creation, while conversion is more limited overall. Under the Representative Preferred Alternative, accumulation and creation occur, but no conversion is modeled because no conversion mechanism is assumed.

Issue 7 evaluates the Lower Division States' 2027-2028 water supply determinations in the Representative Preferred Alternative, which assumes that up to 1.5 maf of shortage is distributed based on the Lower Division States' May 1, 2026, proposal (i.e., LB Priority). The Preferred Alternative establishes a decision framework, so actual shortage volumes and distributions may differ from those modeled. In 2027 all traces show a 1.5-maf Lower Basin shortage. While shortages greater

[11] While the Representative Preferred Alternative models shortages above 1.5 maf in 2028, consistent with the sideboards, under the Preferred Alternative, Reclamation would consult with stakeholders if Lake Mead elevation is projected below 1,000 feet. (See **Chapter 2** for more details on the sideboards under the Preferred Alternative).

than 1.5 maf are modeled in 2028, they are not analyzed. The median 2027-2028 depletions are approximately 1.6 maf for Arizona, 3.9 maf for California, 0.2 maf for Nevada, and 1.3 maf for Mexico. As a percent of apportionment or allotment, they are 58.5 percent for Arizona, 89.2 percent for California, 73.3 percent for Nevada, and 83.3 percent for Mexico.

3.5 Geomorphology and Sediment

3.5.1 Affected Environment

This section describes how sediment and geomorphic processes shape the Colorado River below Glen Canyon Dam. Sandbars within the Grand Canyon provide key ecological, cultural, and recreational functions, supporting habitat, vegetation, archaeological resource protection, and camping areas along the river (Rubin et al. 2002; Mueller et al. 2018; Hazel et al. 2022; Reclamation 2024c). In addition, beaches provide camping areas for whitewater river trips, a significant driver of economic activity in the region.

Sandbars and channel-margin deposits depend on the river's sediment mass balance—the difference between the sediment entering and leaving the system. Before Glen Canyon Dam was built, the river carried large amounts of suspended sediment year-round. After the dam's completion, about 95 percent of the historical sediment supply from the Upper Basin was cut off, leaving the river with a long-term sediment deficit (Topping et al. 2000). As a result, the river now erodes sandbars and channel deposits faster than tributaries can replace them. Since the 1960s, most years have shown net erosion in Marble and Grand Canyons (Topping et al. 2021).

Dam operations also influence sediment behavior. Today's managed flows are much lower and more stable than historical floods, and minimum flows remain above levels that once allowed seasonal sand accumulation. Combined with the reduced sediment supply, these regulated discharges limit sand deposition, shorten the time available for sand storage, and increase erosion of beaches and sandbars (USGS 2011).

Downstream of Glen Canyon Dam, the Paria and Little Colorado Rivers are the dominant sediment sources. Upstream of the Paria, modern Glen Canyon receives little sediment input, making its sediment effectively nonrenewable (Grams et al. 2007). Sand delivered from tributaries tends to remain in the system only for a few months unless flows remain below roughly 9,000 cubic feet per second (cfs) (Topping et al. 2000; Rubin et al. 2002; USGS 2011). Most sediment ultimately continues downstream toward Lake Mead.

Fine sediment—sand, silt, and clay—is the primary material transported by the river and the main contributor to sandbar formation. Sand stored on the riverbed supplies the material that forms sandbars during high flows. Sediment transport increases with flow volume, turbulence, and changes in sediment size delivered by tributary floods. Deposition occurs in low-velocity environments such as recirculation zones of eddies and along channel margins, and storage varies with riverbed topography and tributary activity.

Geomorphically, the river consists of long pools separated by steep rapids formed at debris-fan deposits left by tributary debris flows. These fans constrict the channel, generate rapids, and create recirculating eddies where sandbars form (**Figure TA 5-1** in **TA 5**, Geomorphology and Sediment). Most Grand Canyon sandbars are tied to these fan-eddy complexes and remain dynamic features that continually exchange sand with the river.

To counteract long-term sandbar erosion, Reclamation conducts HFEs that release large, short-duration floods from Glen Canyon Dam. HFEs are the only mechanism capable of producing water stages high enough to rebuild sandbars. Bar size generally increases during HFEs and then diminishes between them, with erosion highest immediately after floods. More frequent HFEs can increase sandbar size if sufficient sand is available (Grams et al. 2025).

3.5.2 Environmental Consequences

Methodology

All modeling used for this resource section was based on modeling performed by the USGS, GCMRC (Grams et al. 2025; Salter et al. 2025), and developed using the CRSS hydrological modeling results. Tributary sediment inputs from the Paria and Little Colorado Rivers were generated using the Wright et al. (2010) model. Outputs were fed to the Mueller and Grams (2021) sandbar model, recalibrated to the 2002–2024 period, based on the long-term monitoring program, and initialized using the January 1, 2025, volume. The model ran each alternative for all 400 traces and 3 initial conditions. Some modifications were made to the Mueller and Grams (2021) sandbar model to include additional sandbars in the calibration dataset, incorporate discharge-dependence into the erosion model, and assume a constant sandbar area (Salter et al. 2025). Two versions of the sandbar model were used to predict sandbar deposition: one for flow rates exceeding 8,000 cfs, the average daily discharge flow; and one for flow rates exceeding 25,000 cfs, the discharge at which sandbars will not be inundated during normal dam operations and will result in usable sandbars for recreational purposes (Salter et al. 2025). Except for modeled HFEs, the sandbar model did not include any sustained releases above 25,000 cfs over the calibration period. See **Section TA 5.2.1**, Methodology, in **TA-5**, Geomorphology and Sediment Resources, for additional information. The modeled sand transport, sandbar volumes, and reservoir operations data used in the impacts analysis is sourced from the USGS, GCMRC (Salter and Grams 2026).

Impact Analysis Area

The impact analysis area used for GCMRC sediment modeling data extends from the Colorado River at Glen Canyon Dam to Lake Mead, including sediment inputs from the Paria and Little Colorado River tributaries. The analysis area for the sandbar model (quantitative model) is from Lees Ferry (RM 0) through Diamond Creek (RM 225). The extent of this model is limited by the availability of study sites in the calibration dataset. However, it is expected that the findings for the reach between Lees Ferry and Diamond Creek are also representative for similar sandbars downstream to Separation Canyon (RM 240), the full-pool extent of Lake Mead. With low Lake Mead elevations, the Colorado River will cut new paths through the mouth of the reservoir, resulting in sediment redistribution that forms new bars and alters the reservoir's delta. Finer particles may remain in suspension and travel further downstream in the reservoir before settling, increasing sediment concentration near the upper reaches of Lake Mead. Impacts on water surface elevations and consequently erosion and deposition patterns in the delta region of Lake Powell may also result. Sediment redistribution within the reservoirs is not evaluated in this EIS due to the absence of an applicable model.

The proposed alternatives may modify the magnitude, timing, or variability of releases from Hoover Dam relative to existing operations. Any such changes would affect sediment resources downstream by altering sediment transport capacity and the degree to which available fine sediment is mobilized or retained. However, because the downstream reach is sediment-starved and the alternatives would not introduce new sources of sediment, significantly modify sediment supply, or change channel morphology, any effects on geomorphology and sedimentation downstream of Hoover Dam are expected to be negligible.

Assumptions

- Reclamation's future operations will remain responsive to hydrology, system conditions, and applicable legal and operational requirements. Reclamation will continue to follow 2016 LTEMP EIS and 2024 LTEMP SEIS guidelines, which include the planning and implementation team process that helps assess monthly release volumes and Secretarial decision-making.
- HFEs require sufficient sand in Marble Canyon (positive sand mass balance) and adequate Lake Powell water levels, both dependent on the chosen HFE duration.
- HFE releases can only be implemented above a 3,500-foot Lake Powell elevation, the elevation required for a release magnitude of 37,000 cfs (Reclamation 2024c; Salter et al. 2025).
- Non-HFE flows can deposit sand, but only sand deposited during flows above 25,000 cfs is considered usable for recreation.
- Sandbar building is fastest during the first 4 days; a 60-hour HFE produces strong deposition while allowing more frequent events and reducing interim erosion.
- Maximum ramp rates (4,000 cfs up / 2,500 cfs down per hour) are in accordance with 2016 and 2024 LTEMP guidelines.
- Sandbar volume modeling uses the assumption that HFEs are implemented as often as possible.
- Most of the sand input from the Paria and Little Colorado Rivers occurs during the summer-fall thunderstorm season between July 1 and November 1.
- If no HFE releases were implemented during the 1-year sediment accounting period, any positive sediment balance would be carried forward to the next accounting period.

Impact Indicators

Issues related to geomorphology and sedimentation that are evaluated in this section are listed below. Each of the five issues is associated with one or two "indicators," which serve as preferred minimum performance against which the issues are compared for the purpose of this analysis.

1. Water Availability in Lake Powell
2. Sand Mass
3. HFE Frequency and Duration
4. Sandbar Volume
5. Sand Transport

Issue 1: Water Availability

An HFE likely to enlarge sandbars requires enough water for a release rate of 37,000 cfs, generally considered the flow rate needed for significant deposition on certain sandbar types (Hazel et al. 2022). A 37,000 cfs release requires Lake Powell to be at or above 3,500 feet in April or November, when HFEs are typically scheduled. Alternatives that more frequently result in water levels greater than this threshold are therefore deemed preferable.

It should be noted that there are challenges to conducting HFEs at a Lake Powell elevation of 3,500 feet. Historically, the lowest elevation at which an HFE has been implemented was approximately 3,523 feet in April 2023. Since the models used an elevation of 3,500 feet as the lowest possible elevation at which HFEs could occur, it is likely that modeling overestimates the number or frequency of HFEs. **Table TA 5-1** in **TA 5**, Geomorphology and Sediment, shows the percentage of modeled HFEs by alternative that were above (or below) this lowest historical elevation.

Figure TA 5-2 in **TA 5**, Geomorphology and Sediment, depicts the ability of each alternative to maintain a Lake Powell pool elevation greater than 3,500 feet in November or April. The preferred minimum performance (the minimum result used as the comparison standard across alternatives) is shown in the highlighted row, which represents the percentage of futures that that an alternative exceeds 3,500 feet in November or April in 100 percent of years. The 3,500-foot threshold was selected because it is undesirable to ever miss the opportunity to take advantage of other favorable conditions such as large sediment loads from the Paria River. Over the 2027–2039 modeling period, the Maximum Operational Flexibility Alternative is the most robust meeting the preferred minimum performance in 97 percent of modeled futures (simulated hydrologic scenarios), followed by the Enhanced Coordination Alternative at 88 percent. The Representative Preferred Alternative meets the preferred minimum performance in 60 percent of futures.

The lowest Lake Powell elevation in the historical record (3,523 feet) is shown in **Figure TA 5-3** in **TA 5**, Geomorphology and Sediment, and displays the same information as **Figure TA 5-2**. With a 3,523-foot threshold, the Enhanced Coordination and Maximum Operational Flexibility Alternatives meet the preferred minimum performance in 29 percent and 24 percent of modeled futures, which is lower than with the 3,500-foot threshold. **Figure TA 5-4** in **TA 5**, Geomorphology and Sediment, also demonstrates that these two alternatives would be the least vulnerable with respect to water availability. The Representative Preferred Alternative meets the preferred minimum performance in 14 percent of futures.

Issue 2: Sand Mass

The second condition required for an HFE release is the availability of sand. Sand that accumulates in Marble Canyon and is transported downstream outside HFE events does not result in sandbar formation. While management under the proposed alternatives would not attempt to control the sediment generation in the Paria River and Little Colorado River, the alternatives would affect how much of that sediment is available for HFEs by impacting the timing and magnitude of releases outside HFE releases.

Glen Canyon Dam releases for hydropower generation tend to be high in July and August (Reclamation 2016). This period also coincides with the summer-fall thunderstorm season in the Paria and Little Colorado watersheds that causes sand to be transported to Marble Canyon. Sand tends to accumulate during September and October because the reduced releases are not enough to transport the sand downstream. Unless it is a particularly dry year, flows increase during the winter months, resulting in the transport of increasing quantities of sediment downstream.

While average flows must be lower than about 11,000 cfs to allow sediment accumulation under most initial conditions (bed conditions following a tributary sediment-supply event), flows greater than 15,000 cfs (900,000 af per month) are likely to be erosive regardless of those initial conditions (Salter et al. 2025). Therefore, futures with flows less than 900,000 af per month (i.e., non-erosive flows) for at least 90 percent of a simulation period are considered preferable. As detailed in **Figure TA 5-5** in **TA 5**, Geomorphology and Sediment, over the 2027–2039 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives meets this condition in 68 percent and 50 percent of simulated futures, respectively, while none of the other alternatives meet this condition in more than 41 percent of simulated futures (the Representative Preferred Alternative meets this conditions in 41 percent of simulated futures).

Historical data indicate that sandbar deposition typically occurs at HFE durations of 60 hours or greater (Grams et al. 2025). A 60-hour duration is required for successful beach building. **Figure TA 5-8** in **TA 5**, Geomorphology and Sediment, shows how often Marble Canyon sand mass exceeds 294,000 metric tons, the average transport capacity for a 60-hour HFE, in November or April. The highlighted row indicates the percentage of futures that meet this condition at least once every 4 years (the preferred minimum performance). Aside from the CCS Comparative Baseline, the percentage of futures in which November or April sand mass exceeds 294,000 metric tons at least every 4 years is comparable across the alternatives, ranging from 77 percent to 79 percent for the 2027–2039 modeling period. All alternatives perform better during each of the three subperiods than over the full modeling period, as the chance of at least one year with a sand mass below 294,000 metric tons increases over longer periods.

Issue 3: HFE Frequency and Duration

To allow for sandbar deposition that is sufficient to at least partially compensate for natural erosion in between HFEs, futures are considered preferable if they predict a spring or fall HFE of 60 hours or greater at least once every 4 years. A 60-hour duration is the minimum duration associated with significant sandbar deposition.

As shown in **Figure TA 5-9** in **TA 5**, Geomorphology and Sediment, for the 2027–2039 modeling period, aside from the CCS Comparative Baseline and No Action Alternative, the percent of futures in which annual HFE duration is greater than 60 hours at least once every four years, is comparable across the alternatives. The percentages range from 54 percent to 64 percent, but the Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best at 60 percent and 64 percent of simulated futures, respectively. This metric is limited by the availability of sand, given the high percentage with which Maximum Operational Flexibility and Enhanced Coordination Alternatives result in enough water for an HFE release (**Figure TA 5-2**). **Figure TA 5-10** in **TA 5**, Geomorphology and Sediment, also shows that Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives perform the best for HFE releases lasting 12 to 96 hours, with 46 percent, 43 percent, and 42 percent of years having HFE releases greater than or equal to 60 hours, respectively. This performance is notable because, excluding the HFE implemented on March 26, 1996, all HFEs implemented have been between 60 and 96 hours (Grams et al. 2025).

Figure TA 5-11 in **TA 5**, Geomorphology and Sediment, shows the distribution of HFE durations for the full sediment year (July 1 to July 1), fall, and spring. The distributions are further categorized into five hydrologic conditions based on the average natural flow rates at Lees Ferry over the preceding 3-year period. The figure illustrates a shift from fall HFE releases to spring HFE releases as the preceding 3-year average Lees Ferry natural flow decreases (i.e., conditions become drier). For the Critically Dry Flow Category (4.46–10.0 maf), only Maximum Operational Flexibility and Enhanced Coordination Alternatives result in HFE durations of any substantial duration, typically occurring in the spring, when snowpack is known and inflow volumes can be more easily predicted. It is important to note the modeling does not imply an expected outcome, just that HFEs remain possible. HFE triggers and final HFE implementation would be a result of the LTEMP process.

Issue 4: Sandbar Volume

The water level during a 25,000 cfs flow condition is the threshold above which camping and recreational activities are considered safe from flooding. The sandbar volume above this level represents the volume of "usable" sand in the canyon. As shown in **Figure TA 5-12** in **TA 5**, Geomorphology and Sediment, sandbar growth generally increases as hydrologic conditions become drier, and Enhanced Coordination and Maximum Operational Flexibility Alternatives perform the best in the Critically Dry Flow Category (4.46–10.0 maf).

Futures are considered preferable if *net* sandbar volumes exceed the sandbar volumes at the start of the simulation for 60 percent or more of the simulation period. As detailed in **Figure TA 5-13** in **TA 5**, Geomorphology and Sediment, the action alternatives perform well for this issue; at least 85 percent of futures have larger sandbar volumes than at the start of the 2027–2039 period for at least 60 percent of the simulation period. Even the CCS Comparative Baseline results in the preferred minimum performance for 68 percent of futures. For reference, the sandbar volume at the start of the simulation period is approximately 1,170 cubic meters (41,300 cubic feet). It is important to note that **Figure TA 5-13** in **TA 5**, does not show the percentage of years with year-over-year sandbar growth; if large increases in sandbar volume occur at the start of a period, it is very possible for sandbar volume to be lower than it was the year before and still be higher than it was at the start of the period. In addition, each future is based on a single simulation and consequently subdivided into the three modeling subperiods. The significant increase in sandbar volume during the 2027–2039 modeling period, when compared with the other subperiods, could be partially attributed to the modeling assumption that HFEs are implemented as often as possible.

Figure TA 5-14 in **TA 5**, Geomorphology and Sediment, shows this issue from a different perspective, providing the percentage of simulated years for which the maximum sandbar volume is less than or equal to a given value. Curves with lower placement in the plot imply better performance for that alternative. While the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) results in the best performance, differences among the alternatives are minimal. The average sandbar volume for the 25 sandbar monitoring sites at the start of the full modeling period is 1,169.512 cubic meters (see **Section TA.5.2.1**, Methodology).

Issue 5: Sand Transport

While sand can be transported downstream with flows well below 37,000 cfs, lower flows are not conducive to sandbar formation and retention. The higher the fraction of sand transported above 37,000 cfs, the more sand will be available for sandbar formation (Hazel et al. 2022; Salter et al. 2025).

Figure TA 5-15 in **TA 5**, Geomorphology and Sediment, shows the percentage of futures for which the total sand mass transported by flow rates above 37,000 cfs (sandbar-forming flow rates) exceeds a given fraction over the 34-year simulation period. Futures are considered preferable if the fraction of sand mass transported by sandbar-forming flow rates is at least 0.4 (40 percent of the sand transport). The highlighted row provides the percentage of futures that meet this criterion. Under the Maximum Operational Flexibility Alternative, 85 percent of simulated futures are considered preferable—that is, at least 40 percent of sand mass is transported by sandbar-forming flow rates in 85 percent of simulated futures. The Enhanced Coordination Alternative is similarly robust, at 83 percent of simulated futures. Performance for the Supply Driven (both LB Priority and LB Pro Rata approaches), Representative Preferred, and Basic Coordination Alternatives are similar, with 78 percent, 76 percent, and 75 percent of futures considered preferable, respectively.

Summary Comparison of Alternatives

Taken as a whole, the results of the analysis suggest that the Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with respect to geomorphology and sediment. This appears to be largely due to their superior ability to preserve Lake Powell water levels above 3,500 feet in November and April, one of two conditions required for an HFE release (**Figure TA 5-2** in **TA 5**, Geomorphology and Sediment). In contrast, the Representative Preferred Alternative performs noticeably weaker in this category, though slightly better than the other alternatives. Impacts to sand mass in Marble Canyon, the other condition required for an HFE release, are comparable across alternatives, including the CCS Comparative Baseline (**Figure TA 5-7** in **TA 5**, Geomorphology and Sediment). During the driest climatic conditions (for which the preceding 3-year average Lees Ferry natural flow is less than 10.0 maf), Maximum Operational Flexibility and Enhanced Coordination Alternatives are the only two alternatives that would result in HFEs of any substantial duration, typically occurring in the spring.

3.6 Water Quality

3.6.1 Affected Environment

Salinity

The Colorado River Basin Salinity Control Forum reviews and makes salinity criteria recommendations for the Colorado River every 3 years. Flow-weighted average annual salinity criteria for the Colorado River are currently 723 milligrams per liter (mg/L) below Hoover Dam, 747 mg/L below Parker Dam, and 879 mg/L at Imperial Dam (Colorado River Basin Salinity Control Forum 2023). The water quality standards for salinity in the Colorado River were approved by the Environmental Protection Agency (EPA) and are reviewed every three years pursuant to Section 303(c)(1) of the Clean Water Act (Colorado River Basin Salinity Control Forum 2023).

Salinity control is accomplished through multiple programs. Federal agencies, including Reclamation, the BLM, and the U.S. Department of Agriculture, pursue improvements on federal lands to reduce salinity loading to the Colorado River (Reclamation 2022). Since the construction of Glen Canyon Dam, annual salinity concentrations downstream of Glen Canyon Dam have varied between 400 and 600 mg/L (Richards 2025). In a review of sampling efforts from 2007–2023, Reclamation has not exceeded the salinity criteria for the Colorado River. See **Section TA 6.1.1**, Salinity, in **TA 6**, Water Quality, for more information on salinity in the planning area and historical salinity concentrations in the Lower Basin.

Temperature

Lake Powell is a monomictic[12] reservoir with strong thermal stratification through much of the spring, summer, and early fall; this means the water is layered, with distinct temperatures and chemical characteristics. Generally, Lake Powell's epilimnion, or uppermost layer, ranges from 25 to 30 degrees Celsius (°C; 77 to 86 degrees Fahrenheit [°F]) in the summer, dropping to 6 to 10 °C (42.8 to 50 °F) in the winter (Deemer et al. 2023). Lake Powell's hypolimnion, or deeper layer, ranges from 6 to 9 °C (42.8 to 48.2 °F) year-round. Since the early 2000s, lower water levels in Lake Powell have led to warmer summer water temperatures in the Colorado River below Glen Canyon Dam (Reclamation and NPS 2016). Temperatures in the Colorado River in the Grand Canyon vary widely over space and time and are primarily controlled by the discharge and temperature released from Glen Canyon Dam and solar radiation dynamics along the river corridor (Mihalevich et al. 2020).

Lake Mead is also monomictic. Lake Mead inflow temperatures are a function of Glen Canyon Dam discharges and downstream weather conditions (Reclamation 2016). Lake Mead's hypolimnion is around 12 °C (53.6 °F) year-round. Its epilimnion ranges from about 14 to 29 °C (57.2 to 84.2 °F) in the spring, summer, and early fall, and drops to about 13 to 15 °C (55.4 to 59 °F) in the winter (SNWA 2023). Further declines in reservoir elevation, coupled with rising air temperatures, may continue to lead to warmer releases from Lake Mead, though this depends on whether the lower Hoover Dam outlet is used (Hannoun et al. 2022).

Harmful Algal Blooms and Nutrients

Nutrients, such as nitrogen and phosphorus, are essential for life, but excess nutrients in water can harm human health and ecosystems and impact recreational opportunities (USGS 2019a; NPS 2025a). In the project area, the most severe algal blooms are caused by cyanobacteria, which can produce toxins that can threaten drinking water quality and harm human health (USGS 2019a). In Lake Mead, water within Las Vegas Bay has the highest concentration of nutrients due to discharges of highly treated wastewater from the Las Vegas metropolitan area. Wastewater is a persistent contributor of phosphorus, whereas stormwater with higher phosphorus contributions is an acute contributor but a minor source overall. This is because storm events are infrequent. Since phosphorus is a limiting nutrient in the Colorado River system, these contributions support algal growth (USGS 2012). Lowering reservoir levels could increase the concentration of nutrients and temperatures, especially in shallow areas, which could be more favorable for algal growth (Hannoun et al. 2022).

[12] Monomictic waterbodies are those that mix completely during one mixing period each year.

Dissolved Oxygen

Dissolved oxygen is a critical factor for fish health. Research on dissolved oxygen thresholds for both warmwater and cold-water fish species shows that salmonids are particularly vulnerable to low dissolved oxygen concentrations compared with warmwater species (Saari 2018). Sustained dissolved oxygen levels below 3 mg/L can significantly reduce survival rates and feeding efficiency, whereas concentrations in the range of 6 to 9 mg/L are considered optimal for growth and survival across all life stages (EPA 1986).

Generally, Lake Powell's dissolved oxygen concentrations are at their highest in the spring to early summer, when inflows are well oxygenated and wind-induced mixing is high. Low dissolved oxygen concentrations move through the reservoir and closer to the dam during the summer into the fall because of organic matter decomposition and chemical reactions that consume oxygen. Dissolved oxygen gradually increases in the winter as a result of the higher oxygen-carrying capacity of cold water and the natural mixing during turnover. When water is discharged through the river outlet works, it becomes well aerated and increases the dissolved oxygen levels in the tailwaters, but only while the river outlet works are open.

Recently, dissolved oxygen levels in Lake Powell and the Glen Canyon Dam tailwaters[13] have been low compared with historical dissolved oxygen levels. This is due to low reservoir elevations and the increasing reservoir age (Deemer et al. 2025). Dissolved oxygen levels below Glen Canyon Dam vary throughout the year, falling as low as 2.2 mg/L in the summer and rising as high as 9 to 10 mg/L in the spring (GCMRC 2025). Dissolved oxygen increases approximately 1 mg/L between Glen Canyon Dam and Lees Ferry. Low dissolved oxygen conditions improve downstream of the Paria Riffle and Badger Rapids as the water is reaerated through whitewater action.

In Lake Mead, dissolved oxygen levels decrease in the bottom of Las Vegas Bay as a result of high decomposition of organic matter from the Las Vegas Wash. When there are greater nutrients in surface water, generally more decomposition and low oxygen occur in bottom waters. Monitoring is ongoing to determine the cause of decreased dissolved oxygen concentrations in isolated areas, but the driver is likely higher temperatures from inflows (Reclamation and NPS 2016).

Metals, Perchlorate, and Per- and Polyfluoroalkyl Substances

The planning area contains sources of metals and regulated chemicals, including perchlorate and per- and polyfluoroalkyl substances (PFAS), although metals are not a typical concern in the planning area and mitigation programs have successfully reduced perchlorate concentrations below applicable regulatory limits throughout the lower basin (Hannoun and Tiejen 2022). Generally, as reservoir elevations decrease, the dilution capacity of reservoirs like Lake Powell and Lake Mead would also decrease. Decreased dilution capacity from lower reservoir elevations could result in greater concentrations of pollutants of concern. For more information, see **Sections TA 6.1.5**, Metals; **TA 6.1.6**, Perchlorate; and **TA 6.1.7**, PFAS, in **TA 6**, Water Quality.

[13] Tailwater refers to waters located immediately below the dam. It is the reach of river immediately downstream of a reservoir that is heavily influenced by reservoir characteristics. Tailwaters are generally expected to have water quality that is more similar to the water quality in reservoirs compared with reaches farther downstream.

3.6.2 Environmental Consequences

Methodology

The analysis methodology for water quality is based on a combination of DMDU; CRSS; GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon; and qualitative analysis. For detailed information on the dissolved oxygen and water temperature models, see **Section TA 6.2.1**, Methodology, in **TA 6**, Water Quality, for more information.

CRSS simulates Colorado River Basin conditions decades into the future and can account for hydrologic uncertainty. CRSS is a monthly time-step model that produces reservoir elevations, dam releases, and salinity concentrations. Refer to **Appendix A**, CRSS Model Documentation for more details on model documentation.

In this section, salinity is analyzed as it relates to the salinity criteria set by the Colorado River Salinity Control Forum. For information on salinity concentration and salinity related to the potential effects on resources in the International Border Region, see **Appendix N**, International Border Region of the Colorado River.

Conditional box plots and robustness heat maps that describe impacts on water quality can be found in **TA 6**. Refer to **Section 3.2**, Analysis Methods, for additional information on interpreting the DMDU conditional box plots, robustness heat maps and vulnerability bar plots.

While reduced water deliveries could have impacts to downstream municipal users, the analysis does not include an analysis of these impacts since the operations of municipal water providers fall outside of Reclamation's regulatory authority and are carried out independently by these third parties.

Impact Analysis Area

The analysis area for water quality is the geographic and temporal scope introduced in **Section 3.2**, Analysis Methods. Due to the data available, the analysis was limited to surface water quality.

Assumptions

- There will be modifications in quantity, timing, temperature, and quality of water released from Glen Canyon Dam and Hoover Dam.

Impact Indicators

- Salinity
- Temperature
- Dissolved oxygen
- Reservoir elevation
- Dilution capacity

Issue 1: How would reservoir storage, reservoir releases, and corresponding changes in river flows downstream of the reservoirs affect salinity?

Increased salinity concentrations from human activities pose a threat to drinking water, irrigation, agricultural production, municipal water supplies, and infrastructure. Reservoirs like Lake Powell and

Lake Mead influence salinity by reducing the effect of salinity transport downstream and possibly acting as a source or a sink (Deemer 2020). Dam releases are typically from deeper in the water column and generally have elevated salinity concentrations relative to surface waters. As reservoir water levels drop, reservoir salinity can often increase (Zohary and Ostrovsky 2011).

Using CRSS outputs, annual flow-weighted average salinity concentrations below Hoover Dam, below Parker Dam, and at Imperial Dam were simulated under various hydrologic conditions. Under all alternatives, a majority (90 percent or greater) of simulated futures did not exceed the salinity criteria in even the most challenging hydrologic conditions. For the Average Flow Category, maximum simulated annual flow-weighted salinity concentrations exceeded the salinity threshold below Hoover Dam under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives. See **Figure TA 6-4** in **TA 6**, Water Quality, for box plots depicting these annual flow-weighted average salinity concentrations.

Under the Dry Flow Category, all alternatives exceeded the threshold, with an increasing number in the Critically Dry Flow Category due to the low reservoir elevations associated with these hydrologic conditions. The highest median salinity concentrations occur in the Enhanced Coordination Alternative, with the difference between the alternatives largest in the Critically Dry Flow Category. Simulated flow-weighted average salinity concentration median values did not exceed salinity thresholds at all sites under all alternatives, even under the driest flow scenarios. Therefore, no significant negative impacts on salinity were associated with any of the alternatives.

All alternatives are truly robust, meeting the preferred level of performance in 90 percent of futures or greater in the first decadal period (that is, 2027 to 2039) below Hoover Dam, below Parker Dam, and at Imperial Dam. See **Figures TA 6-5**, **TA 6-6**, and **TA 6-7** in **TA 6**, Water Quality, for robustness plots of the percentage of futures in which the salinity concentration is less than salinity criteria below Hoover Dam, below Parker Dam, and at Imperial Dam in 100 percent of years.

In a vulnerability analysis of conditions that could cause salinity concentrations below Hoover Dam to exceed 723 mg/L in one or more years, if the future includes a 10-year average flow of 11.8 maf or lower, modeling results do not indicate undesirable performance for all alternatives; over 75 percent of the reference hydrology include averages this low or lower. Further, the hydrologic conditions associated with undesirable performance for the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) (6.8 maf) are less than that of any previously observed conditions in the reference hydrology (7.8 maf). See **Figure TA 6-8** in **TA 6**, Water Quality, for additional information on the vulnerability plot displaying conditions that could cause salinity below Hoover Dam to exceed 723 mg/L in one or more years under each alternative.

Issue 2: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect water temperature?

Water temperature strongly influences biological and chemical processes. For example, the temperature of dam releases affects fish population dynamics in downstream river segments, and elevated reservoir temperatures can lead to harmful algal blooms. **Sections TA 8.2.3**, Issue 2 and **TA 8.2.5**, Issue 4 in **TA 8**, Biological Resources – Fish and Other Aquatic Species, describe the impacts of temperature on fish and other aquatic species at temperature thresholds of 12 °C, 16 °C, and 20 °C (53.6 °F, 60.8 °F, and 68 °F).

Using outputs from GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon, the annual average of daily temperatures and annual maximum Colorado River temperatures at Lees Ferry were simulated under various hydrologic conditions. As shown in **Figure TA 6-9** in **TA 6**, Water Quality, at Lees Ferry under the Average Flow Category, the Enhanced Coordination and Maximum Operational Flexibility Alternatives had lower median simulated annual average and maximum daily temperatures, with a narrower interquartile range, compared with the other alternatives at both Lees Ferry and Pearce Ferry.

Under the Dry and Critically Dry Flow Categories, simulated median values for temperatures increased across alternatives, compared with the Wet and Moderately Wet Flow Categories, and the Enhanced Coordination Alternative had the lowest median values for simulated average and maximum temperatures. Additionally, the interquartile ranges increased across all alternatives, indicating more variability in the annual average of daily temperatures and maximum temperatures as flow conditions become drier. For additional information on the simulated average and maximum Colorado River temperatures at Lees Ferry under various hydrologic conditions, see **TA 6**, Water Quality.

Considering the impacts on fish and other aquatic species, the Enhanced Coordination Alternative had the greatest number of simulated futures that maintained cooler water temperatures at Lees Ferry. These cooler temperatures are beneficial for rainbow trout, and they limit smallmouth bass reproduction, but these temperatures also inhibit native fish growth and reproduction. See **TA 8**, Biological Resources – Fish and Other Aquatic Species, for additional information on changes in water temperature from Glen Canyon Dam downstream through the Grand Canyon to Pearce Ferry and impacts to sportfish, native Grand Canyon fish, and nonnative predatory fish. See **TA 14**, Recreation, for more detailed information on temperature impacts associated with sportfish populations.

Issue 3: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect dissolved oxygen?

Dissolved oxygen dynamics can be affected by reservoir drawdowns through several pathways, including remobilization of deposited sediment as water levels change. As older reservoirs like Lake Powell experience lower elevations, there is greater metalimnion dissolved oxygen consumption, with larger spring snowmelt inflows furthering dissolved oxygen declines (Deemer et al. 2025). Dissolved oxygen is also affected by certain operations. For example, as reservoir levels decrease below 3,490 feet at Lake Powell, use of the river outlet works is triggered; this leads to high dissolved oxygen concentrations downstream of Glen Canyon Dam due to aeration as water passes through the river outlet works (Vernieu 2010).

Using outputs from GCMRC Dissolved Oxygen and Temperature Models for Glen Canyon, Lees Ferry, and Grand Canyon, minimum annual dissolved oxygen concentrations released from Glen Canyon Dam under each alternative were simulated under various hydrologic conditions. Under dry conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives generally had higher simulated minimum annual dissolved oxygen concentrations than the other alternatives, but generally lower simulated minimum annual dissolved oxygen concentrations under critically dry conditions. See **Figure TA 6-11** in **TA 6**, Water Quality, for additional information on minimum annual dissolved oxygen concentration released from Glen Canyon Dam under various hydrologic conditions.

Below 3,490 feet at Lake Powell, releases from the river outlet works would effectively aerate the water, but its use would be limited over the long term to protect Glen Canyon Dam infrastructure. Therefore, elevation at Lake Powell below 3,490 feet and minimum annual dissolved oxygen concentration greater than 2 mg/L were considered. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust, meeting the preferred level of performance in a majority of futures for the first decadal period (that is, 2027-2039). The simulated minimum dissolved oxygen concentrations are greater than 2 mg/L in the fewest number of futures under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives in the first decadal period (that is, 2027-2039). See **Figure TA 6-12** in **TA 6**, Water Quality, for additional information on the robustness of minimum annual dissolved oxygen concentration where the Lake Powell elevation stays above 3,490 feet.

Due to the limitation of long-term use of the river outlet works, vulnerability was only analyzed for conditions that could cause dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years. Only the Enhanced Coordination and Maximum Operational Flexibility Alternatives resulted in undesirable performance (dissolved oxygen concentrations from Glen Canyon Dam releases falling below 2 mg/L or Lake Powell elevations below 3,490 feet) below the lowest 25 percent of previously observed hydrologic conditions. The hydrologic conditions associated with undesirable performance for the CCS Comparative Baseline and the No Action, Basic Coordination, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives fall within a majority of hydrologic conditions that have already been observed. See **Figure TA 6-14** in **TA 6**, Water Quality, for additional information on the vulnerability analysis of conditions that could cause a dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years.

Dissolved oxygen impacts on fish were also analyzed by considering dissolved oxygen concentrations less than 3 mg/L, which is a concentration that leads to reduced survival and feeding efficiencies. Under the Critically Dry Flow Category (4.46–10.0 maf), Lake Powell elevations stay above 3,490 feet, and the simulated minimum annual dissolved oxygen concentration is greater than 3 mg/L, which is critical for fish survival and feeding efficiencies, in at least 90 percent of the years in the greatest percent of futures under the Enhanced Coordination Alternative. See **TA 8**, Biological Resources – Fish and Other Aquatic Species, for more information on the impact of dissolved oxygen on fish.

Issue 4: How would reservoir storage, reservoir releases, and the corresponding changes in river flows downstream of the reservoirs affect harmful algal blooms and nutrients?

Cyanobacteria blooms can alter physical and chemical water quality properties, threaten aquatic species, and release toxins into waterbodies, leading to health effects on recreationists and affecting water supplies. In a mixed-methods literature review assessing risk for cyanobacteria and phytoplankton in response to water level changes, with potential application to Lake Powell and Lake Mead, cyanobacteria were substantially more likely to increase in response to decreases in water levels. The review also suggested that the prevalence of cyanobacteria increases when reservoir water levels decline, subsequently increasing the risk of cyanobacterial blooms in reservoirs with more severe fluctuations in water levels (Hoffman 2025). However, examples also exist of no marked water quality response to long-term water level drawdown, including at Lake Mead. For example, Lake Mead experienced dramatic multiyear reductions in the water level with no apparent effects on nutrient or chlorophyll concentrations (Hannoun and Tietjen 2022).

In a qualitative analysis of simulated reservoir elevations at Lake Powell, the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives would pose an increased risk of cyanobacterial blooms due to the lower simulated Lake Powell elevations. These increased risks would be greatest under the Critically Dry Flow Category (4.46–10.0 maf) associated with lower reservoir elevations. The Enhanced Coordination and Maximum Flexibility Alternatives had the greatest number of simulated futures in which the maximum annual change in water surface elevation was less than 30.71 feet in 5 years or more out of 10 years during the first decadal period (that is, 2027-2039). This could decrease the risk of cyanobacterial blooms associated with severe fluctuations in water levels under the Enhanced Coordination and Maximum Flexibility Alternatives, compared with the other alternatives. For additional information about water quality impacts related to cyanobacteria, see **Section TA 6.2.5**, Issue 4, in **TA 6**, Water Quality. For additional information on how operational activities for the various alternatives would affect reservoir elevations, see **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources.

Issue 5: How would reservoir storage and reservoir releases affect reservoir dilution capacity?

Generally, as reservoir elevations decrease, the dilution capacity of reservoirs like Lake Powell and Lake Mead also decreases. Decreased dilution capacity from lower reservoir elevations could result in greater concentrations of pollutants of concern, such as PFAS and perchlorate.

Given the current data and modeling capabilities, the impacts of the alternatives on pollutants of concern could not be quantitatively assessed. A qualitative review of reservoir elevations under **Section TA 3.2.1**, Issue 1: Reservoir Elevations, indicates that the impact of decreased dilution capacity associated with lower reservoir elevations on pollutants of concern, such as PFAS and perchlorate, would be greatest under the alternatives with the lowest median WY minimum reservoir elevations, including the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives. However, this impact would likely be negligible since it is unlikely that any of the reservoir elevations under the alternatives would significantly reduce dilution capacity or increase the concentration of pollutants of concern.

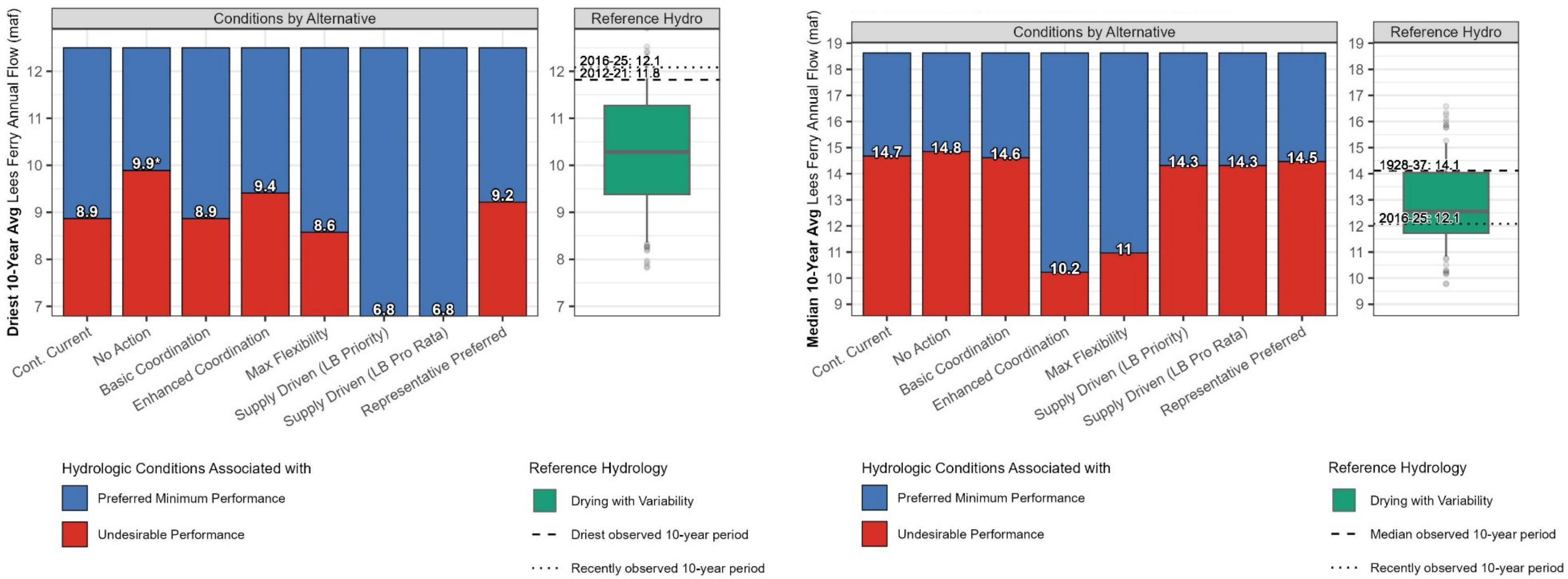
Summary Comparison of Alternatives

In a comparison of the vulnerability analyses for conditions that could cause undesirable performance for simulated salinity and dissolved oxygen, **Figure 3-19** shows that, generally, the CCS Comparative Baseline, and the No Action, Basic Coordination, and Representative Preferred Alternatives are vulnerable to undesirable performance under a relatively wide range of conditions for both simulated salinity and dissolved oxygen compared to the least vulnerable alternatives. **Figure 3-19** also shows that there are vulnerability trade-offs between the two indicators associated with the other alternatives.

Considering simulated salinity, under the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches), the hydrologic conditions associated with undesirable performance (a 10-year drought averaging 6.8 maf or lower) are drier than any conditions in the observed record or the reference hydrology ensemble, in which the lowest 10-year drought averaged 7.8 maf, so they have

Figure 3-19
Conditions that Could Cause Undesirable Performance for Salinity and Dissolved Oxygen

Salinity* / Dissolved Oxygen**



*Undesirable performance for salinity means conditions that could cause salinity below Hoover Dam above 723 mg/L in one or more years.
**Undesirable performance for dissolved oxygen means conditions that could cause dissolved oxygen concentration less than 2 mg/L or Lake Powell elevation below 3,490 feet in more than 10 percent of years.

low vulnerability. However, vulnerability with respect to dissolved oxygen is high: the median 10-year-average flows associated with undesirable performance under the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches) was 14.3 maf; this is wetter than the median observed 10-year period flow from 1928 to 1937 (14.1 maf). Additionally, almost 75 percent of the traces in the reference hydrology ensemble have median 10-year average flows drier than this.

Similarly, there are vulnerability trade-offs associated with the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Considering simulated dissolved oxygen, the Enhanced Coordination Alternative would be vulnerable if the median 10-year-average flow was 10.2 maf or drier, and the Maximum Operational Flexibility Alternative would be vulnerable in the median 10-year-average flow was 11 maf or drier; these conditions are drier than 90 to 100 percent of the traces in the refence hydrology ensemble and far below any observed 10-year-average flow. However, considering simulated salinity, the Enhanced Coordination and Maximum Operational Flexibility Alternatives result in undesirable performance under hydrologic conditions that are greater than the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches). Still, more than 75 percent of the traces in the reference hydrology ensemble are wetter than these values, so the vulnerability is not high.

In comparison of relative values for Lake Powell's reservoir elevation and the Colorado River temperature at Lees Ferry, the alternatives that had higher reservoir elevations would decrease the risk for cyanobacterial blooms and increase the dilution capacity for pollutants. These alternatives also had lower temperatures. This is because the Colorado River temperature at Lees Ferry is influenced in part by Lake Powell's reservoir elevation. The Enhanced Coordination Alternative had the highest median values for WY minimum Lake Powell elevations and the lowest average and maximum temperatures, compared with the other alternatives. The Maximum Operational Flexibility Alternative also had some of the highest median values for WY minimum Lake Powell elevations and some of the lowest average and maximum temperatures, compared with the other alternatives. The Representative Preferred Alternative had the third highest median WY minimum.

Lake Powell elevation so this alternative poses a decreased risk for cyanobacterial blooms and decreased risk of greater concentration of pollutants of concern but it is unlikely that any of the reservoir elevations of the alternatives would substantially reduce the dilution capacity and increase the concentration of pollutants of concern.

Overall, the Enhanced Coordination and Maximum Operational Flexibility Alternatives had the lowest vulnerability for dissolved oxygen and relatively lower maximum and average Colorado River temperatures at Lees Ferry, compared with the other alternatives. These two alternatives were slightly more vulnerable with respect to simulated salinity compared with the Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches); however, the hydrologic condition associated with undesirable salinity performance for the Enhanced Coordination and Maximum Operational Flexibility Alternatives were still drier than more than 75 percent of the traces in the reference hydrology ensemble.

3.7 Air Quality

3.7.1 Affected Environment

This section presents the existing conditions, regulatory framework, applicable laws, and available studies and resources related to air quality. Congress enacted the Clean Air Act (CAA) to ensure acceptable and nonhazardous air quality for the people of the U.S. The EPA subsequently established the National Ambient Air Quality Standards (NAAQS) for pollutants considered harmful to public health and the environment, referred to as criteria pollutants (EPA 2025a). **Table TA 7-1**, in **TA 7**, shows the current NAAQS for each pollutant, which have been fully adopted by Utah, Arizona, and Nevada. The air pollutant sources in Arizona, Nevada, and Utah fall under different jurisdictions and each state implements regulations that further govern fugitive dust, which are discussed in more detail in **Section TA 7.1.4.**

For each criteria pollutant, the EPA classifies areas as in "attainment" if the area complies with the NAAQS or as "nonattainment" if one or more of the NAAQS are exceeded. Areas for which available data are not sufficient to make an attainment status designation are listed as unclassifiable. Air quality is considered in "attainment" or "unclassifiable" for all criteria pollutants within the Arizona counties of La Paz, Mohave, Coconino, Yavapai, and Navajo and the Utah counties of Washington, Kane, and San Juan. Clark County, Nevada, has been designated as serious nonattainment for the 2015 8-hour ozone (O_3) standard and a maintenance area for carbon monoxide (CO) and particulate matter less than 10 microns in diameter (PM_{10}); the county is considered in "attainment" or "unclassifiable" for all other pollutants (EPA 2025b). Air quality within Yuma County, Arizona, has been designated as marginal nonattainment for the 2015 8-hour O_3 standard and moderate nonattainment for PM_{10}; it is considered in "attainment" or "unclassifiable" for all other pollutants. Therefore, the General Conformity Rule would apply for O_3, CO, and PM_{10}. The general conformity de minimis thresholds for all pollutants are presented in **Table TA 7-2**.

CAA regulations also control the release of hazardous air pollutants (HAPs), which are chemicals that are known or suspected to cause cancer or other serious health effects. The NAAQS have not been set for HAPs; rather, HAP emissions are controlled by source type– or industrial sector–specific regulations using maximum achievable control technology standards. There are no project-specific applicable maximum achievable control technology requirements regarding HAPs, as these standards only apply to stationary sources within specific industrial groups.

Several tables present the existing conditions for the analysis area. Criteria pollutants are monitored throughout various parts of the country. The EPA uses the criteria pollutant monitoring data to determine a "design value" for each pollutant and averaging time, which can be compared with the NAAQS. The most recent available 2024 design values for the analysis area counties are provided in **Table TA 7-3**, **Table TA 7-4,** and **Table TA 7-5**. The design value for O_3 for Clark County exceeds the NAAQS for O_3 (0.70 parts per million), and the number of exceedances of the PM_{10} NAAQS exceeds the standard for Clark County. No other design value listed in **Table TA 7-3**, **Table TA 7-4,** and **Table TA 7-5** exceed or approach proximity to the NAAQS (EPA 2025c). In addition, triennially, the EPA publishes a comprehensive summary of air emissions data, known as the National Emissions Inventory (NEI). **Table TA 7-7** through **Table TA 7-10** present the most recent 2020 emissions for the six criteria air pollutants and HAPs for the U.S.; the states of Arizona, Nevada, and Utah; and all counties in the analysis area. The EPA uses the NEI to develop and review regulations, conduct air quality modeling, and conduct risk assessments to understand how air pollution may affect the health in communities across the country.

As set forth in the CAA, the EPA developed and implemented the Prevention of Significant Deterioration (PSD) regulations to protect public health and welfare and to preserve, protect, and enhance the air quality in areas of special value. As part of the PSD, the EPA classifies airsheds as Class I, which are areas for which the PSD regulations provide special protection, or Class II, which allows for moderate pollution increases and reasonable growth, while still applying stringent air quality constraints (NPS 2023a). **Table TA 7-11** presents the Class I areas located within the analysis area and those located in counties adjacent to the analysis area. For those Class I areas that are national parks, the table also provides visibility data. **Table TA 7-11** shows that the visibility ranges from fair to good. In addition, the NPS monitors and evaluates deposition to identify parks that are most at risk and where conditions are declining or improving (NPS 2024a). **Table TA 7-12** shows that nitrogen deposition conditions are fair to poor and sulfur deposition conditions are good, with trend data unavailable for most locations.

Regional modeling, studies, and data discussed that pertain to the analysis area are as follows:

- Historical to present Lake Powell and Lake Mead pool elevations: Figures showing the Lake Powell pool elevations for 1963 through 2025 and the Lake Mead pool elevations for 1935 through 2025.
- Lake Powell and Lake Mead Modeling: This is a 2024 study to model the exposed shoreline area and potential dust emissions at the two reservoirs (Sankey et al. 2024).
- Lake Mead Annual High and Low Elevations: Annual high and low elevations of Lake Mead for years 1935–2024 are available from Reclamation.
- Lake Powell Annual High and Low Elevations: Annual high and low elevations of Lake Powell for years 1964–2024 are available from Reclamation.
- Lake Mead Mapping: The USGS completed a detailed geophysical mapping of the floor of Lake Mead during 1999, 2000, and 2001. These data indicate that a large volume of sediment carried by the Colorado River has accumulated in Lake Mead.
- Lake Powell Mapping: This is a survey of Lake Powell for the purpose of calculating the elevation-area-capacity relationships in Lake Powell.
- Impact of Lost Generation at the Glen Canyon Powerplant: This report presents data showing the changes in generation sources for each of the years 2024–2027.
- Owens Lake California Environmental Quality Act (CEQA) Initial Study: Discussed the Owens Lake Dust Mitigation Program and the objective to implement dust control measures on Owens Lake to reduce emissions. The potential future change for Lake Powell and Lake Mead may also highlight the need for a similar dust mitigation program, should water levels decrease below 500 km^2, for each lake.

Past and present climate trends and impacts are provided for Nevada, Arizona, and Utah. An analysis of regional climate impacts concluded that the rate of average annual temperature increases in the southwest U.S. was among the most rapid nationally (IPCC 2021). Analysis of past records indicates an overall increase in regional temperatures, including in the analysis area. The National Oceanic and

Atmospheric Administration's National Centers for Environmental Information released its climate summaries by state in 2022. The climate summaries for the analysis area states are summarized. More detailed climate discussions for each state can be found through the State Climate Summaries web page (NOAA 2022).

3.7.2 Environmental Consequences

Methodology

This section examines potential effects on air quality resources under the action alternatives and the No Action Alternative, compared with the CCS Comparative Baseline. Potential impacts are considered for the following air quality resources: shoreline exposure area, fugitive dust emissions, and how changes in hydropower impact CO_2e.

CRSS is used in the hydrologic analysis, and the output is organized into five flow condition categories. The five flow condition categories are framed as the Wet Flow Category (16.0–31.11 maf), Moderately Wet Flow Category (14.0–16.0 maf), Average Flow Category (12.0–14.0 maf), Dry Flow Category (10.0–12.0 maf), and Critically Dry Flow Category (4.46–10.0 maf). There are 400 different hydrologic traces for each year over a 34-year period, as shown in **Figure TA 7-2** in **TA 7**, Air Quality.

To support evaluating how potential changes in reservoir water storage might affect potential dust emissions from subaerially exposed reservoir sediment, the subaerial shoreline area and potential dust emissions within Lake Powell and Lake Mead were modeled for this analysis. The shoreline exposure analysis used previously published topographic and bathymetric surveys and geologic mapping (Hirschberg and Pitts 2000; Jones and Root 2021, 2022; Ferrari 2001; Root et al. 2019; Root and Jones 2022; Twichell et al. 2003; Twichell and Cross 2009; Wilson et al. 1969) with new predictions of potential dust emissions using the FENGSHA model (Mallia et al. 2017). The results are presented as Glen Canyon and Lake Mead exposed shoreline area and associated emission rates (Fischella et al. 2026). Resource modeling predicts: 1) the area of subaerial shoreline exposed as a function of monthly water surface elevations at Lake Powell and Lake Mead (respectively); 2) potential dust emissions ($kg/m^2/hr$) as a function of monthly water surface elevations at Lake Powell and Lake Mead modeled using FENGSHA with sustained winds for 15 m/s (approximately 35 miles per hour) for 6 hours. The results are presented as Glen Canyon and Lake Mead exposed shoreline area and associated emission rates (Fischella et al. 2026). Impacts on shoreline exposure and fugitive dust emissions are then described using conditional box plots, as well as DMDU robustness heat maps and vulnerability bar plots. In a conditional box plot, the bold center line of each box represents the median value, the top and bottom of each box capture the 25th to 75th percentile of the modeled results, the lines extend to the 10th and 90th percentiles, and the outliers are represented as dots beyond these lines. Refer to **Appendix E**, DMDU Overview and Approach, for an overview of how to interpret the DMDU robustness heat maps and vulnerability bar plots.

Subaerially exposed shoreline area and potential dust emissions increase as water storage decreases. However, the relationships differ at the two reservoirs due to surficial geology, deposition of reservoir sediment, and topographic and bathymetric terrain; Glen Canyon Dam impounded a deep canyon-bound segment of the Colorado River at Lake Powell, whereas Hoover Dam impounded a comparably broader valley of the river at Lake Mead. When Lake Powell and Lake Mead are filled to minimum power pool, approximately 500 km^2 (123,552 acres) of shoreline is exposed at each reservoir, although this estimate is highly approximate. The minimum power pool, or the lowest reservoir water level at which turbines can continue generating electricity efficiently, is 3,450 feet for Lake Powell and 950 feet for Lake Mead.

Lake Mead $PM_{2.5}$ emissions below 500 million kg (1,102 million pounds) ensures that fugitive dust would be minimized protecting air quality in the area and represents the reasonable approximation of the emission value that would occur when the lake is full enough with water to operate the dam to generate power. Lake Powell $PM_{2.5}$ emissions below 450 million kg (992 million pounds) ensures that fugitive dust would be minimized protecting air quality in the area and represents the reasonable approximation of the emission value that would occur when the lake is full enough with water to operate the dam to generate power.

The increase or decrease in metric tons of CO_2e emissions due to changes in hydropower generation at Glen Canyon Dam, Hoover Dam, Parker Dam, and Davis Dam are presented in conditional box plots. The conditional box plot for each dam compares the median CCS Comparative Baseline generation to the median generation for each alternative and multiple natural flow groups. In each year of every modeled future, the difference in annual hydropower generation between the CCS Comparative Baseline and each alternative was computed to determine the change in generation, whether that be an increase or a decrease. The annual change in generation was multiplied by the 2025 and 2050 Emissions and Generation Resource Integrated Database/National Laboratory of the Rockies emission factor. **Table TA 7-19** and **Table TA 7-20** in **TA 7**, Air Quality, show how the 2025 and 2050 weighted average emission factors were calculated. These emission factors represent the potential CO_2e from each resource type per megawatt-hour (MWh) and the current and future resource mix percentages for the Western Regional Climate Center energy production. The weighted emission factors are multiplied by the changes in MWh for each alternative and flow category.

Impact Analysis Area

The geographic scope of the air quality resources analysis includes Lake Powell to the SIB, which includes Mohave, Coconino, Yavapai, and Navajo Counties in Arizona; Washington, San Juan, and Kane Counties in Utah; and Clark County, Nevada. Specifically, the shoreline exposure analysis area includes Lake Powell and Lake Powell. The analysis areas for changes in CO_2e due to hydropower generation include Glen Canyon Dam, Hoover Dam, Parker Dam, and Davis Dam. The climate trends analysis area is discussed for the western U.S.

Assumptions

- The hydrologic resources results are direct results from CRSS. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation.
- The National Laboratory of the Rockies publishes life cycle assessments and which CO_2e emission factors are associated with each type of electricity generation (NLR 2021).
- The EPA 2023 Emissions and Generation Resource Integrated Database was used to determine the North American Electric Reliability Corporation resource mix (coal, natural gas, oil, nuclear, hydropower, biomass, wind, solar, and geothermal sources) for the Western Electricity Coordinating Council region (EPA 2025d).
- The U.S. Energy Information Administration's Annual Energy Outlook 2023 (EIA 2023) provides the potential generation mix for 2050.

The equivalency calculator is used to convert emissions into concrete, understandable terms, such as the annual CO_2 emissions of cars, households, and powerplants (EPA 2025e).

Impact Indicators

Specific impact indicators were selected to help frame the air quality resources analysis for each alternative. The following indicators were used to assess impacts:

- Shoreline Exposure: These are effects on the shoreline exposure area due to operational activities.
- Shoreline Dust Emissions: These are effects on shoreline dust emissions due to operational activities.
- Potential Change of CO_2e Emissions due to a Fluctuation of Hydropower Generation: These are effects on CO_2e emissions due to operational activities.

Issue 1: How would changing flow characteristics affect the potential exposed shoreline, fallowed agricultural lands, and fugitive dust?

Changes in water storage in lakes can affect the area of shoreline sediment exposed subaerially and potentially available for aeolian transport. This resource modeling evaluates how potential changes in reservoir water storage might affect potential dust emissions from subaerially exposed reservoir sediment. Relationships between potential dust emissions and water storage could be useful for evaluating air quality and related resource impacts associated with Colorado River water management decisions.

Figure TA 7-4 in **TA 7**, Air Quality, shows the WY maximum exposed shoreline area for Lake Powell and Lake Mead. In the Average Flow Category (12.0–14.0 maf), Lake Powell alternatives have varying distributions, with the 25th to 75th percentiles across all alternatives spanning from 225 to 500 km^2 (55,598 to 123,552 acres) of maximum exposed shoreline. The CCS Comparative Baseline, as well as the No Action, Basic Coordination, Representative Preferred and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives, all show similar medians of roughly 400 km^2 (98,842 acres) of maximum exposed shoreline. The Enhanced Coordination and Maximum Operational Flexibility Alternatives have lower and comparable medians of about 300 km^2 (74,132 acres) of maximum exposed shoreline.

The Lake Mead alternatives have varying Average Flow Category distributions, with the 25th to 75th percentiles across all alternatives spanning from 125 to 500 km^2 (30,888 to 123,552 acres) of maximum exposed shoreline. The Supply Driven (both LB Priority and LB Pro Rata approaches) Alternative has the lowest median maximum exposed shoreline, at about 230 km^2 (56,834 acres). The No Action Alternative has the highest median value at roughly 470 km^2 (66,718 acres). The Representative Preferred Alternative has a median maximum exposed shoreline of about 300 km^2 (74,132 acres), with the 25th to 75th percentiles across all alternatives spanning from 220 to 390 km^2 (54,393 to 96,371 acres) of maximum exposed shoreline.

In the Dry Flow Category (10.0–12.0 maf), the 25th to 75th percentiles across all Lake Powell alternatives span from approximately 300 to 545 km^2 (74,132 to 134,672 acres) of maximum exposed shoreline. The Enhanced Coordination and No Action Alternatives have the lowest and highest median maximum exposed shoreline at about 365 and 520 km^2 (90,194 and 128,495 acres), respectively. For Lake Mead, the 25th to 75th percentiles across all alternatives span from approximately 200 to 530 km^2 (49,421 to 130,966 acres) of maximum exposed shoreline. The Supply Driven (both LB Priority and LB Pro Rata approaches) and No Action Alternatives have the lowest and highest median maximum exposed shoreline at about 360 and 490 km^2 (88,598 and 121,082 acres), respectively.

The Representative Preferred Alternative exhibits the following outcomes with respect to the Dry Flow Category: For the Lake Powell maximum exposed shoreline, the median maximum exposed shoreline is about 450 km^2 (111,197 acres), with the 25th to 75th percentiles across all alternatives spanning from 415 to 475 km^2 (102,549 to 117,375 acres) of maximum exposed shoreline. The Representative Preferred Alternative exhibits the following outcomes with respect to the Critically Dry Flow Category: For the Lake Powell maximum exposed shoreline, the median maximum exposed shoreline is about 495 km^2 (122,317 acres), with the 25th to 75th percentiles across all alternatives spanning from 484 to 520 km^2 (119,599 to 128,495 acres) of maximum exposed shoreline. For the Lake Mead maximum exposed shoreline, the median maximum exposed shoreline is about 400 km^2 (98,842 acres), with the 25th to 75th percentiles across all alternatives spanning from 280 to 445 km^2 (69,190 to 109,962 acres) of maximum exposed shoreline. The Representative Preferred Alternative exhibits the following outcomes with respect to the Critically Dry Flow Category: For the Lake Mead maximum exposed shoreline, the median maximum exposed shoreline is about 450 km^2 (111,197 acres), with the 25th to 75th percentiles across all alternatives spanning from 395 to 489 km^2 (97,606 to 120,835 acres) of maximum exposed shoreline.

Lake Mead Robustness

Figure TA 7-5 in **TA 7**, Air Quality, depicts the ability of each alternative to maintain Lake Mead shoreline exposure below the specified area in every month. The preferred minimum performance is shown in the purple highlighted row, which represents the percentage of futures in which the exposed shoreline area for each alternative remains below 500 km^2 (123,552 acres) in every month. For Lake Mead, 500 km^2 (123,552 acres) is a very rough approximation of the area of shoreline exposed when the reservoir is filled to minimum power pool (950 feet). Keeping the Lake Mead shoreline exposure below 500 km^2 (123,552 acres) ensures that fugitive dust will be minimized. Four modeling periods are shown to capture the full modeling period, 2027-2039, 2040-2049, and 2050-2060. The color of a heat map square corresponds with the percent of futures that meet the specified level of performance, which increases from less than 10 percent of futures keeping the Lake Mead shoreline exposure area below the specified value in every month (least robust), to greater than 91 percent of futures keeping the Lake Mead shoreline exposure area below the specified value in every month (most robust). The higher the percentage, the more probable Lake Mead shoreline exposure will remain below the specified km^2 under most future hydrologic scenarios.

Figure TA 7-5 in **TA 7**, Air Quality, shows that the Enhanced Coordination, Representative Preferred, and Maximum Operational Flexibility Alternatives are the most robust at staying below 500 km^2 (123,552 acres) of shoreline exposure over the full modeling period (shown in the top row), doing so in 80 percent, 82 percent, and 88 percent of modeled futures, respectively. The No Action Alternative has the worst performance at a 35 percent success rate over the full analysis period.

In the first decadal breakout (2027–2039), the Representative Preferred, Maximum Operational Flexibility, and Enhanced Coordination Alternatives meet the preferred minimum performance in 92 percent, 93 percent and 88 percent of modeled futures, respectively, which is more robust than the other alternatives. The No Action Alternative has the worst performance at a 54 percent success rate over the full analysis period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently achieve 71–100 percent robustness, while the No Action Alternative only reaches a maximum of 51 percent robustness at even the lowest levels of performance for the 500 km^2 (123,552 acres) of shoreline exposure category.

Figure TA 7-6 in **TA 7**, Air Quality, shows flow conditions that could cause the Lake Mead shoreline exposure area to be above 500 km^2 (123,552 acres) in one or more months. This definition of undesirable performance is based on the highlighted row in **Figure TA 7-5**, which defined a future as successful when exposed shoreline area for an alternative remains below 500 km^2 (123,552 acres) in every month. For this vulnerability analysis, the driest 10-year average Lees Ferry annual flow was determined to be skillful at predicting undesirable performance. The vulnerability threshold for each alternative is described and compared to the Drying with Variability ensemble using this streamflow summary statistic. The driest observed 10-year average flow from 2012-2021 (11.8 maf) and the average flow from 2016-2025 (12.1 maf) are also provided as dashed and dotted lines, respectively, for comparison.

The Basic Coordination Alternative would likely be vulnerable to a Lake Mead exposed shoreline area greater than 500 km^2 (123,552 acres) under a 10-year average Lees Ferry natural flow of 10.2 maf or drier, which is slightly less vulnerable than the CCS Comparative Baseline, which is likely to be vulnerable if the 10-year average is 10.5 maf or drier. The No Action Alternative is vulnerable to a 10-year average of 11.4 maf, which is similar to the driest observed 10-year average of 11.8 maf. The Representative Preferred Alternative is likely to be vulnerable if the driest 10-year average Lees Ferry annual flow is 8.7 maf or less. Compared to the historical periods shown in the reference hydrology panel, this flow has not occurred before. Compared to the Drying with Variability Ensemble that represents potential future hydrologic conditions, 100 percent of the traces have a 10-year period drier than the vulnerability threshold for the Representative Preferred Alternative.

Lake Powell Robustness

Figure TA 7-7 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping the Lake Powell shoreline exposure area below 500 km^2 (123,552 acres) in every month. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust at staying below 500 km^2 (123,552 acres) of shoreline exposure over the full modeling period (shown in the bottom row), doing so in 81 percent and 95 percent of the futures, respectively. The No Action Alternative has the worst performance at a 16 percent success rate over the full analysis period.

In the first decadal breakout (2027–2039), the Enhanced Coordination and Maximum Operational Flexibility Alternatives meet the preferred minimum performance in 87 percent and 98 percent of modeled futures, respectively. The No Action Alternative meets the preferred minimum performance in 25 percent of modeled futures. The CCS Comparative Baseline, as well as the Basic Coordination and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives meet the preferred minimum performance in 54 percent, 45 percent, and 46 percent of futures, respectively. Based on the planned length of this decision, it is important to note that the Representative Preferred Alternative meets the preferred minimum performance level in 66 percent of futures in the 2027-2039 modeling period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently achieve 81–100 percent robustness, while the No Action Alternative only reaches a maximum of 48 percent robustness at even the lowest levels of performance for the 500 km^2 (123,552 acres) of shoreline exposure category.

Figure TA 7-8 in **TA 7**, Air Quality, looks at flow conditions that could cause the Lake Powell shoreline exposure area to be above 500 km^2 (123,552 acres) in one or more months. This definition of undesirable performance is based on the highlighted row in **Figure TA 7-7**, Air Quality, which defined a future as successful when exposed shoreline area for an alternative remains below 500 km^2 (123,552 acres) in every month. For this vulnerability analysis, the driest 10-year average Lees Ferry annual flow was determined to be skillful at predicting undesirable performance. The vulnerability threshold for each alternative is described and compared to the Drying with Variability ensemble using this streamflow summary statistic. The driest observed 10-year average flow from 2012-2021 (11.8 maf) and the average flow from 2016-2025 (12.1 maf) are also provided as dashed and dotted lines, respectively, for comparison.

The Enhanced Coordination Alternative modeling results indicate undesirable performance at a 10-year average flow of 9 maf or drier, which occurs in less than 25 percent of the Drying with Variability traces. The Maximum Operational Flexibility Alternative is least vulnerable, with no Drying with Variability traces occurring below the undesirable performance level of 6.8 maf.

The Representative Preferred Alternative is likely to be vulnerable if the driest 10-year average Lees Ferry annual flow is 10.9 maf or less. Compared to the historical periods shown in the reference hydrology panel, this flow has not occurred before. Compared to the Drying with Variability Ensemble that represents potential future hydrologic conditions, 30 percent of the traces have a 10-year period drier than the vulnerability threshold for the Representative Preferred Alternative.

Shoreline Exposure

Figure TA 7-9 in **TA 7**, Air Quality, shows the WY maximum shoreline dust emissions for Lake Powell and Lake Mead. In the Average Flow Category (12.0–14.0 maf), Lake Powell alternatives have varying distributions, with the 25th to 75th percentiles across all alternatives spanning from approximately 105 to 460 million kg (231 to 1,014 million pounds) of particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) as a result of shoreline exposure. The CCS Comparative Baseline and the Supply Driven (both LB Priority and LB Pro Rata approaches), Basic Coordination, and No Action Alternatives all have similar median maximum monthly emission rates of around 300 million kg of $PM_{2.5}$ as a result of shoreline exposure. The Enhanced Coordination and Maximum Operational Flexibility Alternatives have lower medians. Therefore, these two alternatives would result in less $PM_{2.5}$ than the other alternatives.

The Lake Mead alternatives have varying distributions, with the 25th to 75th percentiles across all alternatives spanning from 80 to 540 million kg (176 to 1,190 million pounds) of $PM_{2.5}$ emissions as a result of shoreline exposure. with the No Action and Supply Driven (both LB Priority and LB Pro

Rata approaches) Alternatives displaying the highest and lowest values at about 500 and 160 million kg (1,102 and 353 million pounds) of $PM_{2.5}$, respectively. As flow categories get drier for WY minimums, the medians for all Lake Powell and Lake Mead alternatives increase the millions of kg of $PM_{2.5}$. As flow categories get wetter for WY minimums, the potential $PM_{2.5}$ decreases.

Lake Mead Robustness

Figure TA 7-10 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping Lake Mead $PM_{2.5}$ below 500 million kg from a shoreline exposure area. The color of a heat map's square corresponds with the percentage of futures that meet this level of performance; the percentage increases from less than 10 percent of futures keeping the Lake Mead emissions below 100 million kg (220 million pounds) (least robust) to greater than 91 percent of futures keeping the Lake Mead emissions above 500 million kg (1,102 million pounds) (most robust). The higher the percentage, the more likely Lake Mead will remain above the minimum power pool (950 feet) under most future hydrologic scenarios. Keeping the Lake Mead emissions below 500 million kg (1,102 million pounds) ensures that fugitive dust would be minimized, which would protect air quality in the area.

The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust at staying below 500 million kg (1,102 million pounds) over the full modeling period, doing so in 69 percent and 76 percent of the futures, respectively. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) can meet the preferred minimum performance in 64 percent of modeled futures. The No Action Alternative has the worst performance at a 22 percent success rate over the full analysis period. The Representative Preferred Alternative meets staying below 500 million kg (1,102 million pounds) of shoreline dust emissions robustness criteria in 58 percent of modeled futures in the full modeling period. Based on the planned length of this decision, it's important to note that it meets the preferred minimum performance level in 74 percent of futures in the first modeling period.

In the first decadal breakout (2027–2039), the Enhanced Coordination and Maximum Operational Flexibility Alternatives can meet the preferred minimum performance in 79 percent and 84 percent of modeled futures, respectively, which is more robust than the other alternatives. Based on the planned length of this decision, it is important to note that the Representative Preferred Alternative meets the preferred minimum performance level in 74 percent of futures in the 2027-2039 modeling period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Maximum Operational Flexibility Alternative consistently achieves 71–100 percent robustness.

Figure TA 7-11 in **TA 7**, Air Quality, looks at flow conditions that could cause Lake Mead emissions above 500 million kg (1,102 million pounds) during at least one or more months. The Enhanced Coordination, Maximum Flexibility, Representative Preferred, and Supply Driven (both LB Priority and LB Pro Rata) Alternatives are vulnerable to similar conditions: 10-year droughts of 9.9 maf, 9.6 maf, 10.2 and 10.2 maf, respectively. The CCS Continued Baseline is more vulnerable, with a 10-year drought of 11.0 maf likely to cause undesirable performance. The No Action Alternative is the most vulnerable; Lake Mead would likely go below 1,000 feet elevation in a 10-year drought averaging 12.1

maf. From 2012 to 2021, the 10-year average was 11.8 maf; therefore, the No Action Alternative is just below the vulnerability of conditions that have already occurred.

Lake Powell Robustness

Figure TA 7-12 in **TA 7**, Air Quality, depicts the performance of each alternative with regard to keeping Lake Powell $PM_{2.5}$ from a shoreline exposure area below 450 million kg (992 million pounds). The color of a heat map's square corresponds with the percentage of futures that meet this level of performance; the percentage increases from a less than 10 percent of futures keeping the Lake Powell emissions below 150 million kg (331 million pounds) (least robust), to a greater than 91 percent of futures keeping the Lake Powell emissions above 450 million kg (992 million pounds) (most robust). Keeping the Lake Powell emissions below 450 million kg (992 million pounds) ensures that fugitive dust would be minimized, which would protect air quality in the area.

The Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust at staying below 450 million kg, doing so in 78 percent and 91 percent of the futures, respectively. The Basic Coordination, Supply Driven (LB Priority approach), and Supply Driven (LB Pro Rata approach) Alternatives perform similarly to the CCS Comparative Baseline, if not slightly worse, succeeding in 21 percent, 22 percent, and 22 percent of futures, respectively, over the full analysis period. The No Action Alternative has the worst performance at a 10 percent success rate over the full analysis period. The Representative Preferred Alternative meets staying below 450 million kg (992 million pounds) of shoreline dust emissions robustness criteria in 38 percent of modeled futures in the full modeling period. Based on the planned length of this decision, it's important to note that it meets the preferred minimum performance level in 59 percent of futures in the first modeling period.

In the first decadal breakout (2027–2039), the Enhanced Coordination and Maximum Operational Flexibility Alternatives meet the preferred minimum performance in 84 percent and 96 percent of modeled futures, respectively, which is considerably more robust than the other alternatives. Based on the planned length of this decision, it is important to note that the Representative Preferred Alternative meets the preferred minimum performance level in 59 percent of futures in the 2027-2039 modeling period.

For the full modeling period, 2027–2039 modeling period, 2040–2049 modeling period, and 2050–2060 modeling period, the Maximum Operational Flexibility Alternatives consistently achieves 91–100 percent robustness (dark blue in color).

Figure TA 7-13 in **TA 7**, Air Quality, looks at flow conditions that could cause Lake Powell emissions above 450 million kg during at least one or more months. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to similar conditions: 10-year droughts of 9.2 and 6.8 maf, respectively. The No Action Alternative has a 10-year drought of 12.2, which is above the reference hydrology box plot averages for 2012–2021 (11.8 maf) and 2015–2024 (12.6 maf). Therefore, the No Action Alternative is more vulnerable and likely to cause undesirable performance.

Other effects are the potential dust-on-snow effects, which may occur when reservoir elevations are low, and there are more dust mobilization and potential acceleration of runoff. Also, changing flow characteristics can affect the fallowing of agricultural lands, especially in regions that rely on consistent irrigation from reservoirs.

Changes in flow characteristics may affect agricultural operations in regions dependent on reservoir-based irrigation, particularly if reduced dam releases decrease water availability for downstream users. In such cases, farmers may be forced to fallow some or all of their fields to conserve limited water supplies for higher-value crops and avoid unsupported planting and irrigation costs. As discussed in **TA 16.2.2** of **TA 16**, Socioeconomics, including **Figure TA 16-1**, estimates of potential fallowed acreage are based on simplifying assumptions regarding water availability, crop profitability, and agricultural decision-making and are intended for regional-scale economic analysis rather than site-specific predictions. Fallowed agricultural lands can be a source of fugitive dust emissions, especially under dry, unvegetated conditions. Screening-level estimates of windblown dust emissions can be developed using generalized U.S. EPA AP-42 emission factors, with PM_{10} emissions typically ranging from approximately 0.1 to 0.5 tons per acre per year depending on soil stability, vegetation cover, and wind exposure; $PM_{2.5}$ emissions are generally a smaller fraction of PM_{10} emissions. Because emissions depend on site-specific conditions such as soil characteristics, vegetation, wind, dust control measures, and the extent and timing of fallowing, these estimates are intended only to indicate the potential magnitude of fugitive dust emissions and are not site-specific predictions.

Clark County, Nevada, is the only county in the analysis area that has been designated as serious nonattainment for the 2015 8-hour O_3 standard and a maintenance area for CO and PM_{10} (EPA 2025b). The potential shoreline exposure discussed above has the potential to increase particulate matter that could further exacerbate the current PM_{10} issue in Clark County.

Issue 2: How would lake reservoir elevations and releases impact power generation and CO_2e emissions?

Issue 2 addresses how operational activities for the various alternatives affect reservoir elevations and, therefore, impact hydropower generation. When there is a change of hydropower, there would be a potential change in CO_2e emissions because emissive alternative energy generation with varying emissions would compensate for this reduction. The box plots compare present-day and potential future electricity mixes, reporting metric tons of CO_2e based on the 2025 resource mix emission factor on the left axis and the 2050 resource mix emission factor on the right axis, using the MWh increase or decrease for each alternative and flow category. Only the 2025 resource mix is discussed in detail. This is because the 2050 resource mix results would have lower metric tons of CO_2e because the emission factor includes more alternative energy resources.

Figure TA 7-14 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a fluctuations in hydropower at Glen Canyon Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the Glen Canyon Dam alternatives have varying distributions of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 288-metric-ton decrease to a 115-metric-ton increase of CO_2e emissions. The No Action Alternative has a median close to zero, representing the smallest decrease relative to the CCS Comparative Baseline. The Enhanced Coordination (134 metric tons decrease of CO_2e) and Maximum Operational Flexibility (143 metric tons decrease of CO_2e) Alternatives have similar medians, resulting in the largest decrease in CO_2e emissions relative to the CCS Comparative Baseline.

In the Critically Dry Flow Category (less than 10.0 maf), all the alternatives, except the Enhanced Coordination and Maximum Operational Flexibility Alternatives, are projected to result in similar behavior, in terms of medians and variability, since they all show a potential increase of CO_2e compared with the CCS Comparative Baseline. The Representative Preferred Alternative exhibits the following outcomes with respect to the Dry Flow Category: For the Glen Canyon Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 84-metric-ton decrease of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 275-metric-ton decrease to a 96-metric-ton increase of CO_2e emissions. The Representative Preferred Alternative exhibits the following outcomes with respect to the Critically Dry Flow category: For the Glen Canyon Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions results in a zero-metric-ton increase or decrease of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 153-metric-ton decrease to a 160-metric-ton increase of CO_2e emissions.

The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 115-metric-ton increase in CO_2e for the Supply Driven (LB Pro Rata approach) and Supply Driven (LB Priority approach) Alternatives, which is equivalent to 23.3 gasoline-powered passenger vehicles driven for 1 year or 20.8 homes' electricity for 1 year.

Figure TA 7-15 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a fluctuation of hydropower at Hoover Dam for each flow category and the alternatives. The Hoover Dam powerplant has 17 commercial generators with a maximum combined capacity of 2,074 MW. The powerplant requires a minimum Lake Mead elevation of 950 feet to produce power. At minimum power pool, the powerplant has an estimated capacity of 117 MW. At Lake Mead elevation of 1,035 feet, Hoover Dam's generating capacity is drastically reduced from 1,274 to 382 MW. In the Average Flow Category (12.0–14.0 maf), the No Action Alternative has the highest median with a 244-metric-ton increase in CO_2e emissions, and the largest interquartile range, with the 25th percentile at 52 metric tons and the 75th percentile at 456 metric tons of CO_2e. The Enhanced Coordination, Maximum Operational Flexibility, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives have medians showing a decrease in metric tons of CO_2e emissions. The Basic Coordination Alternative shows a median near zero metric tons of CO_2e emissions.

In the Critically Dry Flow Category (less than 10.0 maf), the medians for the No Action and Basic Coordination Alternatives display no change in CO_2e emissions relative to the CCS Comparative Baseline. The Enhanced Coordination, Maximum Operational Flexibility, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives all have medians showing a decrease in metric tons of CO_2e emissions, with the Supply Driven Alternative (LB Pro Rata approach) showing the largest decrease at 158 metric tons of CO_2e. The 25th to 75th percentiles across all alternatives span from a decrease of 577 metric tons to an increase of 105 metric tons of CO_2e emissions. The No Action Alternative has the smallest interquartile range, while the Supply Driven Alternative (LB Pro Rata approach) has the largest. The Representative Preferred Alternative exhibits the following outcomes with respect to the Dry Flow Category: For the Hoover Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 146-metric-ton decrease of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 416-metric-ton decrease to a 75-metric-ton increase of CO_2e emissions. The Representative Preferred Alternative exhibits the following outcomes with respect to the Critically Dry Flow Category: For the Hoover Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 115-metric-ton decrease of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 374-metric-ton decrease to a zero-metric-ton increase or decrease of CO_2e emissions. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 456-metric-ton increase in CO_2e (under the No Action Alternative), which is equivalent to 90.3 gasoline-powered passenger vehicles driven for 1 year or 80.6 homes' electricity for 1 year.

Figure TA 7-16 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a fluctuation of hydropower at Davis Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), the Davis Dam alternatives exhibit varying distributions of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 19-metric-ton decrease to a 40-metric-ton increase in CO_2e emissions. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives display similar medians ranging from 19 to 26 metric tons of CO_2e increase. The Representative Preferred Alternative and Basic Coordination Alternative medians are similar at around 10 metric tons of CO_2e increase, while the No Action Alternative has an 8 metric ton decrease in CO_2e emissions. The No Action Alternative is the only alternative with both a median and 25th percentile below zero. In the Critically Dry Flow Category (less than 10.0 maf), the median for the Basic Coordination Alternative displays very little change in CO_2e emissions, while the No Action Alternative shows a 4 metric ton decrease of CO_2e emissions relative to the CCS Comparative Baseline.

The Representative Preferred Alternative exhibits the following outcomes with respect to the Dry Flow Category: For the Davis Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 15-metric-ton increase of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 2-metric-ton increase to a 31-metric-ton increase of CO_2e emissions. The Representative Preferred Alternative exhibits the following outcomes with respect to the critically Dry Flow Category: For the Davis Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 14-metric-ton increase of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 5-metric-ton decrease to a 32-metric-ton increase of CO_2e emissions.

The Maximum Flexibility and Enhanced Coordination Alternatives stay equal to or above the CCS Comparative Baseline under each flow category, except the Wet Flow Category (16.0–31.0 maf). Therefore, they perform consistently the worst. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 40-metric-ton increase in CO_2e (under the Enhanced Coordination Alternative), which is equivalent to 10 gasoline-powered passenger vehicles driven for 1 year or 9 homes' electricity for 1 year.

Figure TA 7-17 in **TA 7**, Air Quality, shows the changes in CO_2e emissions due to a fluctuation of hydropower at Parker Dam for each flow category and the alternatives. In the Average Flow Category (12.0–14.0 maf), Parker Dam alternatives exhibit varying distributions of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 3-metric-ton decrease to a 25-metric-ton increase in CO_2e. Only the No Action and Basic Coordination Alternatives have medians that result in a decrease in CO_2e emissions; though, both are near a zero metric-ton change in CO_2e. The Maximum Operational Flexibility, Supply Driven (LB Priority approach), and Representative Preferred Alternatives have similar medians, ranging from near zero to a 5-metric-ton CO_2e increase. The Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives have the highest medians, exceeding an increase of 14 metric tons of CO_2e emissions.

In the Critically Dry Flow Category (less than 10.0 maf), the medians for the No Action, Basic Coordination, Supply Driven (LB Priority approach), and Representative Preferred Alternatives are similar, displaying a decrease in CO_2e emissions ranging from 2 to nearly zero metric tons. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (LB Pro Rata approach) Alternatives all have medians showing an increase in metric tons of CO_2e emissions, with Enhanced Coordination showing the largest increase at 23 metric tons of CO_2e.

The Representative Preferred Alternative exhibits the following outcomes with respect to the Dry Flow Category: For the Parker Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 2-metric-ton increase of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a zero-metric-ton increase to a 5-metric-ton increase of CO_2e emissions. The Representative Preferred Alternative exhibits the following outcomes with respect to the Critically Dry Flow Category: For the Parker Dam CO_2e emissions resulting from a loss of hydropower generation, the median CO_2e emissions is about a 1-metric-ton increase of CO_2e emissions, with the 25th to 75th percentiles across all alternatives spanning from a 3-metric-ton decrease to a 6-metric-ton increase of CO_2e emissions.

The Enhanced Coordination Alternative is the most reliable because it stays equal to or above the CCS Comparative Baseline under each flow category; therefore, it performs consistently the worst. The Average Flow Category (12.0–14.0 maf) 75th percentile variance results in no more than a 25-metric-ton increase in CO_2e (under the Enhanced Coordination Alternative), which is equivalent to 5.4 gasoline-powered passenger vehicles driven for 1 year or 4.8 homes' electricity for 1 year.

Issue 3: How would climate trends affect lake reservoir elevations?

Climate trends affect lake reservoir elevations in several interrelated ways, driven largely by changes in temperature, precipitation patterns, and hydrologic cycles. Climate trends typically cause more variability and extremes in lake reservoir elevations, including lower lows during droughts, higher highs during storm events, and greater management complexity overall. The following are potential events that could be affected by climate trends and that would potentially affect reservoir elevations:

- Reduced snowpack and earlier snowmelt
- Increased evaporation rates from both lake surfaces and the surrounding land
- Changes in precipitation patterns
- Increased water demand

As discussed in Issue 2, climate events may affect hydropower. Any reduction in hydropower would require other power-generation sources to increase to compensate. The regional power mix can be analyzed to determine the region's potential capacity in order to replace hydropower with other alternative energy sources. Using available information from the Emissions and Generation Resource Integrated Database (eGRID) for the analysis area, **Table TA 7-22** in **TA 7**, Air Quality, shows that renewables, such as hydropower, biomass, wind, solar, and geothermal sources, are 42.8 percent of the Western Electricity Coordinating Council's resource mix, compared with nonrenewable resources, such as coal, oil, nuclear, and gas, totaling 57.3 percent. If the 19.8 percent hydropower is reduced, both renewable and nonrenewable resources would compensate. Other generation sources would likely replace lost hydropower and the mix of replacement sources can vary. However, a recent Argonne study shows that when there is a reduction in hydropower at Glen Canyon Powerplant, the replacement generation is from mostly natural gas–fired generation (gas-combined cycle) and generation from gas combustion turbines, with a small portion also coming from coal-fired generation for 2024 through 2027 (Veselka et al. 2024). In addition, as climate trends are further observed and monitored, Reclamation has an opportunity to discuss any strategies to increase management flexibility, enhance climate adaptation planning, and improve infrastructure resilience.

Summary Comparison of Alternatives

For the Lake Powell WY maximum exposed shoreline area Average Flow Category (12.0–14.0 maf), the alternatives all have similar medians and small variabilities, except the Enhanced Coordination and Maximum Operational Flexibility Alternatives, which have the lowest median km^2 of exposed shoreline and the smallest variability. For the Lake Mead WY maximum exposed shoreline area Average Flow Category (12.0–14.0 maf), the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives performed the best, with the lowest median shoreline exposure area. The CCS Comparative Baseline and No Action Alternative perform the worst and have the smallest variability. The Basic Coordination Alternative performs in the middle. These results are within the range analyzed across the other alternatives from this Final EIS.

For the full modeling period, the Lake Mead shoreline area robustness figure shows that the No Action Alternative performs the worst, with only 35 percent of the futures below 500 km^2 (123,553 acres) of shoreline area. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with 80 percent or more of the futures below 500 km^2 (123,553 acres) of shoreline area. These same trends were seen for the 2027–2039, 2040–2049, and 2050–2060 modeling periods with higher percentages. For the 2027–2039 modeling period and 2040–2049 modeling period, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have 88 percent or more of the futures below 500 km^2 (123,553 acres) of shoreline area.

The Lake Mead vulnerability plot shows that the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are vulnerable to similar conditions and less than 50 percent of the Drying with Variability traces include a driest 10-year average Lees Ferry annual flow this dry or drier. The CCS Comparative Baseline and No Action Alternative are the most vulnerable at 10-year average flows of 10.5 maf and 11.4 maf, respectively.

For the full modeling period, the Lake Powell shoreline area robustness figure shows that the No Action Alternative performs the worst, with only 16 percent of the futures below 500 km^2 (123,553 acres) of shoreline area. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with over 80 percent of the futures below 500 square km^2 (123,553 acres) of shoreline area. Similar trends were seen for the 2027–2039, though with higher percentages. The 2040–2049 and 2050–2060 modeling periods show that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs the worst, then the No Action Alternative. For the 2027–2039, 2040–2049, and 2050–2060 modeling periods, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have 87 percent or more of the futures below 500 km^2 (123,553 acres) of shoreline area.

The Lake Powell vulnerability plot shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are least vulnerable, as fewer than 25 percent of the Drying with Variability traces include a driest 10-year average Lees Ferry annual flow this dry or drier. The CCS Comparative Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are vulnerable under flow conditions associated with more than 75 percent of the Drying with Variability traces and are therefore the most vulnerable.

For the Lake Powell WY maximum shoreline dust emissions Average Flow Category (12.0–14.0 maf), several alternatives have similar medians, though Enhanced Coordination and Maximum Operational Flexibility Alternatives have the lowest median shoreline dust emissions and the smallest variability.

For the Lake Mead WY maximum shoreline dust emissions Average Flow Category (12.0–14.0 maf), the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives performed the best, with the least shoreline dust emissions. The CCS Comparative Baseline and No Action Alternative perform the worst, with the highest shoreline dust emissions. The Basic Coordination Alternative performs in the middle.

For the full modeling period, the Lake Mead shoreline dust emissions robustness figure shows that the No Action Alternative performs the worst, with only 22 percent of the futures below 500 million kg (1,102 million pounds) of $PM_{2.5}$. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with 76 percent and 69 percent, respectively, of the futures below 500 million kg (1,102 million pounds) of $PM_{2.5}$. These same trends were seen for the 2027–2039, 2040–2049, and 2050–2060 modeling periods with higher percentages, and the Maximum Operational Flexibility and Enhanced Coordination Alternatives have 79 percent or more of the futures below 500 million kg of $PM_{2.5}$.

The Lake Mead vulnerability plot shows that the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are least vulnerable, with vulnerability thresholds corresponding to conditions associated with roughly 25 to 50 percent of the Drying with Variability traces. The CCS Comparative Baseline and Basic Coordination Alternative are vulnerable to conditions associated with roughly 50 to 75 percent of the Drying with Variability traces. The No Action Alternative has a vulnerability threshold of 11.7 maf, which is similar to the driest observed 10-year period of 11.8 maf.

For the full modeling period, the Lake Powell shoreline dust emissions robustness figure shows that the No Action Alternative performs the worst, with only 10 percent of the futures below 450 million kg (992 million pounds) of $PM_{2.5}$. The Maximum Operational Flexibility and Enhanced Coordination Alternatives perform the best with 78 percent or more of the futures below 450 million kg of $PM_{2.5}$. These same trends were seen for the 2027–2039 with higher percentages. The 2040–2049 and 2050–2060 modeling periods show that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) perform the worst, then the No Action Alternative. For the 2027–2039, 2040–2049, and 2050–2060 modeling periods, the Maximum Operational Flexibility and Enhanced Coordination Alternatives have 84 percent or more of the futures below 450 million kg (992 million pounds) of $PM_{2.5}$.

The Lake Powell vulnerability plot shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are vulnerable to conditions associated with less than 25 percent of the Drying with Variability traces. The CCS Comparative Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives have vulnerability thresholds corresponding to conditions associated with 75 to 100 percent of the Drying with Variability traces and are therefore the most vulnerable alternatives. The No Action Alternative has a vulnerability threshold of 12.2 maf, which is similar to the recently observed 10-year flow of 12.1 maf.

A general discussion of the effects of climate trends on lake reservoirs is discussed in **TA 7**, Air Quality; however, due to uncertainty, these effects cannot be determined for each specific alternative. In addition, **TA 3**, Hydrologic Resources, details the lake reservoir elevations for the flow categories and alternatives.

3.8 Biological Resources – Fish and Other Aquatic Species

3.8.1 Affected Environment

The affected environment consists of the Colorado River and its tributaries from Lake Powell downstream to the SIB. This area supports a diverse assemblage of aquatic organisms that form a complex food web that sustains both native and nonnative fish populations. Native fish include federally threatened and endangered species, range-wide conservation species (species under a multi-state conservation agreement), BLM sensitive species, and those covered under the LCR MSCP (Reclamation 2024c). Nonnative fish species, including cold-water and warmwater sportfish, are also present (see **Attachment 1** in **TA 8**, Biological Resources – Fish and Other Aquatic Species, for detailed life histories and distributions). River flow variations and dam operations, especially those related to Glen Canyon Dam, significantly influence aquatic habitats within the channel, shorelines, backwaters, and tributary mouths. Several invasive species have been inadvertently introduced, including quagga mussels (*Dreissena bugensis*), New Zealand mud snails (*Potamopyrgus antipodarum*), and various fish and aquatic plants (Reclamation 2024c).

Native Fish Species

Historically, the Colorado River supported 35 native fish species; of these, 26 were unique to the Basin (Miller 1955, 1958; Valdez and Muth 2005). Today, only eight native species remain within the analysis area: humpback chub, razorback sucker, Colorado pikeminnow, bonytail, bluehead sucker, flannelmouth sucker, desert pupfish, and speckled dace (FWS 2002; Valdez and Carothers 1998; Brockdorff 2022); see **Tables 8-1** and **8-2** in **Section TA 8.1**, Affected Environment. Of these species, the humpback chub, razorback sucker, Colorado pikeminnow, bonytail, and desert pupfish are ESA listed as endangered or threatened (Bestgen et al. 2020; Minckley et al. 2003).

Nonnative Fish Species

The presence of nonnative species has both beneficial and detrimental effects on the aquatic community. Although certain nonnative fish species support sport and recreational fisheries, they also pose substantial risks to native communities by increasing predation, competing for resources, and altering habitat conditions (NPS 2021a). High-risk species include smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), flathead catfish (*Pylodictis olivaris*), and brown trout (*Salmo trutta*). Other nonnatives, such as rainbow trout (*Oncorhynchus mykiss*), largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), and striped bass (*Morone saxatilis*), are common and managed as sportfish (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment and **Attachment 1** in **TA 8**) (UDWR 2023).

Native and nonnative aquatic species are summarized across the following three Colorado River reaches: Lake Powell, Glen Canyon Dam to Pearce Ferry, and the LCR MSCP reaches (Lake Mead to Imperial Dam).

Lake Powell

Lake Powell supports 6 native fish species and at least 17 nonnative species (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment) (Smith 2022). Native fish species include razorback sucker, bluehead sucker, flannelmouth sucker, and bonytail. Razorback suckers are present in the reservoir, and bonytail are stocked, with recent signs of reproduction. Colorado pikeminnow are rare, mainly occurring in inflows from the Colorado and San Juan Rivers. Flannelmouth and bluehead suckers are widespread, while speckled dace inhabit shorelines and tributaries.

Recent low water levels have created new riverine habitats, influencing fish movement and connectivity (Cathcart et al. 2018; Ahrens 2022). Water temperature and stratification dynamics affect habitat suitability and downstream releases from Glen Canyon Dam (Hueftle and Stevens 2001). Limnological data indicate changes in phytoplankton biomass and community composition, with potential implications for harmful algal blooms and water quality (Deemer et al. 2023). Invasive bivalves, including Asian clam (*Corbicula fluminea*) and quagga mussel, also alter plankton communities and threaten ecosystem health (USGS 2024).

Glen Canyon Dam to Pearce Ferry

This reach spans nearly 300 miles and is shaped by altered flow regimes and habitat diversity (Valdez and Ryel 1995). Native species include razorback sucker, humpback chub, bluehead sucker, flannelmouth sucker, and speckled dace (see **Table TA 8-2** in **Section TA 8.1**, Affected Environment) (NPS 2023b). Humpback chub also persists in tributaries such as the Little Colorado River and Havasu Creek. Currently, the Grand Canyon supports a native-dominated fish community, with the highest abundance of humpback chub anywhere in its current range and flourishing populations of bluehead and flannelmouth sucker. Nonnative species include rainbow trout, brown trout, bass, sunfish, catfish, and minnows (Shollenberger et al. 2025). Smallmouth bass and green sunfish recruitment are influenced by temperature and flow management (Reclamation 2025b). Invasive species, such as quagga mussels and New Zealand mud snails, are present but face environmental constraints (NPS 2015).

LCR MSCP Reaches (Lake Mead to Imperial Dam)

Lake Mead supports a unique, naturally recruiting population of razorback sucker and a diverse fish community, including humpback chub near the Colorado River confluence (see **Table TA 8-2** in **Section TA 8.1**) (Rogers et al. 2023). Downstream reaches (Lake Mohave, Lake Havasu, and Parker Strip) are managed for sportfish and native fish conservation, with stocking and augmentation programs for razorback sucker and bonytail (LCR MSCP 2024). Habitat creation, genetic monitoring, and pond rearing improve survival and recruitment (Kesner et al. 2012; Reap et al. 2023; Bestgen et al. 2020). Invasive species, including quagga mussel, crayfish, Asian clam, and snails, continue to threaten water quality and native biota (USGS 2025c).

3.8.2 Environmental Consequences

Methodology

DMDU modeling was used to evaluate potential Colorado River management strategies across a wide range of plausible hydrologic futures. The analysis compared five alternatives, a Preferred Alternative, and a Continued Current Strategies baseline representing different river flow and reservoir management approaches. For the Final EIS, modeling used 400 hydrologic traces under a Dry initial condition (with Mid and Wet conditions removed), and analysis of the Preferred Alternative focuses on the first 10 years of impacts due to its 10-year implementation period. DMDU evaluates how alternatives may affect aquatic habitats, water quality, and fish populations, and measures performance using robustness scores that indicate how often resource objectives are met across modeled futures. Results are summarized using visual tools, including conditional box plots that show resource responses under different hydrologic conditions, robustness heat maps that compare long-term performance across scenarios, and vulnerability bar plots that identify the hydrologic conditions under which alternatives fail to meet thresholds. Together, these tools provide a comparative framework for understanding potential system outcomes and the relative resilience of alternatives under uncertain future conditions. Additional issue-specific methodology is described in **Section TA 8.2.1**, Methodology, in **TA 8**, Biological Resources – Fish and Other Aquatic Species.

Impact Analysis Area

The impact analysis area includes the Colorado River corridor from the full-pool elevation of Lake Powell downstream to the SIB, including various habitats and reaches described in the analysis area (see **Section 3.2**).

Assumptions

Modifications in the quantity, timing, temperature, and quality of water released from Glen Canyon Dam and Hoover Dam through the lower Colorado River are expected to influence fish habitats, distributions, and population abundances; this is because changes in flow can alter available habitat and affect species' numbers. Reduced flows are likely to affect backwaters and riverine habitats that support native fish; reduced flows may also affect known spawning sites for razorback sucker. Reservoir conditions are also considered, particularly the potential for low Lake Powell elevations (below 3,570 ft) to increase entrainment of smallmouth bass and other nonnative fishes, which could negatively affect humpback chub and other native species in the action area. The analyses use models such as CRSS and the smallmouth bass population model developed in collaboration with various agencies. For efficiency of analysis, some LCR MSCP reaches are combined for analysis where special status species, habitat conditions, operations, and management are similar. Ongoing fisheries management practices by agencies within the Colorado River Basin are expected to remain consistent into the future.

Impact Indicators

Key impact indicators included the abundance and location of razorback sucker larvae, elevation thresholds where spawning habitats may become limited, and annual monitoring data for sportfish catches. Additional indicators were habitat availability and abundance of native fish species by life stage, changes in backwater area at different flow stages, and shifts in the distribution and abundance of Colorado pikeminnow, razorback sucker, and humpback chub with expanded inflows. The analyses also considered electrofishing and angler catch rates for rainbow trout and brown trout in the Lees Ferry sub-reach, changes in fish habitat and population numbers based on dam releases and flow conditions, and the suitability and area of razorback sucker spawning sites at different flow stages.

Other indicators included changes to Colorado pikeminnow and razorback sucker critical habitat in the Lake Powell inflows, changes to razorback sucker critical habitat in Lake Mead, increased smallmouth bass escapement through Glen Canyon Dam, downstream distribution, salinity concentration changes, and the effects of lower reservoir elevations on shoreline spawning and nursery habitat for razorback sucker. Maintaining reservoir elevation to protect the power pool at Lake Powell (above 3,490 feet) and Lake Mead (above 1,000 feet) and to preserve the Piute Farms Rapid (above 3,666.5 feet) and the Pearce Ferry Rapid (above 1,090 feet) was also important. The analyses further considered reduced abundance and distribution of fish species, water quality impacts, and reduced wetland area and river inflow habitat.

Issue 1: Lower reservoir elevations have reduced lake habitat and extended the inflows of the Colorado River and San Juan River by approximately 35 miles each. How will changes in flow affect the quantity and quality of lake, wetland, and riverine inflow habitats?

Recent declines in Lake Powell's elevation have altered aquatic habitat conditions, affecting ESA-listed native fish and other aquatic species in the Colorado River Basin. Lower reservoir elevations have reduced traditional lake environments while expanding riverine inflow reaches in the Colorado and San Juan Rivers. This change increases the length of exposed riverine habitat, which benefits endangered species such as Colorado pikeminnow and razorback sucker that prefer flowing river conditions and whose designated critical habitat occurs in these inflow areas (see **Tables TA 8-3** and **TA 8-4** in **Section TA 8.2.2**, Environmental Consequences, Issue 1). The most important threat associated with reservoir operations is the establishment and spread of nonnative piscivorous fish, particularly smallmouth bass, which can increase predation and competition pressures on native species such as humpback chub and other fishes targeted for recovery in the Colorado River Basin. Reservoir elevation is a key driver of these risks because it affects the likelihood that smallmouth bass are entrained through Glen Canyon Dam, the effectiveness of Piute Farms Waterfall on the San Juan River as a barrier to upstream fish movement, the extent of riverine critical habitat in the Colorado and San Juan River inflows, and the availability of shoreline habitat that favors nonnative fish reproduction. Accordingly, four primary impact indicators were evaluated: (1) smallmouth bass entrainment through Glen Canyon Dam and subsequent downstream expansion, (2) maintaining Lake Powell elevations below 3,666.5 feet to preserve Piute Farms Waterfall as a barrier to upstream movement of nonnative fish, (3) the extent of riverine critical habitat for Colorado pikeminnow and razorback sucker in the Colorado and San Juan River inflows, and (4) the amount of exposed shoreline habitat favorable for smallmouth bass spawning and recruitment.

Lake Powell elevation influences the extent of riverine critical habitat for Colorado pikeminnow and razorback sucker in the Colorado and San Juan River inflows. When the reservoir rises above approximately 3,598 feet in the Colorado River inflow and 3,600 feet in the San Juan River inflow, portions of designated critical habitat become inundated and converted from flowing river habitat to reservoir conditions (see **Tables TA 8-3** and **TA 8-4**). **Figures TA 8-1** and **TA 8-3** evaluate the robustness of each alternative in maintaining lake elevations below these thresholds and preserving riverine habitat, while **Figures TA 8-2** and **TA 8-4** illustrate the hydrologic conditions under which alternatives may exceed these thresholds. Modeling results indicate that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the most effective at maintaining elevations below these thresholds and protecting riverine habitat and slightly outperforms the CCS Comparative Baseline. In contrast, the Enhanced Coordination and Maximum Operational Flexibility Alternatives are the least robust at maintaining these conditions because they more frequently produce higher Lake Powell elevations, which inundate riverine habitat. The Representative Preferred Alternative performs moderately across these indicators, maintaining elevations below these thresholds in about 40 percent of futures during the initial implementation period.

Reservoir elevation also determines whether Piute Farms Waterfall continues to function as a barrier to fish movement in the lower San Juan River. When Lake Powell elevations exceed approximately 3,666.5 feet, the waterfall becomes inundated, and fish from the reservoir, including predatory nonnative species, can move upstream into riverine habitats. **Figure TA 8-5** evaluates the robustness of each alternative in maintaining elevations below this threshold, while **Figure TA 8-6** identifies the flow conditions that could result in elevations exceeding the threshold. Modeling results show that maintaining this barrier throughout the full modeling period is difficult under all alternatives; however, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs best, followed by the CCS Comparative Baseline. The Representative Preferred Alternative maintains the barrier in approximately one third of futures over the full modeling period and in more than half of futures during the initial implementation period. Although the waterfall also prevents native fish such as Colorado pikeminnow and razorback sucker from returning upstream to historic habitats, maintaining the barrier is generally considered beneficial because it prevents upstream expansion of predatory nonnative fish.

Reservoir elevation affects the availability and types of shoreline habitat around Lake Powell, which in turn influences fish community composition and recreational fisheries. **Table TA 8-5** quantifies how shoreline habitat area changes with reservoir elevation. Higher reservoir levels inundate broad cobble, gravel, and vegetated shorelines that tend to support sportfish such as largemouth bass, bluegill, and crappie, whereas lower reservoir levels expose steep cliff and rockfall habitats that favor smallmouth bass spawning, growth, and recruitment. Modeling results indicate that most alternatives would increase the amount of exposed shoreline habitat relative to the CCS Comparative Baseline (see **Figure TA 3-6** in **TA 3**, Hydrologic Resources), conditions that may favor smallmouth bass population growth and increase the risk that individuals are entrained downstream, potentially increasing predation pressure on native fish populations below Glen Canyon Dam.

Maintaining October 1 Lake Powell elevations above approximately 3,570 feet reduces the likelihood that smallmouth bass occupy forebay areas where entrainment through Glen Canyon Dam is likely. **Figure TA 8-7** evaluates the robustness of each alternative in maintaining October 1 elevations above this threshold, while **Figure TA 8-8** shows the hydrologic conditions under which alternatives are vulnerable to elevations falling below the threshold. Modeling results indicate that the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best in reducing entrainment risk. The remaining action alternatives and the CCS Comparative Baseline perform substantially worse. The Representative Preferred Alternative performs at an intermediate level, maintaining the elevation threshold in about 42 percent of futures during the first implementation period.

Lake Powell reservoir elevations influence native fish conservation outcomes through multiple interacting mechanisms, including nonnative fish establishment, riverine habitat availability, fish passage barriers, and shoreline habitat conditions. Different operational alternatives, therefore, involve trade-offs among reducing risks from nonnative fish, maintaining critical riverine habitat for endangered fish, preserving natural barriers to upstream fish movement, and sustaining reservoir fisheries under uncertain future hydrologic conditions.

Issue 2: Changes in water quantity, release timing, temperature, and quality from Glen Canyon Dam downstream through the Grand Canyon to Pearce Ferry.

The reach of the Colorado River from Glen Canyon Dam to Lake Mead has experienced substantial ecological change due to long-term modifications in flow magnitude, timing, temperature, and water quality associated with dam operations. These changes have influenced habitat conditions and fish populations throughout the Grand Canyon, affecting ESA-listed species such as humpback chub and razorback sucker, as well as other native species and sportfish, including flannelmouth sucker, bluehead sucker, and rainbow trout. Of particular concern is the potential establishment of nonnative piscivorous fish, especially smallmouth bass, which may be entrained through Glen Canyon Dam when Lake Powell elevations decline, and the warm epilimnion aligns more closely with dam penstocks. Entrainment modeling indicates that propagule pressure increases substantially when reservoir elevations fall below approximately 3,530 feet and persists until elevations fall below the minimum power pool of 3,490 feet, after which releases through river outlet works reduce invasion risk (Eppehimer et al. 2025). Maintaining Lake Powell elevations above approximately 3,570 feet at the start of the year substantially reduces the likelihood of entraining smallmouth bass and other undesirable nonnative species. Warmer releases associated with lower reservoir levels may also increase downstream water temperatures, potentially facilitating reproduction and establishment of warmwater nonnative fish that could increase predation and competition pressures on native species.

A combination of hydrologic, water quality, temperature, and biological indicators was used to evaluate these risks. River flows from CRSS were used to characterize hydrologic conditions affecting aquatic habitat, while a smallmouth bass population model integrating reservoir elevation, water temperature, inflow volumes, and outflows was used to estimate propagule pressure at Glen Canyon Dam and population growth rates (lambda) at several locations downstream, including Lees Ferry, the Little Colorado River confluence (RM 61), Havasu Creek confluence (RM 156), and Pearce Ferry (RM 281). Lambda values greater than 1 indicate increasing populations, while values less than 1 indicate declining populations. Key water temperature thresholds used in the analysis included 12 °C (53.6 °F), which supports humpback chub growth; 16 °C (60.8 °F), which promotes spawning of both humpback chub and smallmouth bass; and 20 °C (68 °F), which can cause thermal stress or mortality for trout species.

Water quality conditions were evaluated using modeled dissolved oxygen concentrations in dam releases (see **Figures TA 6-11** through **TA 6-14** in **TA 6**). Results indicate that minimum annual dissolved oxygen concentrations generally remain between approximately 4 and 7 mg/L under average hydrologic conditions but decrease under drier scenarios. Robustness analysis (**Figure TA 6-12**) shows that the Enhanced Coordination and Maximum Operational Flexibility alternatives are most effective at maintaining dissolved oxygen above the hypoxic threshold of 2 mg/L in at least 90 percent of years across modeled futures. Vulnerability analysis (**Figure TA 6-14**) indicates that the CCS Comparative

Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are more likely to produce undesirable conditions under hydrologic scenarios represented in the Drying with Variability ensemble, whereas the Enhanced Coordination and Maximum Operational Flexibility alternatives remain resilient under most modeled drought conditions.

Water temperatures important to native fish habitat were evaluated using historical monitoring data and modeled scenarios within the DMDU framework. Hourly temperature data from monitoring stations near the Little Colorado River and Diamond Creek for water years 2008 to 2025 were used to calculate the number of days per year exceeding biologically relevant thresholds of 12 °C and 16 °C (53.6 °F and 60.8 °F). These thresholds represent conditions that support humpback chub growth (12 °C [53.6 °F]) and spawning (16 °C [60.8 °F]). Historical patterns showed that most years experienced at least 110 days above these thresholds, which was adopted as a benchmark for thermally suitable conditions. Model outputs were then summarized using heatmaps and boxplots to evaluate how management alternatives influence temperature regimes along the river corridor from Lees Ferry to Pearce Ferry and how those conditions affect native fish, trout species, and nonnative predators such as smallmouth bass.

At Lees Ferry, temperature outcomes vary among alternatives and hydrologic conditions (**Figure TA 8-9**). Exceeding 12 °C (53.6 °F) generally promotes humpback chub growth, while temperatures above 16 °C (60.8 °F) promote smallmouth bass spawning and those above 20 °C (68 °F) can reduce rainbow trout survival. Under average hydrologic conditions, most alternatives produce similar temperature patterns, although the Enhanced Coordination and Maximum Operational Flexibility Alternatives result in fewer days exceeding the higher thresholds because they maintain cooler dam releases. Robustness analysis (**Figure TA 8-10**) indicates that the Enhanced Coordination Alternative performs best in maintaining temperatures below 20 °C (68 °F), followed by the Maximum Operational Flexibility Alternative. Vulnerability analysis (**Figure TA 8-11**) shows that most alternatives become susceptible to temperatures above 20 °C (68 °F) during extended drought conditions. The Representative Preferred Alternative performs moderately, meeting the preferred temperature threshold in fewer futures than the highest performing alternatives.

At the Little Colorado River confluence, water temperatures are generally warmer and more conducive to native fish growth than at Lees Ferry (**Figure TA 8-12**). Exceeding the 12 °C (53.6 °F) threshold promotes humpback chub growth, while exceeding 16 °C (60.8 °F) supports spawning but may also favor smallmouth bass. Robustness analysis (**Figure TA 8-13**) shows that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs best at achieving the preferred threshold for humpback chub growth, while the Enhanced Coordination and Maximum Operational Flexibility alternatives perform worst because they maintain cooler water temperatures. However, analysis of the 16 °C (60.8 °F) spawning threshold (**Figure TA 8-14**) indicates that all alternatives perform poorly at achieving sustained mainstem spawning conditions for humpback chub. This result suggests that humpback chub spawning will likely remain concentrated in the Little Colorado River tributary rather than the mainstem.

Farther downstream at the Havasu Creek confluence, temperature conditions are generally warm enough to support humpback chub growth across most alternatives (**Figure TA 8-15**). Robustness results indicate that nearly all alternatives meet the threshold of at least 110 days above 12 °C (53.6 °F) in most futures (**Figure TA 8-16**). However, achieving temperatures above 16 °C (60.8 °F) for extended periods, which could support humpback chub spawning but also promote smallmouth bass reproduction, is less common (**Figure TA 8-17**). The Enhanced Coordination and Maximum Operational Flexibility Alternatives produce fewer days above this threshold, limiting both native and nonnative spawning potential. The Representative Preferred Alternative performs strongly for the growth threshold but more moderately for spawning related temperature thresholds.

At Pearce Ferry, water temperatures are influenced more strongly by ambient air temperatures than by dam releases because of the long distance downstream from Glen Canyon Dam (**Figure TA 8-18**). As a result, differences among alternatives are smaller. All alternatives consistently exceed the 12 °C (53.6 °F) threshold needed for humpback chub growth (**Figure TA 8-19**), but conditions conducive to spawning (temperatures above 16 °C [60.8 °F]) vary more widely (**Figure TA 8-20**). Alternatives that maintain cooler upstream release temperatures, particularly the Enhanced Coordination and Maximum Operational Flexibility Alternatives, produce fewer days above the spawning threshold, which may reduce smallmouth bass reproduction but also limit opportunities for humpback chub spawning in the mainstem.

Temperature outcomes also influence smallmouth bass population growth and entrainment risk. Modeling of smallmouth bass population growth rates (lambda) indicates that the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best at maintaining lambda below 1, indicating declining populations if established (**Figure TA 8-21**). The No Action Alternative and CCS Comparative Baseline perform worst in this regard. Vulnerability analysis (**Figure TA 8-22**) shows that prolonged dry hydrologic conditions increase the likelihood that smallmouth bass populations could grow.

Finally, entrainment modeling evaluates the number of smallmouth bass that may pass through Glen Canyon Dam and survive downstream (**Figure TA 8-23**). The Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best at limiting entrainment, whereas the other alternatives perform substantially worse. Vulnerability analysis (**Figure TA 8-24**) indicates that all alternatives could experience elevated entrainment during dry hydrologic conditions because low Lake Powell elevations align warm surface waters, where smallmouth bass reside, with dam penstocks. Overall, alternatives that maintain higher reservoir elevations and cooler release temperatures generally reduce smallmouth bass invasion risk but may also limit thermal conditions favorable for native fish growth and spawning, illustrating a key management tradeoff in temperature management below Glen Canyon Dam.

Overall, reservoir elevation, dam release temperature, and hydrologic variability strongly influence aquatic habitat conditions and fish population dynamics downstream of Glen Canyon Dam. Alternatives that maintain higher Lake Powell elevations generally produce cooler release temperatures, lower entrainment risk, and reduced growth in the smallmouth bass population, which benefits trout survival and helps limit the establishment of nonnative fish. However, these cooler conditions may also limit thermal opportunities for humpback chub growth and mainstem spawning. Conversely, alternatives that allow warmer water conditions may benefit native fish growth but also increase the risk of smallmouth bass reproduction and establishment. These results illustrate the tradeoffs among management alternatives in balancing native fish recovery, control of nonnative predators, and maintenance of recreational fisheries under uncertain future hydrologic conditions.

Issue 3: Lower reservoir elevations have reduced lake habitat and extended river inflows, including about 30 miles on the Colorado River and 20 miles on the Virgin River, with similar extensions observed at Las Vegas Bay, Echo Bay, and other locations. How will these inflow changes affect the quantity and quality of lake, wetland, and riverine inflow habitats?

The Lower Colorado River Basin from Lake Mead to the SIB has experienced ecological changes driven by fluctuations in reservoir elevations and tributary inflows, which affect the quantity and quality of aquatic habitat for native, nonnative, and recreationally important fish species. Lower Lake Mead elevations reduce littoral shoreline habitat used by sportfish and razorback sucker, while simultaneously extending riverine inflow habitats along the Colorado River, Virgin River, and other tributaries. These changes may alter the extent of designated critical habitat for razorback sucker and influence the distribution and movement of native fishes such as humpback chub and razorback sucker. Reservoir elevation also affects fish passage at Pearce Ferry Rapid, which functions as a natural barrier to upstream fish movement under lower lake levels but becomes inundated at elevations above approximately 1,090 feet. When the rapid is submerged, both native and nonnative fish may move upstream from Lake Mead into the Grand Canyon. Conversely, elevations below approximately 1,000 feet would compromise hydropower generation. To evaluate these conditions, the analysis considered indicators including monitoring data on sportfish catch, shifts in native fish distribution and abundance, and changes in the availability and quality of shoreline and inflow spawning habitats. Monitoring datasets from Arizona Game and Fish Department (AZGFD), Nevada Department of Wildlife (NDOW), and the LCR MSCP were integrated with DMDU modeling results to evaluate how alternative management strategies may affect reservoir elevations, aquatic habitats, and fish community dynamics.

Two key elevation thresholds were evaluated in the analysis. The first threshold is Lake Mead elevation of 1,090 feet, above which Pearce Ferry Rapid becomes inundated and no longer functions as a barrier to upstream fish passage. Robustness analysis (**Figure TA 8-25**) evaluates the percentage of modeled futures in which Lake Mead remains below 1,090 feet for at least 90 percent of months, a threshold based on recent historical conditions, during which the reservoir remained below this elevation approximately 94 percent of the time between 2016 and 2026. Results show that the No Action Alternative performs best, followed by the CCS Comparative Baseline. Among action alternatives, the Basic Coordination Alternative performs best. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives perform the worst. The Representative Preferred Alternative meets the threshold in 20 percent of futures over the full modeling period and in approximately 39 percent of futures during the first implementation decade (2027–2039). Vulnerability analysis (**Figure TA 8-26**) indicates that several alternatives, including the Representative Preferred Alternative, become vulnerable to elevations exceeding 1,090 feet under relatively moderate 10-year average flows of approximately 12.4 maf or wetter, conditions that occur in most traces of the Drying with Variability ensemble. In contrast, the No Action Alternative and CCS Comparative Baseline are less vulnerable and would generally exceed the threshold only under wetter conditions.

The analysis also evaluated the potential for lake elevations to fall below the lowest elevation observed during the recent historical period (1,040.92 feet in July 2022), which serves as a proxy for maintaining shoreline habitats that have historically supported the current fish community. Robustness analysis

(**Figure TA 8-27**) evaluates the percent of modeled futures in which Lake Mead remains at or above this elevation for at least 90 percent of months. Results show that the No Action Alternative performs worst, while the CCS Comparative Baseline and Basic Coordination Alternatives perform modestly better. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives perform substantially better with the Supply Driven Alternative (LB Pro Rata approach) performing best. The Representative Preferred Alternative meets this threshold in 26 percent of futures across the full modeling period, although performance is lower during the initial decade (17 percent). Vulnerability analysis (**Figure TA 8-28**) indicates that most alternatives become vulnerable to elevations falling below 1,040.92 feet under 10-year average flows between approximately 10.9 and 11.7 maf or drier; conditions that are comparable to or slightly drier than the historically observed minimum 10-year average of 11.8 maf.

Overall, reservoir elevation strongly influences aquatic habitat availability and fish community dynamics in Lake Mead and downstream reaches. Alternatives that maintain lower reservoir elevations are more effective at sustaining Pearce Ferry Rapid as a barrier to upstream fish movement, which may help limit the spread of nonnative species into the Grand Canyon but also restrict the movement of native fishes such as the razorback sucker. Conversely, alternatives that maintain higher lake levels improve the likelihood of sustaining shoreline spawning and nursery habitats that support the existing Lake Mead fish community, but increase the potential for fish passage across Pearce Ferry Rapid. If reservoir elevations remain within the historical range observed between 2008 and 2026, the current fish assemblage and habitat conditions are expected to persist. However, prolonged periods outside this historical range, particularly sustained low-elevation conditions, may reduce shoreline spawning habitats and increase ecological stress for aquatic species in the Lake Mead ecosystem.

Issue 4: How would modifications in water quantity, timing, temperature, and quality released from Hoover Dam affect the lower Colorado River, including LCR MSCP reaches 2 through 6 (Hoover Dam to Davis Dam and Lake Mohave, Davis Dam to Parker Dam and Lake Havasu, Parker Dam to Cibola Gage, Cibola Gage to Imperial Dam and Imperial Reservoir, and Imperial Dam to the NIB)?

Hoover Dam operations may influence aquatic habitats and fish populations in the Lower Colorado River from Hoover Dam downstream to Imperial Dam, including reaches managed under the LCR MSCP. Although ESA mitigation measures are already in place through previous consultations, this EIS assesses how different operational alternatives may affect river flows, timing, temperature, and water quality under NEPA. Changes in these factors could influence habitats and population dynamics of endangered species such as razorback sucker and bonytail, as well as other native fishes, including flannelmouth sucker and desert pupfish. Modified flow regimes may affect the extent of backwater and riverine habitats, the location and suitability of razorback sucker spawning areas, and the stability of constructed desert pupfish refuge ponds if flows fall outside historical bounds. Reduced flows could also allow predatory nonnative fish, such as flathead catfish, to expand upstream from the Cibola gage toward Imperial Dam, increasing the predation risk to native fishes. The analysis relies on monitoring data from agencies including AZGFD, NDOW, the California Department of Fish and Wildlife, Reclamation, the LCR MSCP, and U.S. Fish and Wildlife Service (FWS), with the assumption that fisheries management practices, such as stocking of listed species, continue as they have since 2008.

A primary indicator evaluated in the analysis is whether monthly releases from Hoover Dam remain within the range observed during the Interim Guidelines period (2008–2025), representing the recent historical flow regime to which aquatic communities have experienced. Robustness analysis (**Figure TA 8-29**) evaluates the percent of modeled futures in which releases remain within this historical range for 100 percent of months. Results show that the No Action Alternative, CCS Comparative Baseline, and Basic Coordination Alternative are the most robust. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs moderately worse, while the Enhanced Coordination Alternative performs similarly. The Maximum Operational Flexibility Alternative performs the worst. Despite these differences, all alternatives maintain releases within the historical range in more than 92 percent of months across the full modeling period. Decadal analysis shows similar rankings, with the No Action, CCS Comparative Baseline, and Basic Coordination Alternatives meeting the threshold in roughly 75–88 percent of futures, while other alternatives perform somewhat lower but still maintain releases within historical bounds for more than 90 percent of months.

Additional analysis of monthly release magnitudes (**Figure TA 8-30**) compares annual minimum and maximum releases across hydrologic conditions. Under Wet Flow categories, most alternatives produce similar distributions of minimum and maximum releases, indicating comparable operational responses during high inflow periods. However, the Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) tend to produce higher annual maximum monthly releases than other alternatives. As hydrologic conditions become drier, differences among alternatives become more apparent. The No Action Alternative, Basic Coordination Alternative, and CCS Comparative Baseline maintain relatively higher minimum releases during critically dry conditions, indicating continued higher downstream flows even during drought. In contrast, the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) generally result in lower minimum releases during dry periods because these alternatives implement larger shortage reductions to conserve storage in Lake Mead. Even under critically dry conditions, minimum monthly releases remain above the historical reference threshold of 220 kaf in approximately 90 percent or more years for most alternatives, except the Maximum Operational Flexibility Alternative, which falls below that threshold more frequently. Results for the Representative Preferred Alternative fall within the range observed across other alternatives, with median annual minimum and maximum releases remaining within historical bounds under both dry and critically dry conditions.

Operational differences among alternatives produce only modest changes in Hoover Dam release patterns relative to the historical flow regime experienced between 2008 and 2025. Alternatives that maintain higher release volumes during drought conditions, such as the No Action and Basic Coordination Alternatives, may accelerate declines in Lake Mead storage but maintain relatively stable downstream flows. Alternatives that reduce releases during drought conditions may help maintain reservoir elevations while still providing flows within the historical range experienced by aquatic species. Because downstream impoundments such as Lake Mohave and Lake Havasu operate under guide curves that maintain relatively stable elevations across alternatives, and because modeled releases remain largely within historical ranges, aquatic habitats within the LCR MSCP reaches are expected to remain generally similar to recent historical conditions. Under these circumstances, fish community composition and population dynamics downstream of Hoover Dam would likely remain comparable to those observed during the 2008–2025 period, assuming continued fisheries management and habitat restoration efforts.

Summary Comparison of Alternatives

The analysis compares several proposed alternatives for the Colorado River downstream of Glen Canyon Dam using hydrologic modeling, ecological indicators, temperature thresholds, and assessments of ecosystem vulnerability and resilience. A full summary of those findings can be found in **Figure TA 8-31** in **Section TA 8.2.6**, Summary Comparison of Alternatives. Key findings show that the Enhanced Coordination and Maximum Operational Flexibility Alternatives are most robust in maintaining cooler water temperatures, maintaining higher dissolved oxygen levels, and controlling nonnative species like smallmouth bass. However, they may restrict native fish spawning and growth. In contrast, the No Action Alternative and the CCS Comparative Baseline better preserve riverine habitats above Lake Powell and prevent upstream movement of nonnative fish from Lake Powell and Lake Mead; this would benefit endangered species such as Colorado pikeminnow and razorback sucker but reduce lake habitat for sportfish. For Lake Mead and downstream habitats, the No Action Alternative and the CCS Comparative Baseline maintain lower lake elevations that help contain nonnative fish; however, they may also limit native fish access to new habitats. Most alternatives support stable flows and fish communities downstream of Hoover Dam, though the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are less robust in maintaining desirable release patterns. The Representative Preferred Alternative typically falls within the middle of the range of outcomes across issues. Each alternative involves trade-offs between supporting native endangered species, controlling nonnative fish, and maintaining recreational fisheries.

3.9 Vegetation Including Special Status Species

3.9.1 Affected Environment

This analysis categorizes vegetation into marsh, woody riparian, and upland habitat types (collectively referred to as terrestrial habitats) throughout the analysis area, which includes Lake Powell, Glen Canyon Dam to Lake Mead, Lake Mead, and Hoover Dam to the SIB. For additional information on the affected environment, including a list of special status species, please reference **TA 9**, Vegetation Including Special Status Species, and **Attachment 1**, Special Status Plant Species, in **TA 9**. **Table TA 9-1** in **Section TA 9.1**, Affected Environment, provides the approximate acreages of marsh, woody riparian, and upland habitats by reach. Wetlands in the analysis area are typically characterized by marsh habitat, but could also occur in woody riparian habitats.

Marsh habitats occur in areas that are consistently flooded and are typically found in the transition zone between open water and upland ecosystems. Marsh vegetation is sensitive to drought on short timescales, seasonally to annually, and has been found to decrease in cover, species diversity, and productivity when water availability shifts from perennial to intermittent (Stromberg et al. 2005, 2007; Friedman et al. 2022). Woody riparian habitats occur where water is consistently available and periodic flooding occurs. Woody riparian vegetation typically has deeper root systems capable of accessing alluvial groundwater and is not dependent on surface water flows (Stromberg et al. 2013). This vegetation type is sensitive to drought on longer timescales, on an annual to decadal scale, depending on the species (Shafroth et al. 2002). Upland habitats occur in areas without consistent water availability, where vegetation depends on precipitation.

Lake Powell

Short-term and long-term fluctuating water elevations influence Lake Powell's shoreline vegetation. The median annual water elevation fluctuation during the 2007 Interim Guidelines period (between 2008 and 2025) was 31.45 feet (see **Figure TA 9-1** in **Section TA 9.1**, Affected Environment). The drought-induced drawdown of Lake Powell since 2011 has reduced the lake's perimeter and exposed approximately 59,000 acres of formerly submerged land (Root and Jones 2022). Recently exposed sites below full pool of Lake Powell shows a higher percentage and cover of nonnative species, with prickly Russian thistle (*Salsola tragus*) being extremely abundant (Arens 2023). However, native shrubs are outcompeting nonnative plants on sites that have been exposed for more than 3 years; these shrubs are providing diverse ecosystems, including hanging gardens and cryptobiotic crusts, where natural flow patterns are reestablishing (Arens 2023, NPS 2026). As water levels continue to drop, newly established vegetation may begin to decline (Kasprak et al. 2026). Two special status plant species are present in the Lake Powell reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Glen Canyon Dam to Lake Mead

Marsh, woody riparian, and upland habitats from Glen Canyon Dam to Lake Mead are influenced by the peak magnitudes, daily fluctuations, and seasonal patterns of river flows. Most evidence indicates that vegetation composition, structure, distribution, and function are closely tied to ongoing Glen Canyon Dam operations (Reclamation 2016; Palmquist et al. 2023). Marsh and woody riparian vegetation have expanded in this reach since Glen Canyon Dam was completed in 1963 (Sankey et al. 2015). The greatest area of vegetation expansion between 2002 and 2013 was woody riparian vegetation on sandbars in the active channel (Durning et al. 2021). The availability of water at low river elevations from consistent base flows can promote vegetation establishment, whereas prolonged periods of peak flow may inhibit vegetation establishment. When inundation frequency increases by 5 percent or more, vegetation expansion was unlikely to occur (Sankey et al. 2015).

Twenty special status plant species are present in the Grand Canyon to Lake Mead reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Lake Mead

Similar to Lake Powell, short- and long-term fluctuations in water elevation affect Lake Mead's shoreline vegetation. The median annual water elevation fluctuation between 2008 and 2025 was 16.19 feet (see **Figure TA 9-3** in **Section TA 9.1**). The drawdown of Lake Mead from 1998 to 2011 reduced the lake's perimeter by more than 400 kilometers (250 miles) and exposed more than 61,776 acres of formerly submerged land (Engel et al. 2014). Long-term fluctuations allow the establishment of woody riparian vegetation, including the nonnative and invasive tree tamarisk (*Tamarix* spp.); however, as lake levels continue to fall, tamarisk may begin to show drought stress and mortality when water levels fall below their roots.

Overall, native species cover has been found to be greatest on surfaces that have been exposed for a longer period of time (Engel et al. 2014). Native vegetation at Lake Mead has been positively influenced by defoliation from the tamarisk leaf beetle (*Diorhabda* spp.) (beetle). Twenty-one special status plant species are present in the Lake Mead reach and could be affected by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

Hoover Dam to the Southerly International Boundary (SIB)

The LCR MSCP planning area identifies 14 land cover types, including five woody riparian types that are divided into multiple structural types. The marsh land cover type is divided into seven compositional types based on plant composition and vegetation structure (Reclamation 2004; see **Table TA 9-2** in **Section TA 9.1**). Since the beetle's release in 2006, its range has expanded downstream from Lake Mead along the lower Colorado River; by 2019, large beetle populations were detected along the Imperial stretch of the lower Colorado River. In 2020, beetles were present, and defoliation was documented in or around all LCR MSCP study areas (Reclamation 2021). In 2024, beetles were documented to the SIB (McLeod and Pellegrini 2021; Mahoney et. al 2022; RiversEdge West 2025).

In 2024, Reclamation contracted RiverRestoration.Org to map backwater areas (water, marsh, and non-marsh) in the LCR MSCP planning area and to conduct a change analysis between the 2024 effort and a 2000 backwater mapping effort (RiverRestoration.Org 2025). The study found an overall decrease in marsh area between Davis Dam and Morelos Dam from 2000 to 2024. Nine special status plant species are present in the Hoover Dam to SIB reach and could be influenced by operations (**Attachment 1** in **TA 9**, Vegetation Including Special Status Species).

3.9.2 Environmental Consequences

Figures referenced in this section and a description of how to interpret the results of the analysis are provided in **Section TA 9.2**.

Methodology

There are no long-term vegetation monitoring datasets available for Lake Powell, Lake Mead, or Hoover Dam to the SIB that would support quantitative habitat modeling, as was done for the Glen Canyon Dam to Lake Mead section; therefore, a qualitative approach was used to determine the predicted differences in marsh and woody riparian vegetation among the alternatives. As noted in **Section 3.9.1**, Affected Environment, marsh and woody riparian vegetation are affected by water level fluctuations on short (annual) and long (5-year) timescales. Therefore, changes in water elevation over 1-year and 5-year periods were used as proxies to represent potential changes to marsh and woody riparian vegetation.

To determine the changes in water elevation under each alternative, CRSS was applied within the DMDU framework to show maximum variability within 1 year and over 5 years in the robustness heat map figures. A 5-year period was selected to represent longer-term variability in water level fluctuations. The modeled variability from CRSS and the DMDU framework were then compared to historic conditions to determine whether variability would remain the same, increase, or decrease for each alternative. For the purposes of this analysis, historic conditions extend from water year (WY) 2008–2025 (the 2007 Interim Guidelines period). Refer to **Section 3.2**, Analysis Methods, for additional information on DMDU and **Appendix E**, DMDU Overview and Approach, for an overview of how to interpret the DMDU robustness heatmaps.

The DMDU calculations are based on the alternatives meeting a preferred minimum performance, defined by a threshold applied to model output values and a frequency over time. If a modeled future meets both the threshold and frequency, it is considered a successful future. For Lake Powell vegetation, the thresholds correspond to the median observed variability in water elevation over 1 year (for marsh vegetation) and 5 years (for woody riparian vegetation). The CCS Comparative Baseline data displayed on each figure represent the modeled outcome if current management strategies are continued into the future. This information is included for comparative purposes between the alternatives and the modeled future of the analysis area.

Since vegetation can tolerate a range of environmental conditions, failing to meet the threshold criteria once over the full modeling period is not necessarily detrimental to the habitat's establishment or growth over the long term. Therefore, the analysis focuses on the number of times that the model meets the criteria over a 10-year window for marsh vegetation and a rolling 10-year window for woody riparian vegetation.

The GCMRC conducted hydrologic niche modeling for several species on the fixed-site sandbars for each alternative and used these models to estimate the acres of habitat suitability for each species (Butterfield and Palmquist 2026). The data used for this modeling were collected from 2014 to 2019 (Palmquist et al. 2018a) and can be accessed in the associated data release (Palmquist et al. 2022). In addition to habitat suitability, changes to native species richness, proportion native cover, and total native vegetation cover were estimated by combining the modeled habitat suitability. The hydrologic niche modeling includes HFEs. For a detailed analysis of frequency and duration of HFEs under each alternative, see **TA 5**, Geomorphology and Sediment.

Figures presented for this reach are conditional box plots. Refer to **Section 3.2**, Analysis Methods, for additional information on DMDU and **Appendix E**, DMDU Overview and Approach, for an overview of how to interpret the DMDU conditional box plots. The hydrologic niche modeling results used to create these figures can be accessed in the associated data release (Butterfield and Palmquist 2026). The dashed lines included in **Figure TA 9-9** through **Figure TA 9-13**, in **TA 9**, are reference lines to the 50th percentile of modeled 'historical' period, which were modelled using 2000-2025 hydrology under CCS Comparative Baseline using a dry-initial condition (see **Section 3.2.6** for an explanation of initial conditions).

As with Lake Powell, changes in water elevation from historical conditions were used as a proxy to determine potential impacts on marsh and woody riparian vegetation under each alternative for Lake Mead. The same methods for Lake Mead were used as described for Lake Powell.

As with Lake Powell and Lake Mead, the change in water elevation was used as a proxy to determine potential impacts on marsh and woody riparian vegetation under each alternative for the Hoover Dam to SIB reach. However, for this reach, water releases were used to represent changes from historical conditions rather than water elevation. Releases from Hoover Dam, Davis Dam, and Parker Dam were modeled, as releases from these dams determine the amount of water available downstream. Davis Dam and Parker Dam were found to have similar trends as Hoover Dam; therefore, only Hoover Dam results are discussed in detail. The impacts as described in the Hoover Dam to SIB section apply to the entire reach.

Impact Analysis Area

The Lake Powell reach includes Lake Powell up to full pool (water surface elevation 3,700 feet). The Glen Canyon Dam to Lake Mead reach extends from Glen Canyon Dam (RM -15.6) to RM 240. The Glen Canyon Dam to Lake Mead reach begins at Glen Canyon Dam, includes the Colorado River through Grand Canyon, and ends where Lake Mead at full pool occurs at RM 240. The analysis area for this reach extends to the 45,000-cfs modeled stage elevation, corresponding to the maximum controlled flood releases under the current HFE protocol; the analysis area is considered the active floodplain of the Colorado River in this reach under LTEMP (Reclamation 2016)**.** The section from Glen Canyon Dam to Lake Mead is divided into the following three sub-reaches to account for vegetation community changes (Palmquist et al. 2018b): Marble Canyon (RM -15.6 to RM 60), Eastern Grand Canyon (RM 60 to RM 161), and Western Grand Canyon (RM 161 to RM 240).

The Lake Mead reach extends from RM 240 in the Grand Canyon to Hoover Dam. The analysis area for this reach includes the full pool of Lake Mead (water surface elevation 1,229 feet). The Hoover Dam to SIB reach is aligned with the LCR MSCP planning area. As described in **TA 8**, Biological Resources – Fish and Other Aquatic Resources, there are seven reaches within the LCR MSCP planning area. For vegetation analysis, the analysis area includes LCR MSCP reaches 2 through 7 (Reclamation 2004). Reach 1 in the LCR MSCP planning area includes Lake Mead up to the full pool, which is addressed separately as Lake Mead. The analysis area includes the full pool of Lake Mohave and Lake Havasu and the Colorado River's historical floodplain.

Assumptions

The assumptions used for the analysis of impacts are provided in **Section TA 9.2.1**, Methodology.

Impact Indicators

The following impact indicators were used:

- A change in the median and interquartile ranges from modeled historical conditions (Glen Canyon Dam to Lake Mead reach)
- Changes in water fluctuations within a single year compared with historical conditions (Lake Powell, Lake Mead, and Hoover Dam to SIB reaches)
- Changes in water fluctuations in the preceding 5 years compared with historical conditions (Lake Powell, Lake Mead, and Hoover Dam to SIB reaches)

Issue 1: How would changes in the management of the Colorado River impact vegetation, including special status species

Lake Powell. For all alternatives except for the Enhanced Coordination Alternative and the Maximum Operation Flexibility Alternative, increased variability in the first decade (2027–2039; **Figure TA 9-7** in **TA 9**) compared to modeled historic conditions, indicated by a lower percentage of futures meeting the level of performance, would result in changes in marsh vegetation. Whether an area experiences an increase or a decrease in marsh habitat in response to changed conditions is mostly dependent on local topography, but generally an increase in variability is expected to result in a decrease in marsh vegetation due to more frequent dewatering and inundation. In the first decade, the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative are the most robust, meeting the minimum level of performance in 81 percent and 80 percent of futures, respectively. CCS Comparative Baseline and No Action Alternative meet it in 49 percent and 36 percent of futures, respectively.

In the first decade, cover of prickly Russian thistle may increase due to the increased area of upland habitat created during water elevation fluctuations. Cover of prickly Russian thistle would be expected to decrease in the later decades if variability also decreases, reducing areas vulnerable to invasive species establishment on an annual basis. Native vegetation can re-establish over time, particularly in areas exposed for more than 3 years (Arens 2023).

In the later decades (2040–2049 and 2050–2060; **Figure TA 9-7** in **TA 9**), the Enhanced Coordination Alternative is the most robust, meeting the minimum level of performance in 92 percent and 90 percent of futures, respectively. CCS Comparative Baseline and No Action Alternative meet it in 54 percent and 48 percent, and 51 percent and 53 percent of futures, respectively. As variability becomes closer to historic conditions for Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative (as indicated by a higher percentage of futures meeting the level of performance), marsh vegetation may re-establish to a similar historical extent under those alternatives.

For the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative under the Critically Dry Flow Category Lake Powell has a modeled WY minimum median elevation of approximately 3,520 feet and 3,512 feet, respectively (see **Table TA 3-4** in **Section TA 3.2**, Environmental Consequences, in **TA 3**, Hydrologic Resources); these median elevations are 38 and 46 feet below, respectively, the minimum 2024 water elevation of 3,558 feet (see **Figure TA 3-1** in **Section TA 3.1**, Affected Environment). Under the Average Flow Category, Lake Powell has a WY modeled minimum median elevation of approximately 3,613 and 3,605 feet for the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative, respectively (see **Table TA 3-4** in **Section TA 3.2**); these median elevations are approximately 55 and 47 feet higher than the minimum 2024 water elevation. This indicates higher modeled elevations under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative under all but the critically dry modeled conditions. If water elevations gradually rise with similar levels of variability to historical conditions (**Figure TA 9-7**), marsh vegetation is expected to continue to reestablish along the new water line over time. If water elevations rise, some of the side canyons that were exposed as Lake Powell receded may reflood, which would inundate the native plant communities that had reemerged.

If water elevations stay the same or gradually fall with similar variability to historical conditions (**Figure TA 9-7**), marsh vegetation may reestablish to a similar extent along the new water line over time. Under these alternatives, plant communities in the side canyons would remain exposed.

Whether water elevations rise, fall, or remain the same, if variability resembles historical conditions under the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative in the later decades, marsh vegetation **(Figure TA 9-7)** and woody riparian vegetation **(Figure TA 9-8)** is expected to continue to reestablish along the new water line over time. For alternatives that have more variability than historical conditions (**Figure TA 9-7, Figure TA 9-8**), marsh and woody riparian vegetation may reestablish to a smaller extent along the new water line over time. Where variability eliminates or prevents the establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type. Whether an area experiences an increase or a decrease in marsh or woody riparian habitat in response to changed conditions is largely dependent on local topography, but generally an increase in variability is expected to result in a decrease in woody riparian vegetation.

The trends and type of impacts on woody riparian vegetation are the same as those described for marsh vegetation for Lake Powell (**Figures TA 9-7** and **TA 9-8**).

Glen Canyon Dam to Lake Mead Suitable Habitat Area – Marsh. Figure TA 9-9 compares the amount of modeled marsh habitat for each alternative by Grand Canyon sub-reach. Marsh vegetation includes bulrushes (*Schoenoplectus* spp.), rushes (*Juncus* spp.), field horsetail (*Equisetum arvense*), and common reed (*Phragmites australis*).

In Marble Canyon and Eastern Grand Canyon, under the Average Flow Category, Moderately Wet Flow Category, and Dry Flow Category, the medians are near modeled historic conditions (dashed line) and the interquartile ranges are relatively restricted and overlap the modeled historic conditions (**Figure TA 9-9**) for all alternatives, indicating that the amount of habitat suitable for marsh species would likely be similar to historic conditions under these categories. Under the Critically Dry Flow Category, the Maximum Operational Flexibility Alternative, Supply Driven Alternative, and Representative Preferred Alternative medians and interquartile ranges are completely above modeled historic conditions (dashed line), indicating that suitable habitat for marsh species may increase under the Critically Dry Flow Category for those alternatives. Under the Wet Flow Category, the medians and interquartile ranges are mostly below modeled historic conditions (dashed line) for all alternatives, suggesting there would likely be less suitable marsh habitat under all alternatives.

Further downstream in Western Grand Canyon, wider interquartile ranges suggest greater uncertainty in the amount of modeled suitable marsh habitat. The general trends follow that of Marble Canyon and Eastern Grand Canyon, but with more differentiation in the Moderately Wet and Dry Flow Categories; there would likely be similar levels of marsh habitat under the Average Flow Category, less marsh habitat under the Wet and Moderate Wet Flow Categories, and more marsh habitat under the Dry and Critically Dry Flow Categories. Under the Average, Dry, and Critically Dry Flow Categories, the CCS Comparative Baseline and Enhanced Coordination Alternative have wider interquartile ranges than the other alternatives, suggesting greater uncertainty.

The decrease in suitable habitat for marsh species under the Wet Flow Category for all sub-reaches and all alternatives may occur because higher water levels may reduce the overall available terrestrial habitat in the river's active channel (Sankey et al. 2015). The similarity or increase in suitable habitat for marsh species under the Critically Dry Flow Category (4.46–10.0 maf) and the Dry Flow Category for all sub-reaches and all alternatives may be because decreasing water levels increase the amount of exposed shoreline habitat.

Glen Canyon Dam to Lake Mead Suitable Habitat Area – Woody Riparian. Figure TA 9-10 compares the amount of modeled woody riparian habitat for each alternative by Grand Canyon sub-reach. Woody riparian vegetation includes seepwillow (*Baccharis* spp.), arrowweed (*Pluchea sericea*), honey mesquite (*Prosopis glandulosa*), and coyote willow (*Salix exigua*).

Across all three sub-reaches, similar interquartile ranges would suggest woody riparian suitable habitat would respond in a similar way across all alternatives under each Flow Category. However, the wide interquartile ranges suggest a high amount of uncertainty about how vegetation would respond under each of the modeled conditions and alternatives in all three sub-reaches.

Similar to marsh habitat, under the Average, Moderately Wet Flow, Wet Flow, and Dry Flow Categories, there is less suitable habitat for woody riparian species, as indicated by the median remaining below the modeled historic conditions under all sub-reaches and across all alternatives except for the No Action Alternative and Enhanced Coordination Alternative in the Dry Flow

Category. For some alternatives, the interquartile range expands above the modeled historic conditions (dashed line), indicating uncertainty about how vegetation would respond. Under the Critically Dry Flow Category, the medians are typically above the modeled historic conditions (dashed line), indicating a likely increase in suitable habitat for woody riparian vegetation under all alternatives except for the Maximum Flexibility Alternative. However, the large interquartile ranges extend far above as well as below the modeled historic conditions (dashed line) under all reaches and for all alternatives except for the No Action Alternative, indicating the variability is too high to predict whether there would be more or less suitable habitat for woody riparian species under these alternatives. The No Action Alternative remains above the modeled historical conditions for all three sub-reaches. This may be because under the No Action Alternative, there would be less water available, compared with the other alternatives, and thus more exposed shoreline that can support woody riparian species.

Similar to marsh habitat, the decrease in suitable habitat for woody riparian species under the Moderately Wet Flow Category and Wet Flow Category for all sub-reaches and all alternatives may be because higher water levels reduce the overall available terrestrial habitat (Sankey et al. 2015). Whereas suitable habitat for woody riparian species may increase under the Critically Dry Flow Category; this expansion would occur near river level on areas recently exposed by lower water levels. Suitable habitat for both woody riparian and marsh species may overlap in these recently exposed areas, where these habitat types would compete near the river. In areas near the top of the active floodplain, decreasing water levels may provide an opportunity for an increase in upland habitat due to disconnection from the river.

Glen Canyon Dam to Lake Mead Suitable Habitat Area – Arrowweed. Figure TA 9-11 compares arrowweed suitable habitat under each alternative by Grand Canyon sub-reach. Across all three reaches, all alternatives show similar trends: the generally similar and overlapping interquartile ranges suggest arrowweed would respond in a similar way across all alternatives. Arrowweed would respond similarly to marsh and woody riparian habitat: there would be less arroweed suitable habitat under wetter conditions and more arrowweed suitable habitat under drier conditions.

Glen Canyon Dam to Lake Mead – Native Species Richness. Figure TA 9-12 compares the predicted count number of native species (native species richness) under each alternative by Grand Canyon sub-reach. Native species richness includes all habitat types and does not distinguish between marsh, woody riparian, and upland. Across all three sub-reaches, all alternatives show similar trends: The wide and generally similar interquartile ranges suggest native species richness would respond in a similar way across all alternatives.

Under all alternatives, sub-reaches, and flow categories, the median is below the modeled historic conditions (dashed line). For some modeled conditions, the interquartile range is above the modeled historic conditions, indicating uncertainty in how vegetation would respond. Since most of the interquartile range is still below the modeled historic conditions, native species richness may decrease under all modeled conditions. However, given the large interquartile ranges, it is difficult to predict how each alternative may respond. Similar to marsh habitat, the Western Grand Canyon reach has larger interquartile ranges than Marble Canyon and Eastern Grand Canyon, indicating greater uncertainty further downstream.

Species richness at the fixed-site sandbars declined from 2014 to 2019. This trend was driven by low species richness in 2019 (Palmquist et al. 2023). The low species richness in 2019 was likely caused by the HFE that occurred in fall 2018 and the lack of monsoon precipitation in summer 2019. Native species richness may decrease under wet hydrologic conditions because HFEs would be a more frequent occurrence and may decrease under the Critically Dry Flow Category due to a lack of precipitation. Disturbance created by HFEs can also positively impact native species richness, as some species require periodic disturbance. Native species richness may also decrease under the Critically Dry Flow Category due to a lack of HFEs. Under all conditions, a combination of these hydrologic and climatic factors may be driving the variable interquartile ranges.

Glen Canyon Dam to Lake Mead – Proportion Native Species Cover. Figure TA 9-13 compares the proportion of native species cover under each alternative by Grand Canyon sub-reach. The proportion native species cover includes all habitat types and does not distinguish between marsh, woody riparian, and upland vegetation. Across all three sub-reaches, all alternatives show similar trends: The generally wide and similar interquartile ranges in each sub-reach suggest the proportion of native cover would respond in a similar way across all alternatives.

Similar to native species richness, the proportion of native species cover has large interquartile ranges across all modeled conditions and all alternatives. This indicates a large amount of uncertainty in how vegetation would respond under various conditions. Under all reaches, under the Wet, Moderately Wet, Average, and Dry Flow Categories modeled conditions, the median is below the modeled historic conditions (dashed line) for all alternatives except for the No Action Alternative and Basic Coordination Alternative under Average and Dry Flow Categories. Since most of the interquartile ranges are below the modeled historic conditions, the proportion of native cover may decrease under Wet, Moderately Wet, Average, and Dry Flow Category conditions under all alternatives and all sub-reaches. However, given the large interquartile ranges, it is difficult to predict how vegetation may respond under each of the modeled conditions, alternatives, and sub-reaches.

For all sub-reaches, under the Critically Dry Flow Category modeled conditions, the median and interquartile range is above the modeled historic conditions (dashed line) under all alternatives except for the Maximum Operational Flexibility Alternative. This suggests that under the Critically Dry Flow Category modeled conditions, the proportion native cover may stay similar to historic conditions or increase under most alternatives. However, given the large interquartile ranges, it is difficult to predict how vegetation may respond under each alternative.

Encroachment of riparian vegetation into the exposed active channel and into the bare sand of sandbars has been found to be driven by seepwillows, which are a native species (Durning et al. 2021). The proportion of native species cover may decrease under all conditions except for the Critically Dry Flow Category due to the lack of bare sand available for native species, particularly seepwillows, to colonize. The proportion of native cover may increase under the Critically Dry Flow Category because of receding water levels and subsequent increase in available sand.

Glen Canyon Dam to Lake Mead – Annual Total Vegetation Cover. Figure TA 9-14 compares the annual total vegetation cover under each alternative by Grand Canyon sub-reach. Annual total vegetation cover includes all habitat types and does not distinguish between marsh, woody riparian, and upland. Across all three reaches, all alternatives show similar trends: The generally similar and overlapping interquartile ranges suggest annual total vegetation cover would respond in a similar way across all alternatives.

Under the Average Flow Category, across all three sub-reaches, the median for each alternative overlaps or nearly overlaps the modeled historic conditions (dashed line), and the interquartile ranges are relatively small. This indicates that annual total vegetation may be similar to historic conditions under the Average Flow Category.

Across all three sub-reaches, under the Wet Flow Category and Moderately Wet Flow Category, the median and interquartile ranges are at or below the modeled historic conditions (dashed line) for all alternatives except for the interquartile range of the No Action Alternative in the Moderately Wet Flow Category, although the median remains below historic conditions. This suggests that there would be less annual total vegetation cover under the Wet and Moderately Wet Flow Categories under all sub-reaches and all alternatives. Under the Dry Flow Category, the medians are above historic conditions (dashed line) for all alternatives except the CCS Comparative Baseline and Enhanced Coordination Alternative. Under the Critically Dry Flow Category the median and interquartile ranges are above the modeled historic conditions (dashed line) for all sub-reaches and all alternatives except for the CCS Comparative Baseline. This indicates that there may be more annual total vegetation cover under Critically Dry Flow Category.

Similar to the discussions above under *Suitable Habitat Area*, the decrease in annual total vegetation cover under the wet and moderately wet modeled conditions for all sub-reaches and all alternatives may be because higher water levels reduce the overall available terrestrial habitat (Sankey et al. 2015). Conversely, annual total vegetation cover may increase under the Dry and Critically Dry Flow Categories, likely on areas recently exposed by lower water levels. Fewer to no HFEs under the Dry and Critically Dry Flow Categories could also lead to higher vegetation encroachment.

High Flow Experiments

HFEs influence vegetation dynamics in this reach depending on geomorphic setting, duration, and flow volume. HFEs are dependent on sufficient storage and sediment conditions at Lake Powell. Alternatives that prioritize retaining higher levels in Lake Powell are more likely to result in HFEs, which could influence modeled vegetation responses in this reach. The role of HFEs on shaping vegetation in this reach are described in greater detail in the 2024 LTEMP SEIS (Reclamation 2024c).

Lake Mead. In the first decade, all alternatives are equally non-robust, meeting the minimum level of performance in 0 percent of futures. For all alternatives, the increased variability from historical conditions in the first decade (2027–2039; **Figure TA 9-15**) of the analysis may result in decreased cover of marsh vegetation. In later decades (2040–2049 and 2050–2060; **Figure TA 9-15**) when variability becomes closer to historical conditions for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, marsh vegetation may reestablish to a more similar extent compared to the other alternatives. Both of these alternatives are more robust than the CCS Comparative Baseline and No Action Alternative, which meet the minimum level of performance in 16 percent and 14 percent, and 10 percent and 10 percent of futures, respectively. Similar to Lake Powell, when conditions are more variable, cover of nonnative species, such as prickly Russian thistle, may increase; if variability decreases, native cover may reestablish.

As shown in **Figure TA 3-11** (see **TA 3.2**), the interquartile ranges for all alternatives for the Average Flow Category are above the 2024 WY minimum of 1,061 feet except for the No Action Alternative. The interquartile ranges under the Dry Flow Category are closer to the 2024 WY minimum compared to the Average Flow Category, and the interquartile ranges overlap with the 2024 WY minimum for all alternatives under the Critically Dry Flow Category. This suggests that Lake Mead is likely to lower under drier conditions. Conversely, under the Moderately Wet and Wet Flow Categories, the interquartile ranges shift to be higher than the 2024 WY minimum of 1,061 feet (**Figure TA 3-11**, see **TA 3.2**), suggesting that Lake Mead would rise under wetter conditions.

Similar to Lake Powell, whether water elevations rise, fall, or remain the same, if there are similar levels of variability to historical conditions under the Basic Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) in the later decades (**Figure TA 9-15**), marsh vegetation is expected to continue to reestablish along the new water line over time. For alternatives with greater variability than historical conditions (**Figure TA 9-15**), marsh vegetation may reestablish to a smaller extent along the new water line over time. Where variability eliminates or prevents the establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type.

Similar to Lake Powell, the first decade of modeling for woody riparian vegetation is influenced by historical data (**Figure TA 9-16**). All alternatives meet the minimum level of performance in 12 percent or less of futures. The later decades (2040–2049 and 2050–2060; **Figure TA 9-16**) begin to trend towards more similar variability compared to historic conditions, but variability still remains high. The Basic Coordination Alternative and the Maximum Operational Flexibility Alternative are more similar to historic conditions, meeting the minimum level of performance in 26 percent and 50 percent and 22 percent and 52 percent of futures, respectively. Both of these alternatives are more robust than the CCS Comparative Baseline and No Action Alternative, which meet the minimum level of performance in 20 percent and 22 percent, and 20 percent and 24 percent of futures, respectively.

In later decades (2040–2049 and 2050–2060; **Figure TA 9-16**), when variability becomes more similar to historical conditions for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, woody riparian vegetation may reestablish to a more similar extent as existing conditions compared to other alternatives. Where variability eliminates or prevents the establishment of woody riparian habitat, upland habitat may become the dominant habitat type.

Figures TA 9-15 and **TA 9-16** suggest that annual variability in Lake Mead water elevations may be higher, especially in the early decade of the modeling period; however, the variability on a 5-year basis may overall be closer to historical conditions, generally benefiting woody riparian vegetation.

Hoover Dam to the SIB. Similar to Lake Powell and Lake Mead, the first decade of modeling for marsh vegetation is influenced by historical data (**Figure TA 9-17**). In the first decade, the Basic Coordination Alternative is the most robust, meeting the minimum level of performance in 60 percent of futures. CCS Comparative Baseline Alternative and No Action Alternative meet it in 55 percent and 6 percent of futures, respectively. For all alternatives, the increased variability from historic conditions in the first decade (2027–2039; **Figure TA 9-17**) may result in decreased marsh vegetation cover.

In later decades (2040–2049 and 2050–2060; **Figure TA 9-17**), all alternatives trend towards more similar variability compared to historic conditions. All alternatives meet the minimum level of performance in 78 percent or more of futures. The CCS Comparative Baseline and No Action Alternative meet it in 63 percent and 61 percent, and 63 percent and 55 percent of futures, respectively. As variability becomes closer to historical conditions, marsh vegetation may reestablish to a similar extent. Where variability eliminates or prevents establishment of marsh habitat, woody riparian or upland habitat may become the dominant habitat type.

During the 2007 Interim Guidelines period, the annual volume of the Colorado River below Hoover Dam averaged 9.185 maf (see **Section TA 3.1**). For all alternatives under the Average and Dry Flow Categories the interquartile ranges of the modeled annual volume are below 9.185 maf (**Table TA 3-21** and **Figure TA 3-27** in **Section TA 3.2**). This suggests that the annual flow volume below Hoover Dam may decrease under all alternatives under the Average and Dry Flow Categories. The 2007 Interim Guidelines reduced the average annual releases from Hoover Dam by approximately 1.014 maf from prior operating guidelines (**Section TA 3.1**). As described in **Section TA 9.1**, the recent change analysis indicates marsh vegetation generally decreased from 2000 to 2024 (RiverRestoration.Org 2025). If water releases decrease with higher levels of variability, compared with historical conditions (**Figure TA 9-17**), marsh vegetation is expected to continue to decrease over time under Average and Dry Flow Categories. If water releases decrease with similar levels of variability as historical conditions (**Figure TA 9-17**), marsh vegetation is expected to decline at a rate similar to existing conditions under Dry and Critically Dry Flow Categories.

Similar to Lake Powell and Lake Mead, the first decade of modeling for woody riparian vegetation is influenced by historical data (**Figure TA 9-18**). In the first decade, all alternatives are equally non-robust, meeting the minimum level of performance in 0 percent of futures. Increased variability from historic conditions in the first decade (2027–2039; **Figure TA 9-18**) may result in decreased woody riparian vegetation cover due to inconsistent water availability.

In later decades (2040–2049 and 2050–2060; **Figure TA 9-18**), alternatives trend towards variability more similar to historic conditions. The Basic Coordination Alternative is the most robust, meeting the minimum level of performance in 45 percent and 40 percent of futures, respectively. The CCS Comparative Baseline and No Action Alternative meet it in 30 percent and 27 percent, and 29 percent and 26 percent of futures, respectively. The CCS Comparative Baseline and No Action Alternative meet it in 17 percent and 12 percent, and 21 percent and 19 percent of futures, respectively. This increased variability may result in decreased riparian vegetation cover under all alternatives, but to a lesser extent under the Basic Coordination Alternative and No Action Alternative. Where variability eliminates or prevents woody riparian habitat establishment, upland habitat may become the dominant habitat type.

Summary Comparison of Alternatives

Table TA 9-4 in **Section TA 9.2** provides a comparison of alternatives that are most and least similar to historical conditions for each reach.

For Lake Powell marsh and woody riparian vegetation, the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative would result in vegetation most similar to historical conditions. The Maximum Operational Flexibility Alternative would also result in vegetation most similar to historical conditions for Lake Mead's marsh and woody riparian vegetation. However, for the Hoover Dam to the SIB reach, the Maximum Operational Flexibility Alternative and the Enhanced

Coordination Alternative would result in vegetation least similar to historical conditions, which would result in larger changes in vegetation, compared with historical conditions, for that reach. Similarly, the Basic Coordination Alternative would result in conditions least similar to historical conditions for Lake Powell, but would be closest to historical conditions for Lake Mead and Hoover Dam to the SIB. This suggests that no single alternative would result in vegetation similar to historical conditions across all reaches.

For all reaches, multiple alternatives provide variability more similar to historical conditions than the CCS Comparative Baseline, except for the Hoover Dam to SIB reach, where only the Basic Coordination Alternative would result in variability more similar to historical conditions. This suggests that a change in management from current strategies would benefit a large portion of the analysis area; however, it would not benefit the Hoover Dam to SIB reach unless the Basic Coordination Alternative is selected.

For the Glen Canyon Dam to Lake Mead reach, the alternative that would result in vegetation most similar to historical conditions depends strongly on the flow categories. Across all alternatives, all sub-reaches, and all evaluated criteria (the suitable habitat area, native species richness, proportion of native species cover, and annual total vegetation cover), the interquartile ranges often overlap. When the interquartile ranges overlap, it is difficult to determine whether one alternative is truly different from another. Therefore, no single alternative emerged as the best or worst for retaining vegetation similar to historical conditions.

Under all alternatives for Lake Powell, Lake Mead, and Hoover Dam to the SIB, the first decade would experience more variability, which would result in a reduction in marsh and woody riparian habitat compared with historical conditions. All alternatives would see conditions return closer to historical conditions in the second and third decades, which may result in vegetation reestablishing to a similar extent. Where variability eliminates or prevents the establishment of marsh, woody riparian, or upland habitat, there may be a shift to one of the other habitat types.

3.10 Terrestrial Wildlife Including Special Status Species

3.10.1 Affected Environment

This section provides an overview of the general terrestrial wildlife typically found within marsh, woody riparian, and upland habitats in the analysis area, as described in **Section 3.9**, Vegetation Including Special Status Species, including invertebrates, amphibians, reptiles, birds, and mammals. This section also includes special status species, which are defined here as those listed as BLM sensitive species in the overlapping Arizona, California, Utah, and Nevada BLM field offices; species covered under the LCR MSCP; and species listed as threatened, endangered, or proposed for listing by the FWS (BLM 2017, 2018, 2019, 2023; LCR MSCP 2022; FWS 2025). **Attachment 1** in **TA 10**, Terrestrial Wildlife Including Special Status Species, provides a table of the species considered in this document, including their listing status, the river reaches they typically inhabit, and the habitat types most important to their life histories. **Attachment 1** in **TA 10** was developed with input from cooperating agencies and local experts. A full description of the wildlife and special status species that use each of the habitat types is provided in **Section TA 10.1**, Affected Environment, in **TA 10**.

In addition to analyzing the impacts on wildlife in the analysis area as defined in **Section 3.9**, Vegetation Including Special Status Species, impacts are also evaluated for the LCR MSCP conservation areas. These areas were established to provide habitat for species listed under the ESA or that may become listed under the ESA and that use habitat along the Colorado River from Lake Mead down to the SIB (LCR MSCP 2025). The Colorado River in this area has been highly modified by several dams and water diversions, which have affected the growth and establishment of marsh and woody riparian habitat (see **Section 3.9.1**, Affected Environment). The LCR MSCP Habitat Conservation Plan (HCP) and subsequent ESA consultations identified the impacts on marsh, woody riparian, upland, and backwater habitats predicted from existing and anticipated future river operations, and the program established the conservation areas and off-river land acquisitions to mitigate for these losses and provide reliable suitable habitat for wildlife (LCR MSCP 2025). There are 18 conservation areas aimed at conserving 27 species, with a goal of creating 5,940 acres of cottonwood/willow, 1,320 acres of honey mesquite, 568 acres of marsh, and 484 acres of backwater habitats. In addition to the conservation areas, several wildlife refuges and lands managed for wildlife and recreation are present below Hoover Dam. These include Havasu National Wildlife Refuge, Bill Williams River National Wildlife Refuge, Cibola National Wildlife Refuge, Imperial National Wildlife Refuge, Gooseflats Wildlife Area, Lake Mead National Recreation Area, and Mittry Lake Wildlife Management Area.

Section 3.9, Vegetation Including Special Status Species, describes the marsh, woody riparian, and upland habitat types, which are used in this section to determine the affected environment and environmental impacts on wildlife, including special status species. For additional information on the wildlife species considered in this analysis by habitat type, please reference **Section TA 10.1**, Affected Environment, in **TA 10**, Terrestrial Wildlife Including Special Status Species.

3.10.2 Environmental Consequences

Methodology

This Terrestrial Wildlife section relies on the outcomes of the vegetation analysis, the methodology for which is outlined in the Methodology subsection of **Section 3.9.2**, Environmental Consequences.

Impact Analysis Area

The analysis area is the same as described in the Impact Analysis Area subsection of **Section 3.9.2**, Environmental Consequences.

Assumptions

- Upland wildlife species, including special status species, that do not rely directly on the Colorado River or on woody riparian and marsh vegetation influenced by elevation or flows are not included in the impact analysis because changes in operations would not impact these species.
- The evaluation of impacts on wildlife, including special status species, are driven by impacts on vegetation modeling in **Section 3.9** (DMDU-based vegetation analysis).

Impact Indicators

These indicators align with the DMDU figures in **Section 3.9**.

- For terrestrial wildlife species using marsh habitat, changes in water fluctuations within a single year compared with historical conditions
- For terrestrial wildlife species using woody riparian habitat, changes in water fluctuations in the preceding 5 years compared with historical conditions
- For terrestrial wildlife species using upland habitat, changes in water fluctuations over either the preceding single year or preceding 5 years compared with historical conditions

Issue 1: How would changes in the management of the Colorado River impact terrestrial wildlife species habitat availability, including special status species?

Lake Powell

As discussed in **Section 3.11.2**, Environmental Consequences, Lake Powell's surface water elevations fluctuate on a short-term (annual) and long-term (5-year) scale, which causes changes in water availability and which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife, including special status species (hereafter collectively referred to as wildlife), that currently use the Lake Powell analysis area have adapted to these changing conditions.

Under all alternatives, modeling indicates a greater range of variability in Lake Powell's surface elevations compared with historic conditions for both marsh and woody riparian habitat in the first decade (2027–2039) (**Figure TA 9-7** and **Figure TA 9-8** in **TA 9**, Vegetation Including Special Status Species). As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, this greater variability would result in changes in the vegetation extent compared with existing conditions and could decrease vegetation cover. While Lake Powell would continue to support at least some upland, marsh, and woody riparian habitat, the location of conditions suitable to support each of these habitat types is likely to change. Areas that currently support marsh, woody riparian, or upland habitat could transition to one of the other habitat types. Side-canyons that have been exposed due to lower water levels have had an increase in native vegetation, which likely provides suitable wildlife habitat for a range of wildlife species. An increase in water levels could result in the loss of suitable habitat in these areas.

With increased variability, wildlife would have to adapt to changing habitat availability on a larger scale than under historical conditions. For those species capable of moving long distances, such as large mammals, bats, birds, and some amphibians, reptiles, and invertebrates, this change in habitat availability would likely have fewer long-term impacts, provided that suitable habitat is available within their dispersal or migratory range. Habitat transitions could also result in the range expansion or contraction of some species, including into new reaches, as they adapt to changing habitat availability. For less mobile species, such as some small mammals, amphibians, reptiles, and invertebrates, the transition from one habitat type to another may impact foraging, breeding, or sheltering behaviors, which can impact survival and reproduction. Decreased survival and reproduction on a large scale can result in a decreased population size. Smaller local populations are more vulnerable to changes in the environment, which can lead to even greater reductions in population size and an increased risk of the loss of local populations.

During the second decade (2040–2049) and third decade (2050–2060), modeling indicates a range of variability more similar to historical conditions under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative compared with the other alternatives as well as compared with the first decade (2027–2039; **Figure TA 9-7** and **Figure TA 9-8** in **TA 9**, Vegetation Including Special Status Species). This would result in habitat variability similar to what is currently on the landscape; wildlife would need to adapt to changing habitat conditions at the same scale as historical conditions. For all other alternatives, variability would remain high in the second and third decades (as indicated by lower percentages of futures meeting the level of performance), and wildlife would continue to need to adapt to changing habitat availability on a larger scale compared with historical conditions.

In addition to the annual and 5-year changes in water elevation, modeling indicates Lake Powell would gradually rise in elevation over time under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative in all but the Critically Dry Flow Category (**Table TA 3-4** and **Figure TA 3-1** in **TA 3**, Hydrologic Resources). This would result in a shift of marsh and woody riparian vegetation along the new shoreline over time. The rise in water elevation would result in a marginal loss of upland habitat but is not likely to impact wildlife that use marsh or woody riparian habitat, as the shift would be gradual enough for vegetation to continue to reestablish along the new shoreline. Under all other alternatives, modeling indicates water levels would remain the same or decrease in elevation. Similarly, vegetation would reestablish along the lower shoreline as the water elevations change over time. As water elevations lower, the distance to water for upland species would increase. However, given the ability for vegetation to adapt to changing water levels, this change in water elevation, either to a higher elevation under the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative or to a similar or lower elevation under all other alternatives, would not likely impact foraging, breeding, or sheltering behaviors for wildlife. Lower water levels can raise the risk of harmful algal blooms. This risk applies to all alternatives except the Enhanced Coordination and Maximum Operational Flexibility Alternatives and under all conditions except for the Critically Dry Flow Category. This could impact wildlife directly through increased toxicity exposure or indirectly through reductions in habitat quality and quantity.

While monarch butterflies (*Danaus plexippus plexippus*) primarily use woody riparian habitat for migration, they also use marsh and upland habitat regularly. Given the shifting availability of marsh, woody riparian, and upland habitat, and the ability to use features from all three habitat types, monarch butterflies are likely to be able to find suitable habitat under all alternatives in the Lake Powell analysis area. Species-specific impacts will be addressed in future ESA Section 7 Biological Opinions (BOs).

Glen Canyon Dam to Lake Mead

Similar to Lake Powell, the Glen Canyon Dam to Lake Mead reach experiences fluctuating water levels that cause changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife in the Glen Canyon Dam to Lake Mead analysis area have had to adapt to these changing conditions in the past.

As shown in **Figure TA 9-9** and **Figure TA 9-10** in **TA 9**, Vegetation Including Special Status Species, the amount of suitable habitat for marsh and woody riparian habitat across all three sub-reaches of the Glen Canyon Dam to Lake Mead reach is modeled to respond similarly under all alternatives, and the wide interquartile ranges in **Figure TA 9-10** in **TA 9**, Vegetation Including Special Status Species, indicate that future acreages of woody riparian habitat are difficult to predict. For marsh and woody vegetation, for all alternatives and sub-reaches, there is less suitable habitat under the Wet and Moderately Wet Flow Categories and more suitable habitat under the Dry and Critically Dry Flow Categories compared to modeled historical conditions. The Western Grand Canyon sub-reach has wider interquartile ranges, which suggests greater uncertainty in how vegetation will respond under the various alternatives. Woody vegetation has larger interquartile ranges than marsh vegetation, and therefore greater uncertainty. The amount of habitat available for wildlife species, including southwestern willow flycatcher (*Empidonax traillii extimus*) and yellow-billed cuckoo (*Coccyzus americanus*), is affected primarily by modeled conditions rather than by the alternatives. Species-specific impacts will be addressed in future ESA Section 7 BOs.

Similar patterns are apparent for native species richness, proportion of native species cover, and annual total vegetation cover (**Figures TA 9-12**, **TA 9-13**, and **TA 9-14** in **TA 9**, Vegetation Including Special Status Species). Increased species richness, proportion of native species cover, and annual total vegetation cover would be beneficial to wildlife species for foraging and breeding habitat. However, increases in each of these factors are driven by the modeled conditions rather than by the alternatives, with additional habitat available under the Critically Dry Flow Category. This is likely due to encroachment of vegetation into areas exposed by lower water levels.

With potentially decreasing water levels at Lake Powell, the temperature of releases from Glen Canyon Dam could increase, increasing the potential for harmful algal blooms in the Glen Canyon Dam to Lake Mead reach. Harmful algal blooms could impact wildlife directly through increased toxicity exposure or indirectly by reducing habitat quality and quantity (see **TA 6**, Water Quality).

Lake Mead

Similar to Lake Powell, Lake Mead experiences fluctuating water levels on an annual and 5-year time scale that cause changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife in the Lake Mead analysis area have had to adapt to these changing conditions in the past.

As described for Lake Powell, the first decade (2027–2039) exhibits higher variability compared with historical conditions under all alternatives, which would result in changes in habitat availability on a larger scale compared with existing conditions (**Figure TA 9-7** and **Figure TA 9-8** in **TA 9**, Vegetation Including Special Status Species). Marsh and woody riparian vegetation is expected to decrease in response to the increase in variability.

Wildlife species that are capable of moving longer distances would be less likely to be affected by increased variability, provided that suitable habitat is available within their dispersal or migratory range. Even for species that are highly mobile, there may be energetic costs to finding suitable habitat in a fragmented landscape if the distance between suitable habitat locations is outside their typical movement patterns. Increased energetic costs can impact survival and reproduction. Species that are less mobile may experience impacts on foraging, breeding, or sheltering behaviors, which can also impact survival and reproduction. Decreased survival and reproduction through increased energetic costs while searching for suitable habitat or through impacts on foraging, breeding, or sheltering behaviors can result in a decreased population size. Smaller local populations are more vulnerable to changes in the environment, which can lead to even greater reductions in population size and an increased risk of the loss of local populations.

Unlike Lake Powell, at Lake Mead the second decade (2040–2049) and third decade (2050–2060) exhibit variability similar to historical conditions for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, rather than the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative. However, the impacts on wildlife would be the same as described under Lake Powell for the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative. That is, wildlife would need to adapt to changing habitat conditions at a rate more similar to historical conditions under the Basic Coordination Alternative and Maximum Operational Flexibility Alternative and would need to adapt to changing habitat conditions on a larger scale for the remaining alternatives.

As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, for all alternatives, Lake Mead elevations could rise, fall, or remain the same compared with existing conditions under all alternatives (**Figure TA 3-11** in **TA 3**, Hydrologic Resources). Similar to Lake Powell, whether the water elevations increase, decrease, or stay the same compared with existing conditions, wildlife would likely be able to adapt to these slower changes and follow the vegetation as it reestablishes along the shoreline. Should water elevations decrease under any of the alternatives, the lowering of the water elevation in Lake Mead could increase the potential for harmful algal blooms, which could impact wildlife directly through increased toxicity exposure or indirectly through reduced habitat quality and quantity.

Listed threatened and endangered species with potential to occur in the Lake Mead analysis area consist of southwestern willow flycatcher, yellow-billed cuckoo, Yuma Ridgway's rail (*Rallus obsoletus yumanensis*), and Mojave desert tortoise (*Gopherus agassizii*). Impacts have been previously assessed in the LCR MSCP HCP, 2007 Final EIS, and 2004 SEIS and associated BOs. Additional ESA Section 7 and Section 10 processes are ongoing, and additional impacts will be disclosed in future BOs and HCPs.

Southwestern willow flycatcher and yellow-billed cuckoo rely on woody riparian habitat, which has modeled increased variability and therefore decreased habitat availability in the first decade compared with historical conditions. These species are capable of moving long distances to access suitable habitat, although southwestern willow flycatchers exhibit local site fidelity and most readily colonize sites that are near existing breeding sites. The loss of suitable breeding habitat in a river reach could result in southwestern willow flycatchers being slow to recolonize the area even if suitable habitat redevelops. For both species, if water levels fluctuate or rise to the extent that habitat is unavailable, then impacts on nesting may occur.

Yuma Ridgway's rails rely on marsh habitat, which may also experience increased variability and therefore decreased habitat availability in the first decade compared with historical conditions. Yuma Ridgway's rails are also capable of moving long distances to access suitable habitat, although the readiness with which they colonize new areas far from established breeding sites is unclear. For all three species, as variability returns closer to historical conditions in the second and third decades for the Basic Coordination Alternative and Maximum Operational Flexibility Alternative, availability of suitable habitat would likely be similar to historical conditions.

Mojave desert tortoises rely on upland habitat. While upland habitat availability is modeled to change under all alternatives in each of the decades, Mojave desert tortoises would have suitable habitat available upslope and would be capable of moving away from rising water levels. Survivorship would depend on the quantity and quality of available forage in the areas they relocate to. As water levels fluctuate, upland habitat loss would be equal to the areas of change unless water fluctuations stabilize and upland vegetation is able to reestablish. Decreased survival and reproduction on a large scale can result in a decreased population size. Smaller local populations are also more vulnerable to changes in the environment, which can lead to even greater reductions in population size and an increased risk of the loss of local populations.

As described for Lake Powell, monarch butterflies are likely to find suitable habitat under each alternative and are unlikely to be affected.

Hoover Dam to SIB

Similar to Lake Powell and Lake Mead, the Hoover Dam to SIB reach experiences fluctuating water levels on an annual and 5-year timescale that causes changes in water availability, which results in the establishment, reestablishment, or loss of upland, marsh, and woody riparian habitat over time. Wildlife in the Hoover Dam to SIB analysis area had to adapt to these changing conditions in the past.

The LCR MSCP HCP and subsequent BOs set habitat creation goals to mitigate for predicted impacts from covered river operations including flow reductions, water delivery and diversion, changes in point of diversion, generation of hydropower, and operation and maintenance activities in the LCR MSCP planning area (Reclamation 2004; FWS 2005, 2018, 2022, 2024). A summary of the habitat creation goals and habitat created toward those goals as of 2025 (LCR MSCP 2025) are included as **Table 3-5**. Habitat creation goals assumed the predicted habitat impacts from reductions in flow and changes in points of diversion up to 2.083 mafy may occur annually until 2055 and would be permanent, even if impacts never actually occur. Habitat would be created to replace it in LCR MSCP conservation areas. This includes a prediction that all existing cottonwood-willow land cover supported by the river and river connected groundwater would be lost due to flow-related covered activities (with the exception of habitat at Topock Marsh and Lake Havasu). Impacts on marsh from flow reductions from 2.083 mafy to 3 mafy were predicted to be short term in duration and the habitat would recover when inundated again (FWS 2024).

These habitat creation goals are the minimum amount of land cover to be created to meet the habitat requirements for the listed and unlisted species covered by the program. Habitat created by the LCR MSCP will be designed in an integrated mosaic and managed for more than one covered species, including habitat elements for each species.

Table 3-5
Summary of Habitat Creation Goals and Habitat Acres Created from Lake Mead to the SIB

Habitat Type	Habitat Creation Goal (Acres)	Habitat Created through 2025 (Acres)
Marsh	568	362
Woody Riparian (cottonwood-willow only)	5,940	4,954
Woody Riparian (honey mesquite only)	1,320	2,046
Woody Riparian (total)	7,260	7,000

Sources: For habitat creation goals, Reclamation 2004; FWS 2005, 2022, 2024. For habitat created through 2025, LCR MSCP 2020, 2025.

Table 3-6 and **Table 3-7** detail the number of acres affected, habitat created, and habitat creation commitments. Although it is unknown exactly how many acres of habitat will be affected over the next 30 years, referencing the number of acres affected over the last 20 years, the amount of habitat present in the reaches (**Table TA 9-1** in **TA 9**), and how those acres were mitigated allows for a greater understanding of future implications. Future impacts and habitat creation commitments will be included in ESA Section 7 BOs and Section 10 HCPs.

Table 3-6
Summary of Federal and Nonfederal Flow-Related Impacts Included in 2004, 2018, 2022, and 2024 HCPs and BOs

Species	Federal and Nonfederal Flow-Related Impacts (Acres)				
ESA Section 7 Consultation	2004 BO and HCP	Additional Impacts in 2018 Biological Assessment, BO, and HCP	Additional Impacts in 2022 Biological Assessment and BO	Additional Impacts in 2024 Biological Assessment and BO	Total
Yuma Ridgway's rail	133	N/A	7	84	224
Southwestern willow flycatcher	1,784	N/A	0	0	1,784
Yellow-billed cuckoo	1,425	N/A	0	0	1,425
Mojave desert tortoise	0	N/A	0	0	0
Northern Mexican gartersnake	N/A	1,081	7	84	1,172

Under all alternatives, all LCR MSCP conservation areas would retain their water entitlements. During shortage conditions, conservation areas with lower priority water rights (4th to 6th level priorities) may not receive their deliveries. Conservation areas are managed for the appropriate habitat type considering their water priority level and historic shortages decisions. During periods of shortage, there may be a reduction in habitat quality for areas with dense overstory and understory. When insufficient water is available, regardless of cause, to maintain established land cover types as habitat for one or more covered species, the Program Manager would coordinate with the FWS to prioritize the distribution of available water among created habitats to ensure that the greatest benefits for covered species would be provided. As water becomes available, the conservation areas would be managed to improve conditions. Currently, the Cibola Valley Conservation Area is the only LCR MSCP conservation area with 4th to 6th level priority water rights. Impacts on habitat quality if 4th to 6th level priority water rights may be minimized if groundwater is available to the roots of some or all of the vegetation. Current depth to groundwater in the Cibola Valley Conservation Area is approximately 10 feet.

As described for Lake Powell and Lake Mead, the first decade (2027–2039) exhibits high levels of variability compared with historical conditions for all alternatives, which would result in changes in habitat availability on a larger scale compared with existing conditions, especially for woody riparian habitat (**Figure TA 9-17** and **Figure TA 9-18** in **TA 9**, Vegetation Including Special Status Species). Marsh and woody riparian habitat are modeled to decrease in the first decade in response to increased variability. Wildlife species that are capable of moving longer distances are less likely to be affected by the increased variability. Similar to Lake Mead, in the Hoover Dam to SIB reach wildlife species could experience decreased population levels or localized loss of populations if the increased variability results in increased energy expenditure to find suitable habitat or impacts foraging, breeding, and sheltering behaviors.

Table 3-7
ESA Section 7 Habitat Creation Commitments and Habitat Created 2005–Present

Species	Section 7 Habitat Creation Conservation and Mitigation Commitments (Acres)					LCR MSCP Land Cover Created for the Species (2005–2025) (Acres)
	2004 BO	2018 BO	2022 BO	2024 BO	Total	All[14] Created and Creditable
Yuma Ridgway's rail	512	N/A	15	41	568	362
Southwestern willow flycatcher	4,050	N/A	0	0	4,050	945
Yellow-billed cuckoo	4,050	N/A	0	0	4,050	2,553
Mojave desert tortoise	230 acres of existing habitat protection[15]	N/A	0	0	230	230 acres purchased

In the later decades (2040-2049 and 2050-2060), for the Hoover Dam to SIB reach, all alternatives meet the minimum level of performance in 78 percent or more of futures for marsh habitat (**TA 9**,

[14] Lower Colorado River Multi-Species Conservation Program. 2025. Final Implementation Report, Fiscal Year 2026 Work Plan and Budget, Fiscal Year 2024 Accomplishment Report. Bureau of Reclamation, Boulder City, Nevada. Table 1-8
[15] Net loss in habitat is fully mitigated by protecting 230 acres of desert tortoise habitat in accordance with mitigation requirements in the document entitle "Compensation for Desert Tortoise" (Desert Tortoise Compensation Team 1991).

Vegetation Including Special Status Species, **Figure TA 9-17**). For woody riparian habitat, the Basic Coordination Alternative is the most robust. The impacts on wildlife would be the same as described for Lake Powell and Lake Mead; wildlife would need to adapt to changing habitat conditions at a rate more similar to historical conditions under the Basic Coordination Alternative and would need to adapt to changing habitat conditions on a larger scale for the remaining alternatives. This could impact wildlife through changes in foraging, breeding, or sheltering behaviors, which can impact survival and reproductive rates of individuals. Decreased survival and reproduction on a large scale can have population-level impacts.

Under all alternatives, flows from Hoover Dam to SIB are modeled to decrease under the Average and Dry Flow Categories (**Table TA 3-21** and **Figure TA 3-27** in **TA 3**, Hydrologic Resources). As described in **Section TA 9.2**, Environmental Consequences, in **TA 9**, Vegetation Including Special Status Species, a recent change analysis found that marsh vegetation decreased from 2000 to 2024 (RiverRestoration.org 2025). With a higher level of variability and decreased releases, marsh vegetation is modeled to continue to decrease over time and be replaced by either upland habitat or woody riparian habitat. Wildlife species that use marsh habitat in the Hoover Dam to SIB reach are modeled to experience greater levels of habitat loss than under historical conditions if future conditions are dry or average. This habitat loss could impact wildlife species' ability to forage, breed, nest, and shelter in the area, causing them to relocate or possibly experience reduced survival rates. The potential for decreased water levels in Lake Mead could also result in water with increased temperatures being released from Hoover Dam. This could increase the potential for harmful algal blooms, which impact marsh and woody riparian vegetation, and could impact wildlife directly through increased toxicity exposure or indirectly through reductions in habitat quality and quantity.

Federal, state, and tribal managed habitat areas, such as Cibola National Wildlife Refuge, depend on water from the Colorado River to ensure functional habitat for wildlife. If water in the river drops below the level at which water is able to properly flow through diversion structures or pumps are able to function, there may be impacts on habitat unless another method is used to transport water to the managed habitat areas. If a prolonged period of dryness occurs, woody riparian and marsh vegetation may begin to desiccate; however, the extent to which this will occur is unknown.

Listed threatened and endangered wildlife species that have the potential to occur in the Hoover Dam to SIB analysis area are southwestern willow flycatcher, yellow-billed cuckoo, Yuma Ridgway's rail, northern Mexican gartersnake, and Mojave desert tortoise. Impacts have been previously assessed in the LCR MSCP HCP, 2007 Final EIS, and 2004 SEIS and associated BOs. Additional ESA Section 7 and Section 10 processes are ongoing, and additional impacts will be disclosed in future BOs and HCPs. Migrant and transient southwestern willow flycatchers and yellow-billed cuckoos could be affected by the general availability of woody riparian vegetation in which they forage and shelter, which is modeled to decrease in the first decade (2027–2039) under all alternatives (**Figure TA 9-17** and **Figure TA 9-18** in **TA 9**, Vegetation Including Special Status Species). In the second (2040–2049) and third (2050–2060) decades, decreased cover of woody riparian vegetation is modeled under all alternatives, but to a lesser extent under the Basic Coordination Alternative, CCS Comparative Baseline, and the Representative Preferred Alternative (**Figure TA 9-12** and **Figure TA 9-13** in **TA 9**, Vegetation Including Special Status Species). Breeding southwestern willow flycatchers have been present in recent years at Topock Marsh, while breeding yellow-billed cuckoos are found in LCR

MSCP conservation areas and other restored habitats. Woody riparian vegetation in these areas could be affected by the alternatives if they result in shortage allocation reductions of water deliveries. Alternatives that enhance habitat near established populations would benefit species such as the southwestern willow flycatcher that show fidelity to breeding sites. Reductions in water allocations to the conservation areas could reduce the amount of woody riparian habitat available for yellow-billed cuckoo breeding.

Decreased cover of marsh vegetation may occur in the first decade for all alternatives, which could affect the Yuma Ridgway's rail by reducing the amount of habitat available for breeding, feeding, and sheltering. Under all alternatives, marsh vegetation may reestablish in the second and third decades to an extent similar to recent conditions. However, under dry to average future conditions, water is modeled to decrease over time under all alternatives, which could reduce the amount of habitat available to Yuma Ridgway's rails for breeding, feeding, and sheltering.

The most recent confirmed northern Mexican gartersnake sightings have been in Topock Marsh in the Havasu National Wildlife Refuge. Marsh vegetation at Topock Marsh could be affected by the alternatives if they result in shortage allocation reductions of water deliveries. Northern Mexican gartersnakes are less capable of moving long distances. Should a northern Mexican gartersnake be present in marsh habitat experiencing higher levels of variability that results in the loss of that marsh habitat, as is possible in the first decade under all alternatives, northern Mexican gartersnakes may not be able to find suitable replacement habitat, which could cause local loss of populations. In the second and third decades, all alternatives would have conditions similar to historical conditions, which may support northern Mexican gartersnakes in a manner similar to existing conditions. Mojave desert tortoises are likely to be able to move to upland habitat as the habitat conditions change over time.

Water levels are modeled to decrease under all alternatives under Average and Dry Flow Categories. This may result in additional upland habitat for the Mojave desert tortoise. As at Lake Powell and Lake Mead, the monarch butterfly is likely to find suitable habitat under each alternative and is unlikely to be affected.

Summary Comparison of Alternatives

Changes in reservoir elevations and flow variability can alter the extent and location of marsh, woody riparian, and upland habitats that support terrestrial wildlife, including special status species. These habitat shifts affect wildlife by changing the availability of areas used for foraging, breeding, sheltering, and migration. While highly mobile species may relocate to suitable habitat, less mobile species may experience reduced survival or reproduction if habitat availability declines or becomes fragmented, which can reduce population sizes or lead to the loss of local wildlife. For Lake Powell, the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative would result in wildlife habitat availability most similar to historical conditions (**Table TA 9-1** in **TA 9**, Vegetation Including Special Status Species). The Maximum Operational Flexibility Alternative would also result in wildlife habitat availability most similar to historical conditions for Lake Mead. However, for Hoover Dam to the SIB, the Maximum Operational Flexibility Alternative and Enhanced Coordination Alternative would result in wildlife habitat availability least similar to historical conditions, with subsequent impacts on wildlife foraging, breeding, or sheltering behaviors, which can reduce reproduction and survival of individuals. Similarly, the Basic Coordination Alternative would result in wildlife habitat least similar to historical conditions for Lake Powell, but it would be closest to historical conditions for Lake Mead and Hoover Dam to the SIB. Therefore, no single alternative would result in wildlife habitat availability similar to historical conditions across all reaches. For all reaches, multiple alternatives provide variability more similar to historical conditions than the CCS Comparative Baseline except for the Hoover Dam to SIB reach, where only the Basic Coordination Alternative would result in variability more similar to historical conditions for woody riparian vegetation. This suggests that a change in management from current strategies would benefit a large portion of the analysis area but would not benefit woody riparian vegetation in the Hoover Dam to SIB reach unless the Basic Coordination Alternative was selected.

Under all alternatives, the first decade (2027–2039) would experience more variability, which would likely result in a reduction in marsh and woody riparian habitat and, therefore, an increase in impacts on wildlife compared with historical conditions. All alternatives would see conditions return closer to historical conditions in the second decade (2040–2049) and third decade (2050–2060), which would likely result in wildlife habitat reestablishing to a similar extent. Where variability eliminates or prevents the establishment of marsh, woody riparian, or upland habitat, there may be a shift to one of the other habitat types.

For the Glen Canyon Dam to Lake Mead reach, the alternative that would result in wildlife habitat availability most similar to historic conditions depends strongly on flow categories. Under the Dry Flow Category and Critically Dry Flow Category, some differences among the alternatives emerge, presumably because there are greater differences in the lowest flows, the median flows, and peak flows under those conditions. However, across all alternatives, all sub-reaches, and all evaluated criteria (suitable habitat area, native species richness, proportion of native species cover, and annual total vegetation cover), the interquartile ranges of the alternatives often overlap. When the interquartile ranges overlap, it is difficult to say whether one alternative is truly different from another. Therefore, no single alternative emerged as the best or worst for retaining wildlife habitat similar to historic conditions.

For all reaches, a decrease in water elevation or flow could increase water temperatures, which would increase the potential for harmful algal blooms. Harmful algal blooms can cause direct impacts on wildlife through increased toxicity or indirect impacts through decreases in habitat quality and quantity. Under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternative, there would be increased water levels in Lake Powell in all but the Critically Dry Flow Category, which would result in the lowest potential for harmful algal blooms. For Lake Mead, all alternatives may result in a lowered elevation, which could increase the potential for harmful algal blooms in Lake Mead and in the Hoover Dam to SIB reach.

3.11 Cultural Resources

3.11.1 Affected Environment

Cultural resources are the physical evidence of past or present cultures, including archaeological sites, historic-era buildings and structures, objects, trails, landforms, and other places of traditional, cultural, or religious importance. Cultural resources can be human-made or natural features and are, for the most part, unique, finite, and nonrenewable.

A Class I cultural resources record search was conducted for the study area in Arizona, California, Nevada, and Utah (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi 2024). Reclamation is consulting with the Arizona, California, Nevada, and Utah State Historic Preservation Officers (SHPOs), land managing agencies, affected tribes, and other consulting parties to develop a project-specific programmatic agreement under Section 106 of the NHPA and its implementing regulations (36 CFR 800.14). As part of the development of the programmatic agreement, Reclamation, the SHPOs, land managing agencies, affected tribes, and other consulting parties have defined the area of potential effect (APE). For this analysis, the NEPA study area coincides with the APE which also follows the Class I search area.

The study area for the analysis runs from the northern extent of Lake Powell to the SIB and consists of the Colorado River channel from bank to bank except from Glen Canyon Dam to Lake Mead, where it stretches from canyon rim to canyon rim, as well as a 0.5-mile buffer on either side of the riverbank or canyon rim. For additional information on regulatory considerations, including a detailed summary of Section 106 of the National Historic Preservation Act and its implementing regulations under 36 CFR 800, please reference **Section TA 11.1**, Affected Environment, in **TA 11**, Cultural Resources.

Identification Efforts

The Class I records search identified archaeological resources, built environment resources, specially designated cultural resources (National Historic Landmarks [NHLs], National Heritage Areas [NHAs], and National Historic Trails [NHTs]), cultural landscapes, and traditional cultural places (TCPs) within the study area. For additional information on data sources and the types of data collected for each state in the study area, please reference **Section TA 11.1.1**, Identification Efforts, in **TA 11**, Cultural Resources. The Class I records search shows that much of the study area has not been surveyed for cultural resources. Because survey coverage for both Lake Powell and Lake Mead is very low, there is potential for additional undocumented sites to exist in the study area. Data were compiled in August 2023, and the 2023 datasets were incorporated into the analysis. Additionally, the NPS provided updated archaeological site counts for Lake Powell and Lake Mead (including Grand Canyon-Parashant NM) in March 2026, which supplemented the August 2023 dataset for the reservoirs. Therefore, the site counts used in the analysis do not reflect later agency database updates in the study area outside the reservoirs.

This section analyzes impacts on archaeological sites, built environment resources, and specially designated cultural resources. Impacts on tribal resources, tribal perspectives on cultural landscapes, and TCPs are analyzed in **TA 13**, Tribal Resources.

Class I Results

The results of the Class I records search, as summarized below, include archaeological and built environment resources as well as specially designated cultural resources identified in the study area by state. For a more detailed summary on the results of the comprehensive Class I records search for each state, please reference **Section TA 11.1.4**, Class I Results, in **TA 11**, Cultural Resources.

Survey coverage of the study area is variable by state but is overall very low, ranging from 2 or 3 percent in Arizona, 5 percent in Nevada, 11 percent in California, and 37 percent in Utah. Because of the low coverage, the numbers of archaeological sites presented below do not reflect the total number of sites in the study area and are likely only a small fraction of the sites that are present. However, the sites that have been recorded give an overall picture of resources that may be found in the study area and are used in the analysis as a representative data set for what may be present in unsurveyed areas.

Arizona

The 2023 Class I records search initially identified a total of 4,246 archaeological sites in the study area in Arizona. This number included both NPS and non-NPS data, accounting for duplicates between the two datasets (see **Table TA 11-1** in **TA 11**, Cultural Resources). Non-NPS data contained 1,246 previously recorded sites in the study area. The updated site counts provided by NPS in March 2026 totaled 4,135 sites, which includes sites that overlap from the non-NPS dataset (see **Table TA 11-1** and **Table TA 11-3** in **TA 11**, Cultural Resources). The NPS dataset represents a wide range of cultural affiliations and site functions across three NPS park units (GCNP, Lake Mead NRA, and Glen Canyon NRA) (see **Table TA 11-4** and **Table TA 11-5** in **TA 11**, Cultural Resources). For the built environment, 49 previously evaluated resources were identified in the study area in Arizona. Of these, 43 are listed in the National Register of Historic Places (NRHP); these non-NHL resources consist of 8 districts (that is, groupings of resources), 26 buildings, 6 structures, 1 object, and 2 sites. The remaining 6 resources, all districts, are NRHP-eligible (see **Table TA 11-13** in **TA 11**, Cultural Resources). Additionally, 16 unevaluated but notable built environment resources (5 districts, 1 building, 9 structures, and 1 site) were also identified and may be eligible for the NRHP based on extensive research conducted for the Class I records search (see **Table TA 11-14** in **TA 11**, Cultural Resources).

Specially designated cultural resources identified in the study area in Arizona include nine NHLs, most of which are in GCNP, along with Hoover Dam NHL (also in Nevada) and Yuma Crossing NHL (also in California). Yuma Crossing NHL also encompasses the Yuma Crossing NHA (the only NHA identified in the study area), which is only on the Arizona side of the Colorado River. The Armijo Route of the Old Spanish NHT corridor (also in Utah and Nevada), the Juan Bautista de Anza NHT corridor, and the recently designated Butterfield Overland NHT corridor (both of which also cross into California) also cross the study area in Arizona, although there is no known physical evidence of any of these trails (see **Table TA 11-18** in **TA 11**, Cultural Resources).

California

A total of 493 previously recorded archaeological sites are found within the study area in California (see **Table TA 11-6** in **TA 11**, Cultural Resources) along with 63 built environment resources (three districts, a regional park, and various buildings, structures, roads, and transmission lines) (see **Table TA 11-15** and **Table TA 11-16** in **TA 11**, Cultural Resources). Yuma Crossing NHL is the only NHL in the study area in California, and there are no NHAs because the Yuma Crossing NHA designation only includes portions of the NHL on the Arizona side of the river. For the portions of the Juan Bautista de Anza NHT and Butterfield Overland NHT that cross the study area in California, there is no physical evidence of original trail segments known to exist in the study area.

Nevada

In the Nevada study area, 664 archaeological sites have been previously recorded in the NPS and non-NPS datasets (99 non-NPS [Nevada Cultural Resources Inventory System only] and 565 NPS) (see **Table TA 11-7** and **Table TA 11-8** in **TA 11**, Cultural Resources). Research identified 159 previously documented built environment resources (districts, individual buildings, structures, sites, and objects), of which 98 are associated with the construction and ongoing operation of the NRHP-listed Hoover Dam Historic District (also an NHL) on the Nevada side of the Colorado River. In addition to those resources associated with Hoover Dam, there is 1 NRHP-listed structure in Lake Mead NRA (Willow Beach Gauging Station), 26 associated with the development of recreation around Lake Mead and Lake Mohave within Lake Mead NRA, and 3 associated with Davis Dam. The remaining 29 built environment resources include 23 documented on an individual basis (apart from Hoover and Davis Dams and established recreation areas in Lake Mead NRA) and 6 for which no information was available from corresponding archives (see **Table TA 11-17** in **TA 11**, Cultural Resources). Hoover Dam NHL (also in Arizona) and the Mojave Road route of the Old Spanish NHT corridor (also in Arizona and Utah) are the only two specially designated cultural resources in the study area in Nevada. There is no evidence of the Old Spanish NHT identified in the study area.

Utah

A total of 1,384 previously recorded archaeological sites (366 non-NPS and 1,018 NPS) were identified in the study area in Utah (see **Table TA 11-10** and **Table TA 11-11** in **TA 11**, Cultural Resources) along with one built environment resource (NRHP-eligible Hite Crossing Bridge). The Armijo Route of the Old Spanish NHT corridor is the only specially designated cultural resource in the study area in Utah, and, like other NHT corridors, there are no known segments of original trail identified in the study area.

3.11.2 Environmental Consequences

Impacts on cultural resources could result from changes in lake levels or river flows from the annual releases. Direct impacts, which are those immediate in place and time, could occur from processes like wave action or wet-dry cycling, and also include visual, auditory, and atmospheric impacts. Indirect impacts occur later in time and/or farther away in terms of distance and could include easier access to newly exposed archaeological sites that were previously underwater. Impacts on cultural resources analyzed in this section only include those impacts resulting from Reclamation's management of annual releases from Glen Canyon and Hoover Dams, which influence reservoir elevations, river flows, and aeolian (wind-borne) transport. The analysis emphasizes cultural resources within 20 meters (66 feet) of the river corridor because they are the most likely to be affected by changes in river flows.

Methodology

Archaeological Resources

Potential impacts on archaeological resources were evaluated using three approaches: 1) site counts (by elevation) compared to modeled lake levels; 2) a USGS/NPS-developed preservation risk model (Caster et al. 2026); and 3) a USGS aeolian (wind-blown sand) transport model (Kelley et al. 2026; Salter and Grams 2026). Elevations for all sites identified in the Class I records search at Lake Powell and Lake Mead were calculated and used to identify those sites that are at elevations subject to changes in water levels. However, due to the low Class III survey coverage, there are doubtless more sites to be found. Along the river corridor, the analysis considers sites identified within 20 meters (66 feet) of the river corridor (bank to bank). A 20-meter (66-foot) distance is used because the variability of elevation along the river corridor is too great to efficiently sort thousands of sites by elevation. For additional information on these methods, as well as the development of the preservation risk model and the models for wind-deposited sediment, please reference **Section TA 11.2.1**, Methodology, in **TA 11**, Cultural Resources.

Built Environment Resources

Because built environment resources are generally less vulnerable to operational impacts than archaeological resources, which are finite, fragile, and nonrenewable, no modeling was conducted specifically for built environment resources. The primary built environment resources identified in the study area consist of major water management infrastructure constructed as part of Reclamation projects like Glen Canyon Dam, Hoover Dam, and Davis and Parker Dams as well as the smaller dams and the various canals and levee systems in the lower reaches of the Colorado River. These facilities represent critical infrastructure essential to Colorado River operations. None of the alternatives would involve decommissioning, removal, or substantial alteration of these facilities. Accordingly, implementation of the alternatives would not be expected to affect the historic integrity or significance of these resources. Based on this assessment, no direct or indirect impacts are anticipated on built environment resources constituting critical water management facilities, and they are not carried forward for detailed analysis.

There are also built environment resources around the reservoirs and immediately along the river corridor—particularly those developed in response to the creation of Lake Powell and Lake Mead or to provide access to or means across the river in the Grand Canyon—that are not considered critical infrastructure for river operations. As such, these types of properties were designed or located in consideration of fluctuating water levels around both the reservoirs and the river corridor. Therefore, impacts on NRHP-listed or -eligible built environment resources would occur where uncharacteristic water levels and river flows exceed historical ranges. For additional information on methodology for built environment resources, please reference **Section TA 11.2.1**, Methodology, in **TA 11**, Cultural Resources.

Specially Designated Cultural Resources

No modeling was undertaken for NHLs, NHAs, or NHTs. The one NHA identified in the study area (Yuma Crossing) coincides with the Arizona portion of the Yuma Crossing and Associated Sites NHL; therefore, it is analyzed as an NHL. There are no confirmed segments of original trail in the study area for the three NHTs. Impacts on NHLs, as the only specially designated cultural resources identified in the study area, could occur only if river flows are outside the historical range.

Impact Analysis Area

The impacts analysis area consists of the Colorado River corridor from the upper limits of Lake Powell in Utah through the Grand Canyon in Arizona and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

- Once a resource has been inundated by a reservoir, being continuously inundated thereafter is more conducive to preservation than repeated cycles of inundation and exposure (that is, wet-dry cycling and wave action).
- Repeating cycles of inundation and exposure of resources by the reservoirs or the river are damaging to archaeological resources.
- The covering of resources by wind-deposited river-sourced sediment is conducive to preservation.

- While HFEs were considered in the aeolian transport model as part of the individual vegetation and sandbar models, actual HFE frequency may differ from that assumed or predicted in the modeling.
- Impacts on cultural resources can be characterized based on projected minimum and end-of-year lake elevations for very wet through very dry conditions and river flow volumes.
- Cultural resources that have not been previously inundated would not be inundated under the CCS Comparative Baseline, the No Action Alternative, or any action alternatives (that is, no cultural resources located above reservoir spillway elevations or above the levels of current river flows would be inundated).
- The limit of physical impacts on cultural resources by the river is constrained to resources within the river corridor (bank to bank) or within 20 meters (66 feet) of the river.
- Where previous survey coverage is absent within the study area, there may be sites that have not yet been identified that could be affected under the CCS Comparative Baseline, the No Action Alternative, or the action alternatives.
- The Class I records search conducted for the study area in Arizona, California, Nevada, and Utah serves as a representative dataset for the purposes of analysis.
- Lake Mohave and Lake Havasu would continue to follow their target end-of-the-month elevation schedules ("rule curve") (see **TA 3**, Hydrologic Resources), therefore, no cultural resource impacts are expected at these reservoirs.

Impact Indicators

- Projected monthly and end-of-year lake elevations that may expose cultural resources to damage from wave action, wet-dry cycling, or increased ease of access
- Projected WY and CY dam releases resulting in potential river-flow changes that leave cultural resources susceptible to damage from erosion, wet-dry cycling, or increased ease of access
- Projected availability of sediments along the river that may be transported by wind and deposited on archaeological sites

Issue 1: How will any changes in dam operations affect (1) lake elevations at Lake Powell and Lake Mead and (2) river flows downstream, which may affect cultural resources?

Lakes

This section summarizes the potential for archaeological resources to be exposed and, therefore, experience potential impacts from exposure, using the distribution of previously recorded archaeological sites by elevation and the hydrologic modeling results for Lake Powell and Lake Mead elevations. The following summary incorporates the discussion of hydrologic modeling as presented in **TA 3**, Hydrologic Resources. For additional information on the technical details related to Issue 1, please reference **Section TA 11.2.2**, Issue 1, in **TA 11**, Cultural Resources.

Because survey coverage varies across the study area and much of the site location data was recorded prior to modern GPS/GIS technology, precise site counts are not feasible for analysis. Site counts therefore represent a sample used to characterize the overall level of sensitivity within the study area. Representative site counts by elevation were compiled from Class I data using associated elevations based on critical conditions for each lake. For Lake Powell, the critical elevations considered for the analysis are 3,700 feet (the top of the Glen Canyon Dam spillway) to 3,490 feet (the minimum power pool) (see **Table TA 3-2** in **TA 3**, Hydrologic Resources). For Lake Mead, these associated elevations are 1,221 feet (the top of the Hoover Dam Spillway) down to 950 feet (the minimum power pool) (see **Table TA 3-5** in **TA 3**, Hydrologic Resources). Archaeological sites identified in the Lake Powell and Lake Mead dataset were distributed by elevation range (see **Table TA 11-19** and **Table TA 11-20** in **TA 11**, Cultural Resources). Overall, survey coverage for both lakes is very low (around 3 percent), which means the numbers in these tables greatly underrepresent the total number of sites present. There are no NRHP-listed or NRHP-eligible built environment resources within the elevation range for Lake Powell (3,700–3,490 feet). There is one NRHP-eligible district (Echo Bay Developed Area) within the elevation range for Lake Mead (1,221–950 feet); its historic boat ramp falls between 1,221 and 1,100 feet.

The analysis for both Lake Powell and Lake Mead as presented here focuses on average and dry to critically dry flow conditions (Average, Dry, and Critically Dry Flow Categories). For discussion related to wet flow conditions (Wet Flow Category), please refer to **TA 11.2.2**, Issue 1, in **TA 11**, Cultural Resources.

Lake Powell

This section references **Figure TA 3-6** in **TA 3.2.1**, Issue 1*,* and **Tables TA 3-3** and **TA 3-4** at the end of **TA 3**, Hydrologic Resources. The following discussion uses the known number of sites within the Lake Powell dataset provided by NPS staff (see **Table TA 11-19** in **TA 11**). Survey coverage at Lake Powell is calculated to be 3.3 percent of the area below full pool, meaning the number of sites in the Lake Powell data set represents a fraction of the total number of sites present. For additional information on these tables and figures as they were incorporated into the analysis of cultural resources, please reference **Section TA 11.2.2**, Issue 1, in **TA 11**, Cultural Resources.

In general, when the level of Lake Powell is at the top of the Glen Canyon Dam spillway (3,700 feet), all 857 archaeological sites in the Lake Powell dataset (as well as any undiscovered sites below this elevation) would be inundated. Conversely, water levels dropping to minimum power pool could expose up to all 857 archaeological sites (depending on how many of those in the Lake Powell dataset remain above 3,490 feet), leaving them vulnerable to impacts. Again, it is important to note that, because some areas at Lake Powell have not been surveyed, all of the modeled scenarios have the potential to impact undiscovered archaeological resources. Sites exposed at higher elevations may be less vulnerable to impacts from wet-dry cycling and wave action, but ease of access to them may increase depending on their location. Elevations for Lake Powell are assessed based on minimum WY and EOWY elevations.

Under the Average Flow Category, the modeled scenarios begin to diverge in performance. Minimum WY median elevations for the CCS Comparative Baseline and the No Action Alternative fall around and just below 3,550 feet, potentially exposing at least 316 known archaeological sites, along with any undiscovered sites, within and above the 3,540–3,560-foot zone. EOWY median elevations for the CCS Comparative Baseline and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) are around 3,570 feet, while the No Action Alternative is just above 3,580 feet. At these elevations, at least 280 known sites, along with any undiscovered sites above 3,570 feet within the 3,580–3,560-foot zone, could be vulnerable if water levels drop. The Basic Coordination and Representative Preferred Alternatives perform somewhat better, with minimum WY median elevations of approximately 3,560 feet and 3,570 feet, respectively, potentially exposing up to 316 known sites. The EOWY median elevations are higher at around 3,590 feet for the Basic Coordination Alternative and just below 3,600 feet for the Representative Preferred Alternative, potentially exposing at least 249 known sites and any additional sites above 3,590 feet within the 3,600–3,580-foot zone.

The Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best under average conditions. Minimum WY median elevations are around 3,610 feet and 3,600 feet, respectively, which would expose between 197 and 249 known sites. EOWY median elevations are around 3,630 feet for the Enhanced Coordination Alternative and 3,620 feet for the Maximum Operational Flexibility Alternative. At these elevations, the Enhanced Coordination Alternative could expose at least 138 known sites (plus any sites above 3,630 feet within the 3,640–3,620-foot zone), while the Maximum Operational Flexibility Alternative could expose up to 197 known sites. These two alternatives also have the narrowest interquartile ranges for both median elevation metrics. Additional sites would be exposed as water levels decline further and conditions become drier, depending on site elevation.

For the Critically Dry Flow Category, the CCS Comparative Baseline, the No Action Alternative, and the action alternatives struggle to maintain key Lake Powell elevations. Minimum WY and EOWY median elevations for the CCS Comparative Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives fall below 3,490 feet (minimum power pool), with the No Action Alternative declining to just below 3,440 feet. Under these conditions, at least 415 known archaeological sites (approximately 48 percent of the Lake Powell dataset) along with any undiscovered sites, could be exposed and vulnerable. Additional sites may be affected as elevations fall below 3,490 feet, depending on the distribution of the 442 recorded sites below 3,500 feet. The 3,500 foot elevation is important because it provides an approximate 10-foot buffer to protect critical infrastructure, water supply, and hydropower operations, which are critically impacted at an elevation of 3,490 feet (see **Section TA 3.2.1**, Issue 1, in **TA 3**, Hydrologic Resources).

The Representative Preferred Alternative performs slightly better under critically dry conditions, with a minimum WY median elevation just above 3,490 feet. This would still leave at least 415 known sites exposed above 3,500 feet but could protect additional sites if present above the minimum power pool elevation. The EOWY median elevation for this alternative is just below 3,510 feet, which would inundate more sites below this level within the 3,520–3,500-foot zone. The Enhanced Coordination and Maximum Operational Flexibility Alternatives perform the best compared to the others. Minimum WY median elevations are approximately 3,520 feet and 3,510 feet, respectively, with EOWY median elevations around 3,560 feet and 3,550 feet. Relative to these EOWY elevations, both alternatives could expose at least 316 known sites and any undiscovered sites down to around 3,560 feet, with the Maximum Operational Flexibility Alternative potentially exposing additional sites above 3,550 feet within the 3,560–3,540-foot zone. Interquartile ranges for the Enhanced Coordination Alternative indicate that it has the greatest potential to limit site exposure under critically dry conditions, with the upper bound of the EOWY median elevation (75th percentile) reaching approximately 3,600 feet and potentially limiting exposure to 249 known sites.

Lake Mead

This section references **Figure TA 3-11** in **TA 3.2.1**, Issue 1, and **Tables TA 3-6** and **TA 3-7** at the end of **TA 3**, Hydrologic Resources. The following discussion uses the known number of sites within the Lake Mead dataset provided by NPS staff. Survey coverage at Lake Mead is calculated to be 2.8 percent of the area below full pool meaning the number of sites in the Lake Mead data set represents a fraction of the total number of sites present. For additional information on these tables and figures as they were incorporated into the analysis of cultural resources, please reference **Section TA 11.2.2**, Issue 1*,* in **TA 11**, Cultural Resources.

In general, when water-level elevations are at or above 1,221 feet, all 310 archaeological sites in the dataset would be inundated. Conversely, if water levels drop to 950 feet, all 310 sites in the Lake Mead dataset would be exposed, depending on the elevations of sites below 961 feet (see **Table TA 11-20** in **TA 11**, Cultural Resources). Because very little of Lake Mead was surveyed prior to the construction of Hoover Dam in the early 1930s and, as a result, undiscovered archaeological resources are likely to be present in unsurveyed areas, such resources could be affected under any of the modeled scenarios. Elevations for Lake Mead are assessed based on minimum CY and EOCY elevations.

Under the Average Flow Category, the modeled scenarios begin to diverge in performance with respect to minimum CY and EOCY median elevations. As lake levels decline, additional sites may be exposed depending on elevation. The No Action Alternative performs the most poorly, with minimum CY and EOCY median elevations just below 970 feet and just below 980 feet, respectively. These elevations would expose at least 301 known archaeological sites in the Lake Mead dataset as well as sites below this elevation within the 981–961-foot zone, including any undiscovered sites that may be present. The CCS Comparative Baseline performs somewhat better than the No Action Alternative, with a minimum CY median elevation of about 1,030 feet and an EOCY median elevation around 1,040 feet. However, these elevations could still leave at least 286 known archaeological sites, along with any undiscovered sites present, vulnerable to impacts from exposure. The Basic Coordination Alternative has a minimum CY median elevation just above 1,050 feet and an EOCY median elevation just above 1,060 feet, leaving at least 280 known archaeological sites (and any undiscovered sites present) exposed. The corresponding interquartile ranges, from approximately 1,130 feet at the upper limit down to around 1,000 feet, could leave between 227 and 296 known sites vulnerable to impacts from exposure, depending on elevation.

The Representative Preferred Alternative performs slightly better, with a minimum CY median elevation just above 1,090 feet and an EOCY median elevation just above 1,100 feet, potentially exposing at least 265 known archaeological sites along with any undiscovered sites present. The Enhanced Coordination Alternative has a minimum CY median elevation around 1,100 feet and an EOCY median elevation around 1,110 feet, which could expose between 245 and 265 known sites, depending on elevation. The interquartile ranges for this alternative are similar for both minimum CY and EOCY elevations, ranging from around 1,130 feet down to about 1,060 feet and from around 1,140 feet down to around 1,070 feet, respectively. Within these ranges, between 227 and 280 known sites could be exposed, depending on elevation and the presence of undiscovered sites. The Maximum Operational Flexibility Alternative has a minimum CY median elevation just below 1,120 feet and an EOCY median elevation just below 1,130 feet, potentially exposing between 227 and 245 known sites, along with any undiscovered sites present. The interquartile range for this alternative is the largest among the modeled scenarios, ranging from around 1,180 feet, which could leave up to 142 known sites exposed, down to just above 1,040 feet, which could expose up to 286 known archaeological sites and any undiscovered sites also present above these elevations.

The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs the best under average hydrological conditions. The LB Priority approach has minimum CY and EOCY median elevations around 1,140 feet and 1,150 feet, respectively, which could expose between 196 and 227 known sites as well as any undiscovered sites present. The LB Pro Rata approach performs slightly better, with a minimum CY median elevation just above 1,150 feet and an EOCY median elevation around 1,160 feet. These elevations could expose at least 196 known sites as well as sites present above 1,150 feet within the 1,161–1,141-foot zone. Interquartile ranges for the Supply Driven Alternative vary, with the LB Pro Rata approach ranging from just below 1,190 feet (75th percentile) to just below 1,070 feet (25th percentile), and the LB Priority approach ranging from around 1,180 feet (75th percentile) to just below 1,060 feet (25th percentile). Within these ranges, between 85 and 275 known sites could be exposed under the LB Pro Rata approach and between about 142 and 280 known sites under the LB Priority approach, depending on elevation and the presence of undiscovered sites.

As hydrological conditions become critically dry, the modeled scenarios maintain the same relative performance but shift downward collectively by roughly 100 feet in elevation within the Critically Dry Flow Category. For Lake Mead, the 975-foot elevation is important because it provides a 25-foot buffer for water supply and hydropower to stay above minimum power pool (see **Section TA 3.2.1**, Issue 1, in **TA 3**, Hydrologic Resources). Under these conditions, the elevation at which sites are vulnerable to wet-dry cycling and wave action would be lowest across all scenarios. The CCS Comparative Baseline has a minimum CY median elevation around 930 feet, while the No Action Alternative declines further to around 900 feet, both well below the Lake Mead minimum power pool elevation of 950 feet. The EOCY median elevation for the CCS Comparative Baseline is around 960 feet, while the No Action Alternative declines to around 930 feet. At these elevations, up to all 310 known archaeological sites in the Lake Mead dataset, along with any undiscovered sites that may be present, could be exposed depending on the elevations of the four known sites below 961 feet. The Basic Coordination Alternative performs somewhat better, with a minimum CY median elevation just above 970 feet and an EOCY median elevation around 980 feet. The Representative Preferred Alternative performs slightly better, with a minimum CY median elevation around 980 feet and an EOCY median elevation just above 990 feet. Despite these slightly higher elevations, both alternatives could still leave at least 296 known sites (more than 95 percent of the sites in the Lake Mead dataset) along with any undiscovered sites present, exposed during critically dry conditions.

The Enhanced Coordination Alternative has minimum CY and EOCY median elevations around or just above 1,000 feet, with interquartile ranges extending from approximately 1,050 feet down to around 950 feet. Depending on the elevations of the four known sites below 961 feet, this alternative could still leave up to all 310 known sites exposed. The Maximum Operational Flexibility Alternative has similar median elevations, with minimum CY and EOCY values just above 1,010 feet and around 1,000 feet, respectively. These elevations could leave between 291 and 296 known sites (and any undiscovered sites) vulnerable to impacts. The interquartile ranges extend from around 1,060 feet down to approximately 970 feet, potentially exposing between about 280 and 301 known sites depending on the elevations of sites within the 981–961-foot zone.

The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) also performs slightly better compared to other scenarios. The LB Priority approach has minimum CY and EOCY median elevations around 1,010 feet, while the LB Pro Rata approach reaches the highest median elevations under critically dry conditions at or just below approximately 1,030 feet. Even so, between 286 and 291 known sites could still be exposed based on median elevations. Examination of the upper limits of the interquartile ranges indicates that some additional sites could remain inundated, with upper elevations around or just above 1,070 feet for the LB Priority approach (potentially exposing at least 275 known sites) and around 1,090 feet for the LB Pro Rata approach (potentially exposing at least 265 known sites). However, both scenarios would still leave at least 85 percent of the archaeological sites in the Lake Mead dataset, along with any undiscovered sites present, exposed above the water level and therefore vulnerable to impacts.

For the Echo Bay Developed Area, modeled scenarios with minimum CY and EOCY median elevations below 1,100 feet would expose portions of the boat ramp; however, this exposure would occur outside the NRHP-eligible district boundary. Modeled scenarios with elevations above 1,100 feet could partially inundate the ramp, with full submersion occurring at higher elevations along the ramp, which extends up to approximately 1,221 feet. These conditions would be more likely under the Supply Driven Alternative because the interquartile ranges for minimum CY and EOCY elevations under the LB Priority approach extend up to around 1,090 feet. Reservoir elevations exceeding 1,221 feet could affect recreation area infrastructure within the district boundary.

Preservation Risk Modeling

Preservation risk modeling results were compared with the 90th percentile values of modeled values for WY 2008 to 2025 (i.e., the 2007 Interim Guidelines period); the 90th percentile risk value is 2.72 for Lake Powell and 2.24 for Lake Mead (see **Figure TA 11-1** in **TA 11**, Cultural Resources; Caster et al. 2026). If preservation risk exceeds these threshold values, impacts on archaeological sites may occur at levels beyond those expected under historical conditions for the specific reservoir. For the purposes of this analysis, "historical conditions" coincide with the 2007 Interim Guidelines period (WY 2008–2025).

For Lake Powell under the Average Flow Category, the CCS Comparative Baseline and the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives all have preservation risk median values at the 2.72 threshold. The Representative Preferred Alternative has a slightly lower median value of 2.69, followed by the Maximum Operational Flexibility Alternative at 2.65 and the Enhanced Coordination Alternative at 2.52. The Maximum Operational Flexibility and Enhanced Coordination Alternatives share the same interquartile range, from 2.65 (75th percentile) to 2.24 (25th percentile), under average hydrological conditions. The Representative Preferred Alternative has the narrowest interquartile range, from 2.72 to 2.65, while the No Action Alternative shows the greatest variation, ranging from 3.23 to 2.24. Overall, under average modeled conditions, preservation risk values generally remain at or near the 2.72 threshold, indicating that impacts on archaeological sites, if they occur, would not exceed those expected under similar average conditions historically.

Under the Critically Dry Flow Category for Lake Powell, preservation risk median values for the CCS Comparative Baseline and all alternatives exceed the 2.72 threshold. The No Action Alternative has the highest median preservation risk value at 3.71, followed by the Basic Coordination Alternative at 3.42 and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) at 3.39. The Representative Preferred Alternative has a median value of 3.23, while both the Maximum Operational Flexibility and Enhanced Coordination Alternatives have median values of 3.10; however, the interquartile range for the Enhanced Coordination Alternative drops to 2.71 at the lower bound. Because lower preservation risk values indicate better performance, median values below 2.72 would suggest impacts comparable to historical conditions. Under critically dry conditions, however, all median values exceed this threshold, indicating elevated preservation risk relative to historical conditions.

For Lake Mead under the Average Flow Category, the No Action Alternative has the highest preservation risk median value at 2.70. The CCS Comparative Baseline follows at 2.31, and the Basic Coordination Alternative at 2.26, both above the Lake Mead preservation risk threshold of 2.24, indicating greater risk to archaeological sites than would be expected under similar historical conditions. The Enhanced Coordination Alternative has a median value just below the threshold at 2.22, followed by the Representative Preferred Alternative at 2.20 and the Maximum Operational Flexibility Alternative at 2.18. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) has the lowest median preservation risk value at 2.03. Interquartile ranges for the CCS Comparative Baseline, the No Action Alternative, and all action alternatives extend above the 2.24 threshold, including the Representative Preferred Alternative at 2.31. The lower bounds of these ranges generally fall below the threshold, except for the No Action Alternative, which remains above it at 2.35.

Under the Critically Dry Flow Category for Lake Mead, preservation risk median values for all scenarios exceed the 2.24 threshold. The No Action Alternative performs the worst with a median value of 3.07, followed by the CCS Comparative Baseline at 3.00. All action alternatives have lower median values but remain above the threshold, including the Basic Coordination Alternative at 2.64, the Representative Preferred Alternative at 2.38, the Enhanced Coordination Alternative at 2.36, and both the Maximum Operational Flexibility and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives at 2.35. Because none of the scenarios fall below the 2.24 threshold, impacts on archaeological sites under critically dry conditions would exceed those anticipated under similar historical conditions.

Figure TA 11-2 and **Figure TA 11-3** in **TA 11**, Cultural Resources, compare alternatives by showing the percentage of futures in which the preservation risk is below 2.72 for Lake Powell and 2.24 for Lake Mead in at least 90 percent of months. The 2.72 and 2.24 preservation risk values represent the 90th percentile of modeled historical values for WY 2008–2025 (the 2007 Interim Guidelines period), which includes the period of significant reservoir storage loss. To reiterate, if the preservation risk is above those values, impacts on archaeological sites may be greater than expected under historical conditions.

For Lake Powell, over the full modeling period, the Enhanced Coordination Alternative would be the most robust, meeting the 2.72 risk threshold in 47 percent of futures. The Maximum Operational Flexibility Alternative would be less robust, meeting the 2.72 threshold in 28 percent of futures, followed by the No Action and Basic Coordination Alternatives at 17 percent, the Representative Preferred Alternative at 16 percent, and the CCS Comparative Baseline at 15 percent. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) meets the preferred level of performance in 14 percent of futures. This relational pattern is consistent if the full modeling period is broken out into shorter periods, including the first decadal period from 2027–2039 where the Enhanced Coordination Alternative also performs the best at 30 percent whereas the CCS Comparative Baseline performs the worst at 10 percent. It is important to note that 2027, as the beginning of the first 10-year interval, is anticipated to have low reservoir elevations and, therefore, the modeling for this breakout (2027–2039) shows very low percentages of futures met for the preferred minimum of performance across the CCS Comparative Baseline, the No Action Alternative, and all other action alternatives. See **Figure TA 11-2** in **TA 11** (Cultural Resources) for robustness modeled for 2040–2049 and 2050–2060 at Lake Powell.

For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the most robust by meeting the 2.24 risk threshold in 24 percent of futures over the full modeling period. The CCS Comparative Baseline and No Action Alternative meet the preferred minimum of performance in only 6 and 13 percent of futures, respectively. The Maximum Operational Flexibility Alternative would meet the threshold in 19 percent of futures, followed by the Enhanced Coordination Alternative at 15 percent, the Representative Preferred Alternative at 14 percent, and the Basic Coordination Alternative at 10 percent. If the modeling period is broken out, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) can be seen to meet the threshold for only 5 percent of futures in the first decadal period (2027–2039), followed by the CCS Comparative Baseline, the Maximum Operational Flexibility Alternative, and the Representative Preferred Alternative, all three of which meet the preferred level of performance in only 3 percent of futures. The Basic Coordination and Enhanced Coordination Alternatives meet the threshold 2 percent of the time while the No Action Alternative is at 1 percent for the 2027–2039 modeling period. See **Figure TA 11-3** in **TA 11** (Cultural Resources) for robustness modeled for 2040–2049 and 2050–2060 at Lake Mead.

Overall, the Enhanced Coordination Alternative is the most robust for Lake Powell for the full modeling period and the first decadal modeling period (2027–2039), followed by the Maximum Operational Flexibility Alternative. For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the most robust, followed by the Maximum Operational Flexibility Alternative for the full modeling period. Looking at only the 2027–2039 modeling period, while the Supply Driven Alternative (both LB Priority and Pro Rata approaches) still remains the most robust at 5 percent, the CCS Comparative Baseline, Representative Preferred Alternative, and Maximum Operational Flexibility Alternative are all equally, but lesser, robust for the first 10-year period at 3 percent.

River Flows

This section references the discussion presented in **Section TA 3.2.4**, Issue 4, as presented in **TA 3**, Hydrologic Conditions, with additional references to other sections as appropriate. The analysis focuses on Average Flow and Critically Dry Flow Categories. In all categories except the Critically Dry Flow Category, the high end of the results range has been cut off to improve comparisons in the average and drier flow conditions.

For the purposes of analyzing potential impacts related to changes in river flow, archaeological sites that may be physically affected are those located along or immediately adjacent to the river, where erosion caused by moving water may occur. As with the Lake Powell and Lake Mead datasets discussed above, variable survey coverage and older locational data must be taken into account. To identify the number of archaeological sites, built environment resources, and specially designated cultural resources that may be affected by changes in flow, sites with all or portions of their boundaries in the river corridor (bank to bank) or within 20 meters (66 feet) of the river corridor were identified from the overall dataset using a GIS. For additional information on the cultural resources identified along the river by reach, please reference **Section TA 11.2.2,** Issue 1 in **TA 11**, Cultural Resources.

For all reaches, the impacts from changes in river flow would include water erosion from river currents during higher releases and flows but may also include exposure from lower water levels where either dam release or flow volumes are reduced; however, these impacts are only considered in this analysis when volumes fall outside the parameters of past releases or flows.

Glen Canyon Dam to Lake Mead

This section summarizes the potential for cultural resources to be affected by river flows below Glen Canyon Dam and references the median and interquartile WY release volumes (in maf) from the dam illustrated in **Figure TA 3-21** in **Section TA 3.2.3** and in **Table TA 3-14** at the end of **TA 3**, Hydrologic Resources. Since 2008 with the implementation of the 2007 Interim Guidelines, releases from Glen Canyon Dam have been in the range of around 7.0 maf to around 12.5 maf, averaging around 8.7 maf (see **Section TA 3.1.3**, Lake Powell and Glen Canyon Dam, in **TA 3**, Hydrologic Resources). In general, WY releases from Glen Canyon Dam that fall outside the historical range of around 7.0–12.5 maf have greater potential to impact known cultural resources within 20 meters (66 feet) of the river as well as on undiscovered resources that may be present along the river corridor. In addition, higher WY release volumes can increase erosion along the river corridor, even when releases remain in this historical range.

River flows from Lake Powell to Lake Mead primarily consist of controlled releases from Glen Canyon Dam. WY releases from the dam in the Average Flow Category would generally fall within the range of past annual release volumes as neither the CCS Comparative Baseline, No Action Alternative, nor the action alternatives (including the Representative Preferred Alternative) have median volumes that fall below 7.9 maf in the Average Flow Category. Therefore, there would be no additional impacts because none of the modeled scenarios would deviate from the established range. In the Average Flow Category, the interquartile range for the Enhanced Coordination Alternative would be the only modeled scenario that deviates from the range of past release volumes (7.0 maf up to 12.5 maf), as it is modeled to potentially drop to around 6.9 maf (25th percentile). Reductions in the volume of WY releases would affect river flows, thereby potentially exposing the Steamboat Charles Spenser. The same drops in river flows, resulting from reduced WY releases from Glen Canyon Dam, would not be detrimental to the one known historic property within 20 meters (66 feet) of the river because the boundary of the Lees Ferry and Lonely Dell Historic District extends into the river channel.

In the Critically Dry Flow Category, median WY release volumes for the CCS Comparative Baseline, No Action Alternative, and all action alternatives would fall below 7.0 maf, to as low as around 5.1 maf under the Enhanced Coordination Alternative. Under the critically dry hydrologic conditions, the No Action Alternative would perform better than the others relative to the upper limits of the interquartile ranges (75th percentile), which are around 7.7 maf for the CCS Comparative Baseline and around 8.2 maf for the No Action Alternative. The Representative Preferred Alternative has one of the narrowest interquartile range under critically dry hydrological conditions, with an upper limit around 6.0 maf, which is still below the bottom of the range of past flow volumes at 7.0 maf. All the modeled scenarios could impact the Steamboat Charles Spenser if the reduced volumes of these WY releases cause the river to drop below previous water levels. On the other hand, these same potential drops in river water level would protect the only NRHP-listed property within 20 meters (66 feet) of the river (the Lees Ferry and Lonely Dell Historic District), as previously discussed.

Hoover Dam to Davis Dam

This section summarizes the potential for cultural resources to be affected by river flows below Hoover Dam to Davis Dam and refers to the median and interquartile CY release volumes from Hoover Dam as illustrated in **Figure TA 3-25** in **Section TA 3.2.3** and **Table TA 3-19** at the end of **TA 3**, Hydrologic Resources. Since 2008, CY releases from Hoover Dam have been in the range of around 8.5 maf to around 9.6 maf, averaging around 9.2 maf (see **Section TA 3.1.7**, Hoover Dam to Lake Mohave, in **TA 3**, Hydrologic Resources). In general, CY releases from Hoover Dam that fall outside the historical range of around 8.5 to around 9.6 maf have greater potential to impact known cultural resources within 20 meters (66 feet) of the river as well as on undiscovered resources that may be present along the river corridor. For the Average Flow Category, the No Action Alternative is the only modeled scenario under which median CY release volume would remain within the 8.5–9.6 maf range for previous release volumes below Hoover Dam in this reach at around 8.6 maf. The CCS Comparative Baseline falls just under previous release volumes at around 8.3 maf. The action alternatives would not perform as well, with the median CY releases for the Basic Coordination Alternative in the Average Flow Category around 8.0 maf, followed by the Representative Preferred Alternative at around 7.9 maf, the Maximum Operational Flexibility Alternative at around 7.8 maf, the Supply Driven Alternative (LB Priority and LB Pro Rata approaches) at around or just below 7.7 maf, and the Enhanced Coordination Alternative at just below 7.6 maf. Where impacts on archaeological sites result from erosion caused by moving water, these may be less likely to occur if the reduced CY release volumes cause the river to drop below previous water levels. The same drops in river water levels would not be detrimental to NRHP-listed Willow Beach Gaging Station.

For the Critically Dry Flow Category, median CY release volumes would be well below previous volume ranges under the CCS Comparative Baseline, No Action Alternative, and all action alternatives, which would fall below 8.0 maf, down to as low as around 6.4 maf for the Maximum Operational Flexibility Alternative, with the Enhanced Coordination Alternative slightly higher at around 6.5 maf. Again, relative to impacts on archaeological sites that may be subject to erosion caused by moving water, the ranges of all the modeled scenarios may be less likely to physically affect archaeological sites if the reduced CY release volumes cause the river to drop below previous water levels. Likewise, these same potential drops in river water level would not impact the NRHP-listed Willow Beach Gaging Station previously discussed.

Within this reach is Lake Mohave, which is operated under a rule curve that maintains end-of-month target elevations between 630 feet and around 646 feet and which has been kept relatively constant at around 641 feet since 2008 (see **Section TA 3.1.7**, Hoover Dam to Lake Mohave, in **TA 3**, Hydrologic Resources). There are no anticipated impacts on any known cultural resources around the reservoir in this portion of the reach, regardless of scenario, because Lake Mohave would continue to be operated under the existing rule curve.

Below Davis Dam

No impacts under the CCS Comparative Baseline, No Action Alternative, and all action alternatives are expected below Davis Dam. Davis and Parker Dams will continue to be operated under the current rule curves that determine end-of-month target elevations for Lake Havasu (see **Section TA**

3.1.8, Davis Dam to Lake Havasu, in **TA 3**, Hydrologic Resources). Imperial Dam is operated to maintain a nearly constant elevation to meet water delivery requirements for major diversions to California and Arizona (see **Section TA 3.1.10**, Cibola Gage to Imperial Dam, in **TA 3**). Additionally, the river below Imperial Dam is characterized by several stretches of mechanically channelized river corridor.

Issue 2: How will changes in dam operations affect sediment availability for aeolian transport to protect archaeological sites in the Grand Canyon?

This section references **Section TA 11.2.3**, Issue 2, in **TA 11**, Cultural Resources, as well as **Section TA 9.2.2**, Issue 1, in **TA 9**, Vegetation Including Special Status Species, and **Section TA 5.2.5**, Issue 4, in **TA 5**, Geomorphology and Sediment. As discussed in S**ection TA 11.2.1**, Methodology, in **TA 11**, the aeolian transport model looks at favorable conditions for wind-deposited sand to be present to protect archaeological sites over long periods of time using projected vegetation cover and exposed sand area or sandbar volume (Butterfield and Palmquist 2026; Kelley et al. 2026; Salter and Grams 2026). The vegetation and sandbar volume modeling used is from the Marble Canyon sub-reach from Lees Ferry to the Little Colorado River. The exposed sand modeling was conducted for the portion of the river from Lees Ferry to Bright Angel Creek. Although the analyses are limited to these reaches, the results provide general insight into sediment and vegetation responses that may also occur in other portions of the river corridor with similar geomorphic and hydrologic conditions.

Overall, less annual total vegetation cover is better for aeolian sand transport because it leaves available sand exposed to be picked up by the wind. As discussed in **Section TA 9.2.2**, Issue 1, and seen in **Figure TA 9-14** in **TA 9**, Vegetation Including Special Status Species, for all modeled scenarios in wet and moderately wet conditions there would be less annual total vegetation cover (below modeled historical conditions, indicated by the dashed line in **Figure TA 9-14**) from higher water levels and longer HFEs. As conditions grow drier, water flows diminish, and HFEs are shorter, annual total vegetation cover thereby increases (see **Figure TA 9-14** in **TA 9**). In dry and critically dry conditions, total annual vegetation cover increases and differentiation between alternatives can be seen. For the Critically Dry Flow Category, the medians and interquartile ranges are above the modeled historical conditions (dashed line) for all sub-reaches and all alternatives except the interquartile range for the CCS Comparative Baseline, which drops just below the dashed line (see **Figure TA 9-14** in **TA 9**). This indicates that there may be more annual total vegetation cover, especially under critically dry flows.

As discussed in **TA 5**, for an HFE to be triggered, enough sand needs to be available in Marble Canyon and enough water needs to be available in Lake Powell (as measured by water level), with both the required amounts of sand and water being dependent on the selected HFE duration. Additionally, HFE releases can only be implemented when Lake Powell water levels are at or above 3,500 feet, with sandbar deposition occurring most rapidly during the first 4 days of an HFE event. Lastly, sandbar volume modeling uses the assumption that HFEs are implemented as often as possible (see **Section TA 5.2.1**, Modeling Criteria and Assumptions). For the aeolian transport model, increased exposed sandbar volume means more sand is available to protect archaeological sites. In general, as conditions get drier and the amount of water flowing through the river decreases, exposed sandbar volume increases (see **Section TA 5.2.5**, Issue 4, in **TA 5**, Geomorphology and Sediment). Differences in performance among the alternatives also increase as hydrological conditions become drier, with the

Enhanced Coordination and Maximum Operational Flexibility Alternatives performing the best for the Critically Dry Flow Category (see **Figure TA 5-12** in **Section TA 5.2.5**).

The results of the WY average of exposed sand area modeling are seen in **Figure TA 11-4** (see **TA 11**, Cultural Resources), with the 90th percentile and median (50th percentile) of modeled sand areas depicted as two dashed lines. As with exposed sandbar volume, increased exposed sand area is beneficial for the aeolian transport of sand to protect archaeological sites. In the Average Flow Category, median exposed sand area is around the 90th percentile (upper dashed line) and the median (50th percentile, lower dashed line) of modeled sand area (in million square meters). As conditions become drier, all modeled scenarios perform similarly with modeled median exposed sand area above the observed median, with the No Action, Enhanced Coordination, and Maximum Operational Flexibility Alternatives having slightly higher median values than the CCS Comparative Baseline and the other action alternatives, particularly in the Critically Dry Flow Category. Under critically dry conditions, the Maximum Operational Flexibility Alternative has the most variability with the greatest interquartile range.

The above three models are used in the aeolian sand modeling. **Figure TA 11-5** in **TA 11**, Cultural Resources, shows the results of the aeolian sand modeling, in which some futures meet one of two criteria: either the annual sand area is greater than the median observed sand area over the last 20 years and the vegetation cover area is less than median observed area over the last 20 years or the sandbar volume is greater than 1.5 times the initial condition. Based on previous studies and as shown in the table (in the highlighted row), those criteria being met at least 1 out of every 3 years is the optimal condition for enough sand to be available for aeolian transport.

Over the full modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would be the most robust at meeting the preferred minimum performance in 19 and 18 percent of futures, respectively, followed by the No Action Alternative only in 14 percent of futures. The Basic Coordination Alternative meets the preferred minimum of performance in only 9 percent of futures, with the Representative Preferred Alternative meeting it in only 6 percent of futures. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the least robust, meeting the preferred minimum performance in only 3 percent of futures, with the CCS Comparative Baseline only slightly higher at 4 percent of futures. If the year interval is lengthened to 1 out of 4, 5, or 6 years, the models perform in a similar overall pattern, with the Enhanced Coordination Alternative performing the best until reaching 1-out-of-6-year interval when the No Action Alternative performs the best over the full modeling period.

If the modeling period is broken out for the first 10 years, the No Action Alternative performs the best, meeting the preferred minimum performance in 38 percent of futures for the highlighted interval, followed by the Enhanced Coordination Alternative at 35 percent of futures in the first decadal period (2027–2039), followed by the Maximum Operational Flexibility Alternative at 30 percent of futures. The Basic Coordination Alternative and the CCS Comparative Baseline meet the preferred minimum of performance in 18 percent and 19 percent of futures, respectively, followed by the Representative Preferred Alternative at 17 percent. The Supply Driven Alternative (both the LB Priority and LB Pro Rata approaches) performs with only 9 percent of futures meeting the minimum preferred performance. Due to aeolian transport favoring drier conditions because more useable sand is available and the beginning of the first decadal period (2027-2039) is anticipated to have low reservoir elevations, the modeling for this breakout (2027–2039) depicts more modeled futures meeting the preferred minimum of performance across the CCS Comparative Baseline, the No Action Alternative, and all action alternatives than over the full modeling period. Refer to **Figure TA 11-5** in **TA 11** (Cultural Resources) for robustness modeled for 2040–2049 and 2050–2060 relative to multi-model aeolian transport condition.

The overall results seem to indicate an increase in the percentage of futures over time, which may correlate to increased available sand over time; however, the perceived increase is driven by an increase in sandbar volume over time in the modeling with the understanding that HFEs would continue as planned. In reality, the decision to conduct HFEs depends on annual review and the actual HFE frequency may differ from that assumed or predicted in the modeling.

Summary Comparison of Alternatives

The Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform better for Lake Powell in terms of maintaining water levels in drier conditions that would expose fewer archaeological sites and protect more through inundation. Because the continuous inundation of archaeological sites is more conducive to preservation than repeating cycles of inundation and exposure due to the risks of wave action, changes in lake elevations that may expose previously inundated resources to impacts such as wet-dry cycling and wave action are the biggest concern. As conditions become drier at Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would perform the best in the Average Flow Category with median water elevations from around 3,600 feet to around 3,630 feet. They also would perform best in the Critically Dry Flow Category; however, between 3,510 feet and 3,560 feet for these two action alternatives, potentially leaving (at minimum) between 316 and 381 archaeological sites and any undiscovered sites above these elevations exposed. The Enhanced Coordination Alternative is the most robust in terms of the preservation risk model, meeting the minimum preferred performance in 47 percent of futures, followed by the Maximum Operational Flexibility Alternative at 28 percent of futures over the full modeling period. This relational pattern is consistent if the full modeling period is broken out into shorter ranges, including the first decadal period (2027–2039) where the Enhanced Coordination Alternative also performs the best at 30 percent of futures, followed again by the Maximum Operational Flexibility Alternative at 25 percent of futures.

For Lake Mead, however, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would perform the best in the Average Flow Category, followed by the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Projections indicate that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would have median elevations between 1,140 feet and 1,160 feet, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives would have median elevations between 1,100 feet and 1,130 feet, respectively, during average hydrological conditions. Recalling that lower reservoir levels means that more sites will be exposed, in the Critically Dry Flow Category, all scenarios would result in the exposure of at least 306 known archaeological sites (all but four in the Lake Mead dataset) as well as any undiscovered sites. However, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would have the potential to expose fewer sites with upper interquartile ranges up to around 1,030 feet. In addition, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the most robust for Lake Mead with respect to preservation risk, with 24 percent of the modeled futures meeting the 2.24 threshold over the full modeling period, followed by the Maximum Operational Flexibility Alternative with 19 percent of futures. When examining the first decadal period (2027–2039) at Lake Mead, the percentage of futures meeting the preferred minimum of performance drops drastically. This is because the anticipated water levels for Lake Mead in 2027 are expected to be low and for this reason, robustness modeling shows a substantial drop in performance. For this first 10-year period, the Supply Driven Alternative (both LB Priority and LB Pro Rata) continues to perform the best, but only at 5 percent of futures, followed by the CCS Comparative Baseline, the Maximum Operational Flexibility Alternative, and the Representative Preferred Alternative, all three of which meet the preferred level of performance in only 3 percent of futures.

Overall, for Lake Powell, the Enhanced Coordination and the Maximum Operational Flexibility Alternatives perform better in drier conditions and have the greatest potential to expose fewer known sites (therefore protecting more through inundation) while, for Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) followed by the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform better in drier conditions. The Representative Preferred Alternative falls in the middle for both lakes. The No Action and Basic Coordination Alternatives have the least potential to protect archaeological sites at both lakes.

Complicating these conclusions are modeling results for releases from both Glen Canyon Dam (WY releases) and Hoover Dam (CY releases), which show that, in the reaches between Glen Canyon Dam and Lake Mead and Hoover Dam to Lake Mohave, the median dam release volumes for both would drop lower under the Enhanced Coordination and Maximum Operational Flexibility Alternatives specifically in the Critically Dry Flow Category than compared to the CCS Comparative Baseline, the No Action Alternative, and the other action alternatives. Under all the modeled scenarios, the Steamboat Charles Spenser could be affected if the reduced volumes of the WY releases from Glen Canyon Dam cause the river to drop below previously observed water levels. On the other hand, these same potential drops in river water level may provide some protection from river currents for resources within 20 meters (66 feet) of the river.

Below Davis Dam, few to no impacts (regardless of flow category) are expected because the dams below Lake Mohave are operated under guidelines that maintain lake elevations or target water deliveries, and there are several stretches of channelized banks.

Relative to sediment availability for aeolian transport in the Grand Canyon, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would have the best outcome for increasing the availability of sand for wind transport to protect archaeological sites. Both alternatives have a similar percentage of futures meeting the preferred minimum of performance (in at least 1 out of every 3 years) at 19 and 18 percent, respectively. Although this seems to be a small percentage, these two action alternatives perform better than the CCS Comparative Baseline, the No Action Alternative, and the other action alternatives, all of which meet the preferred minimum of performance in 9 percent or fewer of futures.

3.12 Paleontological Resources

3.12.1 Affected Environment

Overview and Study Area

This section summarizes the paleontological resource environment of Lake Powell, Lake Mead, and the lower Colorado River corridor. The full detailed analysis of the paleontological resources' affected environment can be reviewed in **TA 12**, Paleontological Resources. Paleontological resources include any fossilized remains, traces, or imprints of organisms preserved in rock. The Paleontological Resources Preservation Act of 2009 (PRPA; 16 USC 470aaa–470aaa-11) and its implementation rule (43 CFR 49) require Department of the Interior agencies to preserve, manage, and protect paleontological resources on lands administered by Reclamation, the NPS, the BLM, and the FWS. The PRPA ensures these federally owned resources are available for current and future generations to enjoy and study as part of America's national heritage.

The study area for paleontological resources stretches from the northern extent of Lake Powell to the SIB in California via the Colorado River. It covers approximately 1 million acres across Utah, Arizona, Nevada, and California. This area includes known and unknown resources in Lake Powell and Lake Mead.

It is important to note that the resources within fluctuating water levels are vulnerable to wave action; those resources above water are at risk from visitation impacts. The PRPA requires federal protection, but the ongoing exposure of these resources highlights the need for more effective preservation efforts. The PRPA also requires Department agencies to develop plans for inventory and monitoring using scientific principles and expertise. These plans must emphasize interagency coordination and collaborative efforts, when possible.

Potential Fossil Yield Classification System

The study area was mapped using the BLM's Potential Fossil Yield Classification (PFYC) system. This system assigns ranks to geologic units based on the relative abundance of vertebrate or other fossils and the sensitivity of those fossils to adverse impacts. For more information on how the PFYC system was created and is regularly updated, please refer to **Section TA 12.1.1**, Study Area, in **TA 12**, Paleontological Resources. **Table 3-8**, below, depicts the acreages of PFYC ranks within the study area. Geologic units with a higher potential for containing paleontological resources are assigned a higher number. Approximately 27 percent of the mapped area is classified as high/very high potential (PFYC 4-5). Maps of the study area can be found in **Section TA 12.1.1** (**Map TA 12-1** through **Map TA 12-8**).

Table 3-8
Acres of PFYC Classes in the Study Area

PFYC Class	Total Acres
1 (very low)	70,500
2 (low)	154,600
3 (moderate)	103,600
4 (high)	179,300

PFYC Class		Total Acres
5 (very high)		24,200
U (unknown)		113,700
W (water)		373,100
	Total acres	**1,019,000**

Source: Reclamation GIS 2025; NWS GIS 2023.
*PFYC data do not cover the entire study area, especially in the waterbodies and portions of the Colorado River.

Key Drivers and Trends

Fluctuating water levels in both Lake Powell and Lake Mead pose significant threats to paleontological resources, including fossils and trackways preserved in sedimentary rocks. In reservoirs, cycles of inundation and exposure weaken softer rocks, such as sandstone, making them more susceptible to erosion. As water levels recede, previously submerged fossils are exposed to environmental factors like wind, sun, and temperature changes, which accelerate degradation. While sediment deposition can temporarily protect some sites, the exposure of fossil-rich layers as water levels recede increases the likelihood of weathering, fragmentation, and disturbance from human activity.

Human activity further exacerbates these challenges because exposed fossil sites attract recreational use, leading to soil compaction, vegetation damage, and unauthorized fossil collection. Water-related impacts, such as flooding, controlled reservoir releases, and increased river erosion, also threaten fossil preservation by accelerating the removal of fossil-bearing sediments. While erosion can reveal new paleontological resources, it simultaneously increases the risk of their loss. The study area, characterized byon steep topography and high recreational use, faces elevated erosion rates, making the balance between discovery and preservation increasingly challenging.

Erosion is the primary agent that exposes paleontological resources on the surface to then await discovery and documentation. Lake Powell and Lake Mead are interconnected; adjustments of water releases at Lake Powell have a downstream effect on Lake Mead. The impacts on paleontological resources due to natural processes are the same at both reservoirs, but the intensity of impacts and the resources affected vary. Paleontological resources in Glen Canyon NRA are largely more understood and considered to be highly scientifically important. Most of the area is ranked PFYC 4 (high) or PFYC 5 (very high), including the shorelines (BLM GIS 2025). In Lake Mead NRA, the paleontological resources are less understood, and much of the shoreline is mapped as PFYC U (unknown; BLM GIS 2025). Therefore, the erosion concerns at Lake Powell are extremely high, as these conditions are affecting geologic units with high and very high paleontological value.

Reservoirs and Colorado River Corridor Overview

Lake Powell and Glen Canyon Dam

Lake Powell and Glen Canyon Dam make up most of Glen Canyon NRA, which spans southern Utah and northern Arizona and contains one of the most extensive sedimentary records on the Colorado Plateau. This record represents approximately 300 million years of geologic history and chronicles significant events, including the assembly and breakup of Pangea, the evolution of inland seas, and the incision of the Colorado River (Anderson et al. 2010).

Glen Canyon NRA staff is conducting a paleontological resources inventory survey; because of the size of the recreation area, the survey is being done in phases, with the latest phase completed in 2024. The three inventory reports provide the baseline data for a breadth of paleontological resources found within Glen Canyon NRA. Despite these efforts, natural processes such as erosion, mass wasting, and fluctuating water levels continue to expose and degrade fossil-bearing strata. Additionally, impacts from human intervention, such as vandalism, and unauthorized fossil collection, pose ongoing threats to resource preservation (Graham 2016; Santucci et al. 2009). In some areas, the buildup of sediment from dam operations may enhance fossil preservation by burial, while in others, it prevents discovery of those fossils. For more information about the paleontological resources in Glen Canyon NRA, please reference **Section TA 12.1.1**, Study Area.

Grand Canyon National Park

The Colorado River corridor of Grand Canyon National Park contains paleontological resources of exceptional scientific significance, spanning nearly 1.2 billion years of the earth's history. The river corridor is renowned for its dramatic display of geomorphic effects created by fluvial incision and its unique dry preservation of fossils from the Ice Age (Mead et al. 2020). The river channel serves as the physical axis along which the park's oldest and youngest fossil-bearing strata are exposed. The river channel is organized into two principal paleontological occurrences documented in the Grand Canyon National Park Centennial Paleontological Resource Inventory (Santucci and Tweet 2021): ancient body and trace fossils preserved within the canyon's deep bedrock formations, and Pleistocene and Holocene fossils recovered from dry caves and sediment deposits along the corridor walls.

The objective of the Grand Canyon National Park Centennial Paleontological Resource Inventory was to identify the scope, significance, distribution, and management issues associated with fossils in the park (Santucci and Tweet 2021). The river corridor presents particular management challenges due to its difficult terrain and limited accessibility, and the inventory acknowledges that systematic survey of inner canyon fossil localities remains incomplete. Despite this, the Colorado River corridor constitutes one of the most scientifically valuable zones within Grand Canyon National Park.

Lake Mead and Hoover Dam

Lake Mead NRA covers 1.5 million acres of southeastern Nevada and northwestern Arizona. Lake Mead NRA showcases a stratigraphic record spanning more than 500 million years of geologic history, documenting the evolution of the southwestern margin of North America. The NPS completed a comprehensive paleontological resource inventory in 2018. This inventory established baseline data for fossil-bearing formations and identified areas with high fossil potential; the inventory is confidential.

Resources at Lake Mead NRA are vulnerable to the same natural processes and human impacts described at Glen Canyon NRA. Continued monitoring and research are recommended to protect resources at Lake Mead NRA.

Lower Colorado River Corridor

Reclamation completed a paleontological resource inventory for the lower Colorado River region in 2020, which contained the river corridor as it extends from southern Nevada to the Mexico border (Bonde and Slaughter 2020). The corridor contains a sedimentary geologic record spanning 500 million years. Although not fully continuous, the corridor includes units representative of most geologic periods.

Under current conditions, water-related impacts such as erosion and recreation threaten the preservation of paleontological resources in the lower Colorado River corridor. Flooding events and controlled releases of reservoir waters can submerge fossils or increase river velocity and erosion, consequently displacing fossils from their geologic units. Water systems with steep cliffs and undercutting are also subject to higher rates of erosion and potential resource loss than flatter areas. Water-based recreational opportunities may unintentionally invite theft, vandalism, or indirect disturbance to fossils.

3.12.2 Environmental Consequences

Methodology

In this section, impacts on paleontological resources include those resulting from Reclamation's management of the water in Lake Powell and Lake Mead. Two types of analyses are used to evaluate impacts: preservation risk modeling, developed by the USGS and NPS, and aeolian transport-vegetative cover-HFE joint modeling, also developed by the USGS (Caster et al. 2026; Kelley et al. 2026). Additionally, PFYC data were used to analyze areas of high potential to contain fossils within the impact analysis area, and CRSS modeling of reservoir elevations was used to determine exposure risks.

The paleontological Preservation Hazard Model is informed by PFYC data and natural preservation hazards (slope erosivity, fetch distance, and water fluctuations) (Caster et al. 2026). To analyze this model using the DMDU framework, the model summarizes 10-foot elevation bins in Lake Powell and 5-foot elevation bins in Lake Mead so that each elevation from full pool to empty has a preservation risk rank. Next, projected monthly lake elevations are related to those elevation bins to estimate the preservation risk rank. As lake elevations drop, preservation risk generally increases. The model assumes that all resources have value, and dense resources and high erosion potential represent the highest risk; those with low erosion potential and no predicted resources represent the lowest risk.

Impact Analysis Area

The impact analysis area for paleontological resources consists of the Colorado River corridor from the upper limits of Lake Powell in Utah, through the Grand Canyon and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

The paleontological resource results are direct outputs from the Preservation Hazard Model and Joint Model. The impact analysis area includes known, unknown, and predicted resources and does not identify specific localities.

Impact Indicators

Four impact indicators were used to assess the impacts on paleontological resources due to operational activities: end-of-year lake elevations, changes in river flows, paleontological preservation risk rank, and the increase or decrease in sandbar building and the availability of windblown sediments to protect exposed resources.

Issue 1: How would fluctuations in water levels due to changes in dam operations (primarily in Lake Powell and Lake Mead) impact the exposure, erosion, and degradation of paleontological resources, including fossils and trackways?

For a detailed analysis of how the alternatives and CCS Comparative Baseline influence the preservation risk rank and impact the exposure, erosion, and degradation of paleontological resources, please reference **Section TA 12.2.2**, Issue 1.

This analysis references the modeling of paleontological preservation risk at the reservoirs. The model defines a historically derived threshold that is the 90th percentile risk rank from 2008 to 2024 LTEMP values. Exceeding this value means that a larger percentage of potential resources are exposed to erosion risks than what has happened since the reservoirs were filled. A higher number means a higher risk. The threshold at Lake Powell is a preservation risk rank of 2.93; the 2.93 threshold is a reference line based on past conditions (2008-2024) used to judge when risk is unusually high. The threshold at Lake Mead is 2.33.

Lake Powell

Reference **Table TA 12-4** and **Figures TA 12-4**, **12-5**, and **12-6** for the full modeling results of the preservation risk at Lake Powell. As shown in **Figure TA 12-4**, the Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative have similar ranges that are around or below the threshold in the Average Flow Category (12.0–14.0 maf). However, the Enhanced Coordination Alternative has a median risk value that is approximately 14 percent lower than what is modeled for the Maximum Operational Flexibility Alternative (2.45 and 2.85, respectively). In the Dry Flow Category (10.0–12.0 maf), the Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative perform similarly well, although all alternatives exceed the historically derived threshold under the Critically Dry Flow Category (4.46–10.0 maf).

Focusing on trends in the drier hydrologic conditions, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs similarly to the CCS Comparative Baseline; the medians and ranges are above the threshold in the Dry and Critically Dry Flow Categories, although the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) exhibits slightly less variability. The No Action and Basic Coordination Alternatives also perform similarly, with medians higher than those of the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and CCS Comparative Baseline.

The Representative Preferred Alternative generally performs in the middle of the range of alternatives; it performs slightly better than the Supply Driven Alternatives (both LB Priority and LB Pro Rata approaches) and slightly worse than the Maximum Operational Flexibility Alternative. At Lake Powell, the Representative Preferred Alternative does not perform notably for preserving paleontological resources.

When looking across the full modeling period (which includes the full range of potential hydrologic futures, or modeled hydrologic scenarios), the Enhanced Coordination Alternative performs significantly better than all other alternatives and the CCS Comparative Baseline, maintaining a preservation risk rank below the historically modeled threshold in 36 percent of futures. This is a difference of greater than 10 percent between the Enhanced Coordination Alternative and the closest performing alternative, the Maximum Operational Flexibility Alternative (successful in 22 percent of futures). Based on the planned length of the decision, it is notable that the performance of all alternatives worsens between the full modeling period and the 2027-2039 subperiod, except for the Representative Preferred Alternative, which actually improves from 12 percent to 13 percent of futures in which the threshold is met.

These trends are supported by the vulnerability analysis (**Figure TA 12-6**), which looks at flow conditions that could cause the preservation risk rank to exceed the threshold. The Enhanced Coordination Alternative results in undesirable performance when the 10-year average flow is below 11.2 maf. Approximately 75 percent of the reference hydrology traces include averages this low or lower. As a historical reference, the driest observed 10-year average for the Lees Ferry flow was 11.8 maf and occurred from 2012 to 2021. The CCS Comparative Baseline and Basic Coordination, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives performed the same, with paleontological resources becoming vulnerable at approximately 12.2 maf. For reference, the recently observed flow from 2016-2025 was 12.1 maf, meaning that these alternatives are vulnerable to conditions that have already occurred.

At Lake Powell, the Enhanced Coordination Alternative performs the best with respect to maintaining preservation risk ranks at or below the historically defined threshold, followed closely by the Maximum Operational Flexibility Alternative. The Representative Preferred Alternative generally performs in the middle of the alternatives, indicating that paleontological resources in Lake Powell would be subject to exposure, erosion, and degradation more frequently than what has been historically observed

Lake Mead

Reference **Table TA 12-4** and **Figures TA 12-7**, **12-8**, and **12-9** for the full modeling results of the preservation risk at Lake Mead. As shown in **Figure TA 12-7**, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the Maximum Operational Flexibility Alternative perform almost identically in the Average Flow Category (12.0–14.0 maf), with similar median preservation risk ranks and an interquartile range at or below the 2008–2024 defined threshold. The Enhanced Coordination Alternative has a slightly greater median preservation risk, but it has a similar interquartile range to the other best-performing alternatives. The Representative Preferred Alternative performs similarly to the Enhanced Coordination Alternative, but it has greater variability and a larger proportion of its interquartile range above the historically defined threshold. Under all flow conditions, the No Action Alternative repeatedly exhibits the highest median and largest interquartile range, indicating that conditions would be unpredictable but more likely than not would result in greater risk to the preservation of paleontological resources.

Under the Dry and Critically Dry Flow categories, the Representative Preferred Alternative continues to perform similarly to the Enhanced Coordination Alternative, though it exhibits medians and interquartile ranges above the historically derived threshold. The Representative Preferred Alternative is outperformed by the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), which maintains an interquartile range below the threshold in both the Dry and Critically Dry Flow categories.

When looking across the full modeling period, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) was the most robust at achieving a risk rank of 2.3 in 90 percent of months, doing so in 35 percent of futures. The other action alternatives range between robustness of 2 percent of futures (No Action Alternative) and 16 percent of futures (Maximum Operational Flexibility Alternative). However, it is notable that no alternatives achieve robustness in the 2027-2039 subperiod, with performance dropping significantly (greater than 10 percent) for the Supply Driven (both LB Priority and LB Pro Rata approaches), Maximum Operational Flexibility, and Enhanced Coordination Alternatives. The Representative Preferred Alternative is successful in 3 percent of futures between 2027 and 2039, indicating that paleontological resources would certainly be exposed and subject to erosion and degradation in Lake Mead during this time.

These trends are supported by the vulnerability analysis (**Figure TA 12-9**). Paleontological resources are the most vulnerable to risk under the CCS Comparative Baseline and the No Action Alternative. Undesirable performance occurs at 12.5 maf; nearly 100 percent of the reference hydrologic traces include average flows of 12.5 maf or lower. These two scenarios are vulnerable to conditions that have already occurred; the 10-year average flow at Lees Ferry from 2016 to 2025 was 12.1 maf. The Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives are vulnerable to increased risk to paleontological sites at flows of 12.2 maf, indicating that these resources are vulnerable to conditions that have already occurred. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be vulnerable at flows of 11.6 maf; nearly 75 percent of all hydrologic traces are drier 11.6 maf.

At Lake Mead, paleontological resources would be the least vulnerable to exposure, erosion, and degradation under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). The Representative Preferred Alternative performs similarly but would result in greater instances of exposure and erosion. Given the length of the planned decision, paleontological resources in Lake Mead would almost certainly be subject to drier conditions than what has been historically observed, resulting in greater risk to preservation.

Issue 2: How would altered sediment transport, including both fluvial and aeolian deposition patterns, affect the preservation and stability of paleontological resources?

The preservation and stability of paleontological resources along the Colorado River corridor are closely tied to sediment dynamics, particularly the deposition and redistribution of fine sediments through fluvial and aeolian processes. Sediment burial helps protect surface-exposed resources from erosion, weathering, and human disturbance, while changes in the magnitude or timing of sediment delivery may either enhance or degrade preservation conditions. However, increased exposure of sandbars and sediment surfaces typically heightens the risk of erosion, weathering, and loss of fossil integrity, while sediment deposition and rapid burial may provide temporary protection from degradation. Frequent water level fluctuations that alternately expose and inundate sediments are generally detrimental to long-term preservation.

Fluvial Sediment Transport

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to the fraction of total sand mass transported by sandbar-forming flows. For more information, please reference **TA 5**, Geomorphology and Sediment.

As shown in **Figure TA 12-10** in **TA 12**, Paleontological Resources, the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform similarly, achieving sandbar-building conditions in 83 and 85 percent of futures, respectively. The Supply Driven (both LB Priority and LB Pro Rata approaches) and Representative Preferred Alternatives are similarly robust (78 percent and 76 percent of futures, respectively). Sandbar-building conditions indirectly result in the preservation and stabilization of paleontological resources present in and around the sandbars. Fossils may be buried during sediment transport and protected from erosion and other types of degradation in the fluvial channel. It is likely that paleontological resources would be buried by fluvial sediment transport at a significant frequency under the Representative Preferred Alternative, resulting in better conditions for preservation.

In contrast, the No Action Alternative was successful in only 44 percent of futures; the CCS Comparative Baseline produced 36 percent of successful futures. Under the No Action Alternative, fossils and other paleontological resources would be indirectly affected by sandbar erosion between HFEs and not effectively reburied during sandbar-building events.

Aeolian Sediment Transport

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to favorable conditions for windblown sand to be present to protect paleontological resources over long periods of time. The model incorporates the vegetation, sandbar volume, and exposed sand area modeling. For more details, please reference **Section TA 12.2.1**, Methodology.

Figure TA 12-12 in **TA 12**, Paleontological Resources, shows the results of the aeolian sand modeling, in which the percentage of futures meet one of two criteria: Either the annual sand volume is greater than the median observed sand volume over the last 20 years and the vegetation cover area is less than the median observed area over the last 20 years, or the sandbar volume is greater than 1.5 times the initial condition. The highlighted row shows when those conditions are met at least 1 out of every 3 years, which is the optimal time frame for enough sand to be available for aeolian transport based on previous studies.

Over the full modeling period, the Enhanced Coordination and Maximum Operational Flexibility Alternatives are the most robust; they meet the desired conditions of at least 1 out of every 3 years in 19 percent and 18 percent of futures, respectively. The No Action Alternative meets the desired conditions in 14 percent of futures, and the Representative Preferred Alternative meets the desired conditions in only 6 percent of futures. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the least robust, meeting the desired conditions in only 2 percent of futures. If the year interval is lengthened (that is, to 1 out of 4, 5, or 6 years), the models perform in a similar overall pattern, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives performing the best.

When results are split out over intervals from 2027–2039, 2040–2049, and 2050–2060, the percentage of futures meeting the desired conditions increases for all alternatives. The robustness of the Representative Preferred Alternative increases from 6 percent of futures to 17 percent between 2027 and 2039. These results seem to indicate an increase in acceptability over time, which may correlate to increased available sand over time; however, the perceived increase is driven by an increase in sandbar volume over time in the modeling with the understanding that HFEs would continue as planned. In reality, the decision to conduct HFEs depends on the annual review.

It is notable that the Representative Preferred Alternative meets the desired conditions in 17 percent of futures between 2027 and 2039, indicating that the conditions required for aeolian transport will not occur frequently, exposing paleontological resources to erosion and other weathering mechanisms.

Issue 3: How would adjustments to dam operations and water levels alter human access to newly exposed fossil sites, and what are the potential risks of increased disturbance, unauthorized collection, and recreational impacts on paleontological resources?

This section summarizes the potential for paleontological resources to be exposed to increased levels of disturbance, unauthorized collection, and recreational impacts using the hydrologic modeling results for Lake Powell and Lake Mead elevations. This analysis incorporates the analysis of reservoir elevations detailed in **Section TA 3.2.1**, Issue 1: Reservoir Elevations, in **TA 3**, Hydrologic Resources**.** For a detailed analysis of how the alternatives and CCS Comparative Baseline influence the risk of human disturbance to paleontological resources, please reference **Section TA 12.2.4**, Issue 3.

Lake Powell

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to increased disturbance at, unauthorized collection of, and recreational impacts on paleontological resources at Lake Powell. For a more detailed analysis of recreation at Lake Powell, please refer to **TA 14**, Recreation.

As shown in **Figure TA 3-7** in **TA 3**, Hydrologic Resources, the alternatives perform similarly with respect to maintaining lake elevations and achieving desirable paleontological preservation risk ranks. The Maximum Operational Flexibility Alternative and the Enhanced Coordination Alternative are the most robust at staying above a 3,500-foot elevation in 100 percent of months over the full modeling period, doing so in 86 percent and 74 percent of futures, respectively. These results are similar to the robustness of both alternatives with regard to achieving the historically derived preservation risk threshold in 90 percent of months.

The No Action Alternative is the least robust at maintaining a 3,500-foot elevation in 100 percent of months, doing so in 20 percent of futures over the full modeling period. The No Action Alternative is only 71–80 percent robust at maintaining this elevation in 60 percent of months. The CCS Comparative Baseline, Basic Coordination Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) perform similarly, maintaining the 3,500-foot elevation in 100 percent of months in 29 percent, 25 percent, and 24 percent of futures, respectively.

The Representative Preferred Alternative meets this robustness criteria in 28 percent of modeled futures in the full modeling period. Based on the planned length of this alternative, it is important to note that it meets the preferred minimum performance level in 49 percent of futures between 2027 and 2039. Alternatives that keep Lake Powell at or above 3,500 feet more often will keep most sites below that level underwater (and protected) more of the time. Therefore, the risk of human disturbance would be for resources above 3,500 feet. The preservation risk rank historically derived threshold is achieved at approximately 3,500-foot elevation at Lake Powell. Under the Maximum Operational Flexibility Alternative, elevations at Lake Powell would be most consistently at or above 3,500 feet, which would result in the inundation of the most paleontological resources and the least amount of shoreline expansion for visitors to access resources.

Lake Mead

This section presents a comparison of the No Action Alternative, CCS Comparative Baseline, and action alternatives with respect to increased disturbance at, unauthorized collection of, and recreational impacts on paleontological resources at Lake Mead.

As shown in **Figure TA 3-12** in **TA 3**, Hydrologic Resources, the alternatives perform similarly with respect to maintaining lake elevations and achieving desirable paleontological preservation risk ranks. The Supply Driven Alternative (LB Pro Rata approach) and Maximum Operational Flexibility Alternative are similarly robust at keeping Lake Mead's elevation above 975 feet in 100 percent of months, doing so in 73 percent and 70 percent of futures, respectively. The Enhanced Coordination Alternative and the Supply Driven Alternative (LB Priority approach) are also similarly robust, maintaining Lake Mead's elevation above 975 feet in 65 percent and 61 percent of futures, respectively.

The Representative Preferred Alternative meets this robustness criteria in 50 percent of modeled futures in the full modeling period. Based on the planned length of this alternative it is important to note that it meets the preferred minimum performance level in 66 percent of futures between 2027 and 2039.

The No Action Alternative is the least robust, keeping Lake Mead elevation above 975 feet in 100 percent of months in 21 percent of futures over the full modeling period. Robustness of the CCS Comparative Baseline is 38 percent; robustness of the Basic Coordination Alternative is 50 percent.

Summary Comparison of Alternatives

Continuous inundation preserves paleontological resources better than repeated exposure to waves and wet-dry cycles. Changes in lake elevations that may expose previously inundated fossils and other resources are the biggest concern. When lake elevations drop, indirect impacts, such as those from human disturbance and recreational use, can also occur. For Lake Powell, the Enhanced Coordination Alternative performs best with regard to minimizing the preservation risk in all hydrologic conditions, except the Critically Dry Flow Category (4.46–10.0 maf), followed by the Maximum Operational Flexibility Alternative. Both alternatives exhibit median risk ranks that are at or below the threshold.

The Basic Coordination Alternative is the least effective action alternative with regard to meeting the paleontological preservation risk threshold at Lake Powell. This alternative becomes successful at the Moderately Wet Flow Category (14.0–16.0 maf), but it consistently exceeds the threshold at the Average Flow Category (12.0–14.0 maf) and drier. The No Action Alternative and CCS Comparative Baseline perform similarly to the Basic Coordination Alternative.

For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the Maximum Operational Flexibility Alternative perform similarly and produce a median preservation risk rank around, or just above, the historically derived threshold in all hydrologic conditions except for the Critically Dry Flow Category (4.46–10.0 maf). All alternatives exceed the historical preservation risk conditions under the Critically Dry Flow Category (4.46–10.0 maf).

Under the Maximum Operational Flexibility Alternative, critical lake elevations would be maintained above 3,500 feet in Lake Powell and 975 feet in Lake Mead in 86 percent and 70 percent of futures, respectively. The operations proposed under the Maximum Operational Flexibility Alternative would result in the least amount of time that paleontological resources below critical elevations are exposed to human disturbance and the associated impacts. The No Action Alternative would be the least robust at both reservoirs.

Under the Maximum Operational Flexibility Alternative, the paleontological preservation risk would be minimized to the greatest extent at both reservoirs. Paleontological resources that remain inundated would not be exposed to erosion, degradation, and the repeated cycles of inundation and exposure and wave action. The Enhanced Coordination Alternative would also minimize the paleontological preservation risk in the reservoirs, but it would do so more consistently at Lake Powell than at Lake Mead. Considering the amount of, and scientific importance of, paleontological resources present in Lake Powell, the Enhanced Coordination Alternative would be the most effective at minimizing the risk in this reservoir. The Enhanced Coordination Alternative would also be effective in Lake Mead, but not as effective as the Maximum Operational Flexibility Alternative.

The river corridor, from below Hoover Dam to the SIB, is not well mapped by the PFYC system. Classifications in the corridor are mostly PFYC W (water). While possible, the presence or impacts on scientifically important vertebrate fossils are not anticipated within the river corridor when compared with the potential for known or undiscovered fossils in the reservoirs. The Enhanced Coordination Alternative and the Maximum Operational Flexibility Alternative are the most robust alternatives with regard to sediment transport in the river corridor. Sediment transport would indirectly preserve and stabilize the known and unknown fossil localities.

Operations under the Maximum Operational Flexibility Alternative would indirectly create conditions that are most conducive to the preservation of paleontological resources in the analysis area, as indicated by this alternative's comparatively strong performance across the full suite of models.

For both Lake Powell and Lake Mead, the Representative Preferred Alternative generally performs somewhere in the middle of the action alternatives, never outperforming all alternatives in terms of paleontological resource risk reduction, fluvial and aeolian sediment transport, or maintaining significant lake elevations. Given the length of the planned decision, it is notable that paleontological preservation risk will likely be heightened under the Representative Preferred Alternative, as more resources will become exposed and eroded due to fluctuating reservoir levels and flows.

3.13 Tribal Resources

3.13.1 Affected Environment

The Colorado River, its canyons, and the associated ecosystems figure prominently in the cultural traditions of many tribal communities. For these tribes, the river and canyons are living entities consisting of sacred spaces, the homes of their ancestors, the residence of the spirits of their dead, and the source of culturally important resources. Indigenous worldviews do not separate cultural and natural environments as Western science often does; instead, they view all resources—whether considered cultural or natural in Western frameworks—as interconnected and interdependent. Many tribes see themselves as stewards of the Colorado River and its canyons, which are a vital part of the living and spiritual world. Caring for the river and the canyons is their responsibility. Tribal resources can include archaeological resources, archaeological structures, topographic features, habitats, plants, wildlife, and minerals that Indigenous peoples, tribal nations, or other groups consider essential for the preservation of traditional culture and traditional values. For many tribes, the trails used to access the river are also considered culturally important landscape features. Tribal interests also include values and resources reflected in other sections in this Final EIS, including water for drinking and agriculture, recreational resources, and many other socioeconomic and environmental aspects that overlap other sections.

The traditional values of living communities can be manifested at locations called TCPs, Indian sacred sites, or cultural landscapes. Many tribes consider the Colorado River and its canyons to be a TCP. As described by NPS guidance on TCPs (NPS 2024b), a TCP is "a building, structure, object, site, or district that may be listed or eligible for listing in the National Register for its significance to a living community because of its association with cultural beliefs, customs, or practices that are rooted in the community's history and that are important in maintaining the community's cultural identity." Of the groups concerned, the Hualapai Tribe (Coulam 2011), Hopi Tribe (Hopi CPO 2001), Navajo Nation (Maldonado 2011), and Pueblo of Zuni (Dongoske 2011) have prepared NRHP nomination forms for the Colorado River and its canyons as a TCP. Reclamation is actively consulting with the tribes regarding the Colorado River and its canyons, including associated traditional ecological knowledge; Reclamation will incorporate that knowledge as it becomes available.

The study area for tribal resources is identical to that discussed in **TA 11**, Cultural Resources, and **TA 18**, Indian Trust Assets. It extends from the northern extent of Lake Powell to the SIB and consists of the Colorado River channel from bank to bank, except from Glen Canyon Dam to Lake Mead, where it stretches from canyon rim to canyon rim. The study area also includes a 0.5-mile buffer on either side of the riverbank or canyon rim. The study area coincides with the search area used for a Class I records search conducted for this EIS document (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi 2024).

The 14 Native American tribes listed here consider portions of the study area to be part of their homelands; the following eight tribes are associated directly with the Grand Canyon: A:shiwi (Zuni), Ndee (Western Apache), Diné (Navajo), Havasupai, Hualapai, Hopi, Nüümü (Southern Paiute), and Yavapai. Five tribes—the Cocopah, Pipa Aha Macav (Mojave), Piipaash (Maricopa), Quechan, and Xalchidom (Halchidhoma)—have homelands along the lower Colorado River where it flows south to the Gulf of California. One group, the Núuchi (Ute), used northeastern portions of the river and study area. Contemporary Native American communities face a host of common issues such as widespread poverty, health disparities, and housing shortages. For the Native American tribes discussed here, water shortages and the potential to impact agriculture is a significant concern. Brief ethnographic summaries of these tribes are provided in **Sections TA 13.1.1** through **TA 13.1.13**. These summaries focus on indigenous cultural connections to the Colorado River landscape and are derived primarily from the multivolume Class I cultural resources literature review conducted in support of this analysis (Tremblay et al. 2024a, 2024b; Eddy et al. 2024; Winslow et al. 2024; Eskenazi et al. 2024).

Several known or documented TCPs within or adjacent to the study area have been listed or are eligible for listing in the NRHP (**Table TA 13-1**). For example, Sugarloaf Mountain to the west of the lower Colorado River is identified as a TCP by the A:shiwi, Diné, Hopi, Hualapai, Nuwuvi, Pipa Aha Macav, and Yavapai. The Ripley Intaglios are considered sacred by all the Yuman Tribes. The Yuman Tribes consider their origin place, Avi Kwa Ame (Spirit Mountain), to be sacred; it is beyond the project study area but within the newly created Avi Kwa Ame National Monument. Through ongoing consultation with tribes, the locations of several additional places that are considered sacred have been disclosed to Reclamation cultural resources staff. At the request of these tribes, descriptions and locations of those sacred places are confidential. Tribes discussed in this section revere the Colorado River. The Grand Canyon itself is an NRHP-eligible TCP for multiple tribes. Several important locations within the Grand Canyon TCP have been formally recorded in the canyon for the A:shiwi and Hopi and documented in ethnographic studies for the Diné and Hualapai.

Tribes consider places associated with origin stories, migrations, songs, and ceremonies to be sacred TCPs, as are ancestral sites, trails, cairns, rock writing, petroglyphs, pictographs, and geoglyphs. All water sources, especially those that come from belowground, are sacred. Plants, animals, and minerals are considered traditional cultural resources, often associated with specific locations. Reclamation is in ongoing consultation with tribes to identify specific locations and resources that are important to each tribe.

3.13.2 Environmental Consequences

Methodology

Of primary concern is how the alternatives might affect the integrity and sacredness of tribal resources. Because these resources attain significance through tribal cultural customs, and because many of these resources are sacred and their locations are confidential, the tribes are best situated to understand how the alternatives might affect them. Accordingly, the impact analysis is primarily qualitative and informed by ongoing tribal consultation.

There are many federally recognized tribes with entitlements to or contracts for Colorado River water or who may be affected or have interests in the alternatives. There are 30 federally recognized tribes within the geographic Basin. Reclamation consults regularly with these tribes regarding Colorado River issues. Additionally, the Ten Tribes Partnership is a coalition of 10 federally recognized tribes with rights and unresolved claims to Colorado River water. The partnership was created in 1992 and has an ongoing consultation relationship with Reclamation. Of the 22 federally recognized tribes in Arizona, 4 have quantified water rights, or partially quantified rights to water from the mainstream Colorado River through the Consolidated Decree. Another 10 tribes in Arizona have entered water rights settlements that include Central Arizona Project (CAP) water, one source of which is Priority 4 Arizona Colorado River water. Several more tribes hold CAP contracts. Reclamation consults not only with tribes who hold water rights or are located within the Basin's geographic boundary but also with a total of 43 tribes who may be affected or have interests in actions on the Colorado River. Consultation and coordination with these tribes are ongoing.

Impact Analysis Area

The study area for tribal resources is identical to that discussed in **TA 11**, Cultural Resources. It includes the Colorado River corridor from the upper limits of Lake Powell in Utah, through the Grand Canyon in Arizona and Lake Mead in Arizona, and from Hoover Dam to the SIB.

Assumptions

- Tribes will provide information regarding specific tribal resources and potential impacts on those resources during consultation.

Impact Indicators

- Qualitative assessment of potential impacts on TCPs informed by tribal consultation
- Qualitative assessment of potential impacts on culturally important resources informed by tribal consultation and by reference to relevant quantitative analysis sections of the EIS (for example, **TA 9**, Vegetation, and **TA 8**, Biological Resources – Fish and Aquatic Resources)

Issue 1: How would changes in dam operations affect TCPs?

TCPs are historic properties that are principally significant for their association with culturally significant events, as told through Indigenous oral history, or their association with individuals named by those traditions. Impacts on TCPs would consist primarily of changes to the natural environmental context resulting from continued active management of reservoir levels and water releases to downstream river segments. Impacts could also occur as reservoir elevations change and expose TCPs to increased erosion or visitation. Because TCPs are a specific category of historic property, adverse impacts on TCPs would be addressed through the project's programmatic agreement developed in compliance with Section 106 of the NHPA or through ongoing consultation with affected tribes.

Exposure of TCPs as lake levels fluctuate as a result of management actions described by the alternatives could facilitate access to these culturally important locations by tribal members; however, exposure would also increase access for non-Native visitation. End-of-year lake elevations for each alternative are explored in detail in **TA 3**, Hydrologic Resources, and are summarized here in the discussion of impacts on TCPs.

Across all alternatives and the CCS Comparative Baseline, Lake Powell's median WY elevations are generally similar under wet hydrologic conditions, except for the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), which shows lower median elevations. As conditions become drier, Lake Powell's elevations decrease and the differences among alternatives become more pronounced, with operations varying widely at lower water levels.

In the two driest flow categories, the Enhanced Coordination Alternative maintains the highest median reservoir elevations, followed by the Maximum Operational Flexibility Alternative. Both alternatives keep median reservoir elevations well above the critical threshold of 3,500 feet, even during dry periods; therefore, they would expose the fewest number of TCPs to increased erosion or visitation. In contrast, the No Action Alternative and the Basic Coordination Alternative have median elevations that fall below this critical threshold in dry hydrologic conditions, and these alternatives would facilitate the greatest access to TCPs and potentially expose them to wave erosion. Under the Representative Preferred Alternative, Lake Powell elevations remain relatively stable compared to other alternatives. In both the Dry Flow and Critically Dry Flow categories the Representative Preferred Alternative maintains median elevation above 3,500 feet. The Critically Dry Flow category shows greater variability in median elevations.

For Lake Mead, median EOCY elevations also decline as conditions become drier, but the relative performance of each alternative remains consistent. The Supply Driven Alternative (LB Pro Rata approach) consistently has the highest median reservoir elevations across all flow categories, followed by the Supply Driven Alternative (LB Priority approach); therefore, these would expose the fewest number of TCPs to increased erosion or visitation. The No Action Alternative consistently has the lowest median elevations, with the CCS Comparative Baseline having the second lowest; these alternatives would facilitate the greatest access to TCPs and subsequent erosion. Most action alternatives show wide variability in Lake Mead's elevations, except for the Maximum Operational Flexibility Alternative, under which the elevation reliably remains above 975 feet. Under the Representative Preferred Alternative, Lake Mead elevations show moderate variability in dry conditions and somewhat lower variability in critically dry conditions staying above 975 feet in most years.

Issue 2: How would changes in dam operations affect lake elevations (primarily in Lake Powell and Lake Mead) and river flows downstream, which could impact sacred sites?

Sacred sites are specific locations that a tribe has identified as sacred because of the sites' traditional religious significance or because the sites are a discrete location for ceremonial use. Sacred sites often overlap significantly with TCPs and with Indigenous archaeological sites. Accordingly, impacts on sacred sites are qualitatively similar to impacts on archaeological sites. Of primary concern are direct impacts like wave action and wet-dry cycling that could occur from changes in lake levels or from changes to river flows caused by annual releases. Impacts on archaeological sites are analyzed in detail in **TA 11**, Cultural Resources, and that discussion is summarized here.

At Lake Powell and Lake Mead, continuous inundation of sacred sites or Indigenous archaeological sites helps preserve them better than cycles of flooding and exposure, which increase risks from wave action. The main concern is that dropping lake elevations could expose such sites that were previously underwater, making them vulnerable to wet-dry cycles and wave impacts. As water levels fall, more sites become exposed to these risks at lower elevations. Sites at higher elevations may be less affected by wet-dry cycling and wave action but could become more accessible, depending on their location.

Hydrologic models show that during wet hydrologic conditions, Lake Powell's water levels are projected to remain above 3,660 feet in all scenarios. As conditions get drier, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain the highest median water levels during the Average Flow Category (12.0-14.0 maf), staying at or above 3,620 feet. These alternatives also perform best in the Critically Dry Flow Category (4.46-10.0 maf), but projected medians are still below 3,580 feet; this means sacred sites or archaeological sites—and any unknown sites—at these elevations would be exposed.

For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the highest water levels during both the Average and Critically Dry Flow Categories, followed by the Enhanced Coordination and Maximum Operational Flexibility Alternatives. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) has projected median elevations up to 1,150 feet in the Average Flow Category, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives have medians around 1,100 feet. In the Critically Dry Flow Category, all scenarios would expose sacred sites or archaeological sites and any unknown sites; however, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) could protect more sites, with upper interquartile ranges reaching about 1,120 feet. Under the Representative Preferred Alternative, Lake Powell and Lake Mead elevations are comparable to other alternatives though Lake Mead elevations show greater variability across alternatives for the driest flow categories.

This pattern is reflected in the Preservation Risk Model analysis. For Glen Canyon, the Enhanced Coordination Alternative is the most robust, and will impact the fewest sites, with 30 percent of modeled futures in the initial modeling period staying below the preservation threshold, followed by the Maximum Operational Flexibility Alternative at 25 percent. Under the Representative Preferred Alternative the preservation threshold is met in 16 percent of modeled futures. For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the most robust during the initial modeling period, with 5 percent of modeled futures meeting or staying below the threshold. The Maximum Flexibility Alternative and Representative Preferred Alternative both stay below the preservation threshold in 3 percent of modeled futures.

For the Colorado River stretches between Glen Canyon Dam and Lake Mead, and between Hoover Dam and Lake Mohave, water release volumes in the Wet (16.0-31.11 maf) and Average Flow Categories generally remain within the range of past annual releases. However, in the Critically Dry Flow Category, median annual release volumes drop below 7.0 maf below Glen Canyon Dam, with the Enhanced Coordination Alternative reaching as low as 5.1 maf. Below Hoover Dam, the median annual flows fall below 8.0 maf, with the Enhanced Coordination and Maximum Operational Flexibility Alternatives dropping to 6.5 maf. As a result, in critically dry hydrologic conditions, lower water levels increase the likelihood of sacred sites or archaeological sites near the riverbanks being exposed. The Representative Preferred Alternative has one of the narrowest interquartile range under critically dry hydrological conditions, with an upper limit around 6.0 maf, which is still below the bottom of the range of past flow volumes at 7.0 maf.

Below Davis Dam, impacts are expected to be minimal or nonexistent in any flow category. This is because the dams below Lake Mohave are managed to maintain lake elevations or meet targeted water deliveries, and many sections have channelized banks that further reduce exposure risks.

Issue 3: How would changes in dam operations impact natural resources important to Native Americans, including riparian vegetation and wildlife?

Indigenous worldviews do not differentiate between cultural and natural environments, as they do in Western science. Under many Indigenous perspectives, resources considered separately as cultural or natural are all interconnected and interdependent (Berkes 2018). Human interventions that disrupt these interconnections are considered adverse impacts. This EIS discusses many of these resources, such as water quality, air quality, terrestrial wildlife, and others. Although all resources are considered interconnected, Indigenous oral histories and ongoing consultation with Native American groups have identified riparian vegetation communities and aquatic wildlife as resource categories of particular concern along the Colorado River corridor. Accordingly, Reclamation considers riparian vegetation and aquatic wildlife (native and nonnative fish) below. Adverse impacts on these resources important to Native Americans would be addressed through ongoing consultation with the affected tribes.

TA 9, Vegetation, presents in detail the quantitative impacts on riparian vegetation communities and evaluations of which alternatives best support historical vegetation community conditions. Historical vegetation communities are those that prevailed in the decades prior to reservoir inundation and from Indigenous worldviews are the preferred condition. Those quantitative analyses are summarized here. Woody riparian vegetation is moderately tolerant of water fluctuations, but if variability increases over a 5-year period, these areas tend to decrease. Conversely, if water level variability decreases annually or over 5 years, woody riparian vegetation may expand.

For Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would maintain woody riparian vegetation most similar to historical conditions. For Lake Mead, the Maximum Operational Flexibility Alternative would best match historical vegetation patterns. However, in the stretch from Hoover Dam to the SIB, these two alternatives would cause vegetation to differ most from historical conditions, leading to greater changes in that area. The Basic Coordination Alternative would be least similar to historical conditions for Lake Powell but would be closest to historical vegetation patterns for Lake Mead and the Hoover Dam to SIB reach. The Representative Preferred Alternative would be least similar to historic conditions for Lake Powell and Lake Mead. This means no single alternative matches the historical vegetation conditions across all areas.

Most alternatives provide variability closer to historical conditions than the CCS Comparative Baseline in most reaches, except for Hoover Dam to the SIB, where only the Basic Coordination Alternative does so. This suggests that changing current management strategies would benefit much of the analysis area.

For the stretch between Glen Canyon Dam and Lake Mead, the alternative that best maintains historical vegetation depends on whether the starting hydrologic conditions are wet or dry. Under dry and critically dry hydrologic conditions, differences between the alternatives become more noticeable, especially in the lowest, median, and peak flows. However, across all alternatives, sub-reaches, and evaluation criteria (habitat area, native species richness, proportion of native species cover, and total annual vegetation cover), the interquartile ranges often overlap, making it hard to identify a clear best or worst alternative for preserving historical vegetation conditions.

Under all alternatives for Lake Powell, Lake Mead, and Hoover Dam to the SIB, the first decade is expected to have greater variability and reduced woody riparian habitats, compared with historical conditions. Conditions improve in the second and third decades, allowing vegetation to recover and be reestablished. If variability prevents woody riparian habitats from forming, the area may shift to another habitat type.

Quantitative impacts on aquatic wildlife are considered in detail in **TA 8**, Biological Resources – Fish and Other Aquatic Species, and those quantitative analyses are summarized here. Decreased water levels at Lake Powell affect lake and river habitats for culturally important native and nonnative fish. Among the alternatives, the No Action Alternative stands out because it increases the amount of exposed river habitat for endangered Colorado pikeminnow and razorback sucker, which is beneficial for these species. However, this also means less lake habitat for sportfish, which could negatively affect recreational fishing.

All alternatives except the Enhanced Coordination and Maximum Operational Flexibility Alternatives keep Lake Powell below critical elevation thresholds (3,598 feet for the Colorado River and 3,600 feet for the San Juan River), thereby increasing river habitat. The Enhanced Coordination and Maximum Operational Flexibility Alternatives are less effective in this regard, as they tend to flood critical habitats and reduce the value of riverine habitat.

No alternative is particularly successful at maintaining Piute Farms Waterfall as a barrier to prevent nonnative fish from moving upstream. On the other hand, all alternatives support native fish passage over the waterfall when it is inundated. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the CCS Comparative Baseline are the most effective at maintaining the waterfall as a barrier, while the Enhanced Coordination and Maximum Operational Flexibility Alternatives are more likely to allow inundation and fish passage.

For Lake Powell, the Representative Preferred Alternative provides moderate protection of riverine critical habitat but does not perform as well as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). Overall, it represents a moderate balance but is less robust than the best-performing alternatives for specific indicators.

For Lake Mead, the alternatives would affect tributary inflow habitats of culturally important fish populations. The No Action Alternative and CCS Comparative Baseline are the most effective at keeping Lake Mead below 1,090 feet for at least 90 percent of months. This helps restrict nonnative fish and maintain the current species composition in the Grand Canyon. However, these lower elevations also hinder native species—such as razorback sucker, flannelmouth sucker, and humpback chub—from moving upstream into Grand Canyon habitats.

The Basic Coordination Alternative performs moderately well in balancing these outcomes. In contrast, the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives are less effective, as they more often allow Lake Mead to rise above critical thresholds. This can make it easier for both native and nonnative fish to move upstream.

Among the alternatives, the Supply Driven Alternative (LB Pro Rata approach) is the most reliable for keeping Lake Mead above its historical minimum elevation, which supports greater habitat stability.

Summary Comparison of Alternatives

TCPs are historic properties significant to Indigenous communities, mainly due to their association with culturally important events or individuals, as described in oral traditions. The main impacts on TCPs come from changes in the natural environment caused by managing reservoir levels and water releases, as well as increased exposure, erosion, and visitation where water levels drop. Adverse impacts on TCPs are addressed through a programmatic agreement and ongoing consultation with tribes, in compliance with the National Historic Preservation Act.

As lake levels fluctuate, TCPs may become more accessible to both tribal members and non-Native visitors. Under wet hydrologic conditions, most alternatives keep Lake Powell's water levels high and exposure of TCPs low, except for the Supply Driven Alternative, which has lower elevations. In dry hydrologic conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain the highest water levels, limiting TCP exposure, while the No Action and Basic Coordination Alternatives result in lower elevations and greater access to TCPs. For Lake Mead, water levels also drop as conditions get drier. The Supply Driven Alternative (LB Pro Rata approach) keeps the highest water levels and limits TCP exposure, while the No Action Alternative and CCS Comparative Baseline have the lowest levels, increasing access to TCPs. Under the Representative Preferred Alternative, Lake Powell and Lake Mead elevations remain relatively stable compared to other alternatives with increasing variability in the driest flow categories.

Sacred sites are locations identified by tribes for their religious or ceremonial significance; these sites often overlap TCPs and Indigenous archaeological sites. Impacts on sacred sites are similar to those affecting archaeological sites, with the main concerns being damage from wave action and wet-dry cycling caused by fluctuating lake and river levels. Continuous inundation helps preserve these sites, while exposure due to falling water levels increases risks.

During wet hydrologic conditions, Lake Powell's water levels are expected to remain high, minimizing exposure. As conditions become drier, the Enhanced Coordination and Maximum Operational Flexibility Alternatives maintain higher water levels than others but still fall below critical thresholds in extremely dry scenarios, exposing more sacred sites. For Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the highest water levels and protects more sites, especially in dry hydrologic conditions. For the river stretches between Glen Canyon Dam and Lake Mead, and between Hoover Dam and Lake Mohave, annual water releases in wet and average years generally match historical volumes. In critically dry years, releases drop significantly, increasing the risk of exposing sacred and archaeological sites near riverbanks. Below Davis Dam, impacts are minimal due to managed lake elevations and channelized banks.

Indigenous perspectives view cultural and natural resources as interconnected, so any disruption to these links is a potential impact. Along the Colorado River, riparian vegetation and aquatic wildlife are especially important to Native Americans. Woody riparian vegetation is moderately resilient to water fluctuations, but increased variability over several years can reduce these habitats. For Lake Powell, the Enhanced Coordination and Maximum Operational Flexibility Alternatives best maintain vegetation similar to historical conditions. For Lake Mead, the Maximum Operational Flexibility Alternative performs best, while the Basic Coordination Alternative is closest to historical conditions for Lake Mead and the Hoover Dam to SIB reach. No single alternative matches historical vegetation patterns across all areas, but most alternatives perform better than the CCS Comparative Baseline in most reaches. The Representative Preferred Alternative would be least similar to historic conditions for Lake Powell and Lake Mead.

Lower water levels at Lake Powell benefit endangered river species (Colorado pikeminnow and razorback sucker) by increasing their habitat, especially under the No Action Alternative; however, lower water levels reduce lake habitat for sportfish. Most alternatives (except the Enhanced Coordination and Maximum Operational Flexibility Alternatives) keep Lake Powell below critical thresholds, favoring river habitats. The Enhanced Coordination and Maximum Operational Flexibility Alternatives tend to flood critical habitats, reducing the river habitat value.

For Lake Mead, the No Action Alternative and CCS Comparative Baseline maintain lower water levels; this helps restrict nonnative fish but also limits upstream movement of native fish. The Basic Coordination Alternative offers a moderate balance. The Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives more often allow Lake Mead to rise above critical thresholds, which can facilitate movement for both native and nonnative fish. The Supply Driven Alternative (LB Pro Rata approach) is most reliable for maintaining Lake Mead above its historical minimum, supporting habitat stability. Overall, the Representative Preferred Alternative provides moderate protection of riverine critical habitat but does not perform as well as the Supply Driven Alternative (LB Pro Rata Approach).

3.14 Recreation

3.14.1 Affected Environment

This section describes existing recreational conditions along the Colorado River system from Lake Powell to the SIB. The analysis focuses on four primary recreational resources: shoreline public use, reservoir boating, river and whitewater boating, and sport fishing. For a more detailed description of these recreational resources, please refer to **Section TA 14.1**, Recreation, Affected Environment.

Geographic Reaches

Lake Powell and Glen Canyon National Recreation Area

Glen Canyon NRA receives approximately three to five million visitors annually (NPS 2025b). Lake Powell is the primary recreational feature within Glen Canyon NRA, and it supports swimming, power boating, houseboating, water skiing, fishing, personal watercraft use, nonmotorized boating, hiking, camping (developed and primitive), and viewing of cultural and geologic resources.

Recreational boating is the dominant activity on Lake Powell, with nearly two million visitors accessing the reservoir by private or rental boats (NPS 2025c). Operability of boat ramps and marinas is highly dependent on the lake's elevation. Several ramps and the Dangling Rope Marina have been closed in the last decade due to low water levels, requiring boaters to concentrate use at fewer facilities and increasing congestion at remaining ramps. The NPS is pursuing new ramps and facility modifications to maintain boating access at lower pool elevations (NPS 2025d).

Access to Rainbow Bridge National Monument has become more limited as lake levels have declined. At elevations below 3,544 feet, concession-operated boat tours can no longer reliably reach the area, and private boaters often must traverse mud, debris, and shallow water between the shoreline and the established trail (NPS 2021b). This has substantially reduced access for many visitors.

Additional shoreline issues at Lake Powell include the following:

- Harmful algal blooms: Increasingly frequent harmful algal bloom events can result in temporary closures of water-based recreation areas to protect public health (Deemer et al. 2023).
- Quagga mussels**:** Established populations of quagga mussels encrust canyon walls, shorelines, boats, and infrastructure. Accumulated shells along beaches can create hazards for visitors and pets and increase facility maintenance needs (NPS 2016).
- Newly exposed lands**:** Declining water levels have exposed approximately 100,000 acres of previously inundated Glen Canyon, revealing arches, side canyons, rock formations, and archaeological sites (Baker 2022; Kolbert 2021). These areas provide new hiking and sightseeing opportunities but are fragile and vulnerable to erosion and vandalism.

Glen Canyon Dam to Lake Mead (Colorado River Corridor)

The 15.5-mile reach downstream of Glen Canyon Dam to Lees Ferry is located within Glen Canyon NRA and is used extensively by anglers, campers, commercial float trips, and private boaters. Warmer water temperatures in recent years have increased use by paddle boarders, kayakers, and canoeists.

Downstream, GCNP begins at the confluence of the Colorado and Paria Rivers. GCNP, a United Nations Educational, Scientific and Cultural Organization World Heritage Site, receives approximately four to six million visitors annually and provides a range of backcountry and river-based experiences (NPS 2025e). Camping along the Colorado River corridor occurs on undeveloped sandbars. The number, size, and suitability of campsites vary over time due to the fluctuating size of sandbars, which are affected by dam operations, tributary floods, vegetation encroachment, and management closures. In general, campsites become fewer or harder to use between HFEs that build sandbars, as vegetation growth, erosion, tributary floods, and aeolian sand movement affect the beaches. The river corridor also borders tribal lands for approximately 108 miles, where the Navajo Nation, Hualapai Tribe, and other tribes manage additional shoreline recreation, such as guided rafting, camping, hunting, and hiking. Access to tribal lands requires permits from the respective tribes.

Lake Mead National Recreation Area

Lake Mead NRA encompasses Lake Mead, Lake Mohave, and the surrounding desert landscapes. Lake Mead NRA receives roughly five to eight million visitors annually (NPS 2025f). The primary recreational activities include boating, fishing, water sports, swimming, camping, hiking, and wildlife viewing. The Overton Wildlife Management Area and other shoreline sites provide additional opportunities for hunting, birdwatching, and photography.

Declining reservoir elevations at Lake Mead have exposed extensive mudflats in several shoreline areas. Visitors attempting to "chase the waterline" on foot or by vehicle for fishing and shoreline access have sometimes become stuck in wet, unstable sediment, necessitating rescues and increasing safety concerns. Multiple launch ramps and some marinas have closed because water levels dropped below critical elevations; these closures have concentrated use at the remaining facilities and contributed to crowding and operational challenges.

As lake temperatures, warm, recreation managers face increasing water quality concerns, including harmful blue-green algal blooms and rare but serious incidents involving *Naegleria fowleri,* which is known as the brain-eating amoeba (NPS 2022).

Lower Colorado River Reaches (Davis Dam to the SIB)

Downstream of Hoover Dam, recreation along the Colorado River is supported by a network of public recreation areas, national wildlife refuges, and state parks, including Davis Camp, Laughlin/Bullhead City, Havasu NWR, Lake Havasu State Park, Bill Williams River NWR, Cibola NWR, Imperial NWR, Martinez Lake, and various small shoreline facilities near Yuma.

Across these reaches, visitors engage in boating, houseboating, fishing, water skiing, swimming, paddling, hunting, hiking, wildlife viewing, and camping. Lake Havasu, in particular, is a high-use destination for motorized boating, angling, spring break, and family recreation. River segments adjacent to NWRs provide more natural settings valued for wildlife viewing, hunting, and low-density boating.

Flows below Hoover Dam are consistently low due to upstream diversions and delivery obligations. As a result, the range of operational changes evaluated across the alternatives is not expected to meaningfully alter flow conditions in a manner that would measurably affect recreation opportunities in this reach. Given the limited variability in flows and the constrained nature of water-based recreation downstream of Parker Dam, a detailed analysis was determined to be unwarranted.

Potential effects in this area would be negligible and would not differ substantially amongst the alternatives. Impacts on recreation below Hoover Dam are not further considered in this EIS.

Recreational Uses

Shoreline Public Use

Shoreline public use in the study area is supported by marinas, boat launch ramps, docks, campgrounds, and access points to major destinations. These facilities provide access for day use, extended boating trips, camping, hiking, and viewing of natural and cultural resources. Fluctuations in reservoir elevations influence the operability and safety of these facilities. Declining water levels can result in temporary or long-term closures of ramps and marinas, relocation or modification of facilities, congestion at remaining access points, and reduced or more difficult access to popular shoreline destinations.

Reservoir Boating

Reservoir boating throughout the system is directly affected by fluctuating water levels. As reservoir elevations decline, navigational hazards (for example, exposed rocks, sandbars, and constricted channels) increase, and safe boating capacities decrease. Management responses include the placement of buoys and markers, installation of warning signs, and formal closure of unsafe areas. Quagga mussel infestations further complicate reservoir boating operations by fouling boats, infrastructure, and shorelines.

In the upstream tributaries to Lake Mead, sediment deposition and receding water levels have created shallow, poorly defined channels. When lake elevations fall below approximately 1,170 feet, the upper end of Lake Mead becomes too shallow for most motorized boats to navigate upstream into the lower Grand Canyon. As Lake Mead has receded, the Colorado River has incised into deposited sediments near Pearce Ferry, forming a new high-hazard rapid (Pearce Ferry Rapid) that blocks upstream motorized navigation and has altered takeout operations.

Large changes in reservoir navigability are not anticipated under the proposed range of operations at Lake Mohave and Lake Havasu because these reservoirs are managed to meet relatively stable monthly target elevations. Lake Mohave and Lake Havasu are therefore not included in the environmental analysis.

River and Whitewater Boating

Whitewater boating is the primary recreational activity on the Colorado River between Lees Ferry and the downstream takeouts at Diamond Creek or Pearce Ferry. Trips may be commercial or private, use a variety of boat types, and range up to 25 days in length. GCNP staff manages river use under the Colorado River Management Plan, which establishes limits on daily launches, group size, trip length, and the timing of motorized and nonmotorized use (NPS 2006).

Navigability and the user experience are influenced by discharge levels, debris fan rapids, and changing channel conditions. Lower flows and increased side-canyon debris can make certain rapids more technically demanding.

Flow levels are a key determinant of whitewater trip quality and safety (Bishop et al. 1987; Shelby et al. 1992; Hall and Shelby 2000; Stewart et al. 2000; Neher et al. 2017). Studies and user surveys indicate that flows below about 10,000 cubic feet per second (cfs) and above about 45,000 cfs are generally considered less than optimum, while flows between approximately 20,000 and 26,000 cfs are considered optimal for most whitewater users (Shelby et al. 1992; Bishop et al. 1987; Neher et al. 2017). Flows of 8,000–9,000 cfs are regarded as the minimum acceptable levels for safely running trips with passengers (Bishop et al. 1987; Shelby et al. 1992; Stewart et al. 2000).

Downstream of Hoover Dam, the proposed alternatives are not expected to substantially affect river or whitewater boating conditions between Hoover Dam and the SIB.

Sport Fishing

Sport fishing is an important recreational use across the study area. Although specific elevation thresholds for angler satisfaction are not well defined, fishing quality is closely linked to reservoir habitat, water temperature, access via ramps and marinas, and boat navigability.

Lake Powell supports warmwater fisheries, including for striped bass, smallmouth bass, largemouth bass, walleye, catfish, and panfish. Forage species, such as threadfin shad, are sensitive to temperature changes and influence predator populations.

The 15.5-mile tailwater reach below Glen Canyon Dam supports a Blue Ribbon[16] rainbow trout fishery at Lees Ferry. Historically, cold-water releases limited survival and reproduction of warmwater species entrained from Lake Powell. Recent warmer and lower-oxygen releases have increased the risk of establishment and recruitment of nonnative predators, such as smallmouth bass, which potentially reduces trout quality. Please refer to **TA 14**, Recreation, for more information on rainbow trout dynamics in this reach.

Lake Mead and Lake Mohave support diverse warmwater fisheries (for striped bass, largemouth bass, catfish, panfish, and stocked trout). Low reservoir levels have affected hatchery operations at Lake Mead, leading to facility modifications and water supply changes. Farther downstream, Lake Havasu and the lower river reaches support striped bass, largemouth and smallmouth bass, catfish, crappie, sunfish, and other species, with some areas subject to seasonal closures (for example, Cibola Lake) to protect wildlife.

Overall, sport fishing opportunities remain widespread throughout the system but are sensitive to changes in hydrology, water temperature, water quality, and access conditions associated with reservoir elevations and dam operations.

3.14.2 Environmental Consequences

Methodology

Consistent with Reclamation's 2007 Final EIS and 2024 Final SEIS, the analysis builds on traditional threshold-based evaluation methods by integrating DMDU concepts, including robustness heat maps and vulnerability bar plots. These tools highlight how each alternative performs across a wide range of plausible hydrologic futures with regard to shoreline public use facilities, reservoir boating and navigational hazards, whitewater boating, and sport fishing. Refer to **Section 3.2.6**, Decision Making

[16] A Blue Ribbon fishery designation indicates a high-quality recreational fishery that meets specific criteria, including water quality, natural reproduction capacity, and management strategies.

under Deep Uncertainty, for an overview of interpreting the DMDU robustness heat maps and vulnerability bar plots.

Method Used to Assess Shoreline Public Use Facilities

The evaluation of shoreline facilities relies on thresholds provided by the NPS that identify reservoir elevations at which specific marinas, docks, and launch ramps require modification, relocation, or closure. These thresholds serve as impact indicators for the loss or degradation of shoreline public use. Using the DMDU framework, the analysis examines the percentage of futures in which a given alternative maintains a minimum proportion of operable recreational sites throughout the summer high-use season (May 31–August 31). This period was selected because visitation is highest, and operational disruptions have the greatest impact on user experiences and local economies. Representative facilities were selected from Lake Powell and Lake Mead to align with the regional economic modeling (see **TA 16**, Socioeconomics). The analysis then analyzes the performance of alternatives in maintaining representative elevations important for reservoir boating access, including the minimum for safe navigation, a historic low, and the elevation at which all boat ramps and/or planned extensions would become inaccessible.

Method Used to Assess Reservoir Boating and Navigation Hazards

Reservoir boating impacts are analyzed using critical navigational thresholds identified in the 2007 Final EIS and continued in the 2024 Final SEIS. Threshold elevations indicate levels below which safe navigation becomes substantially impaired due to shallow channels, newly exposed hazards, or blocked passageways. DMDU outputs evaluate the frequency with which each alternative avoids falling below these elevations. This approach highlights the reliability of each alternative in maintaining safe boating conditions over multiple hydrologic futures.

Method Used to Assess Whitewater Boating

The evaluation of whitewater boating relies on minimum flow thresholds known to influence navigability, safety, and trip management. Prior studies (Shelby et al. 1992; Stewart et al. 2000) identify 8,000 cfs as the preferred minimum daytime flow for whitewater boating with passengers, 5,000 cfs as a low-flow threshold below which trip disruption and safety hazards increase, and 20,000–26,000 cfs as the preferred range for optimal whitewater boating experiences. DMDU heat maps assess the percentage of futures in which the alternatives maintain flows above the minimum thresholds during the daytime (7:00 a.m. to 7:00 p.m.) across the modeling period.

Methods Used to Assess Ferry and Taxi Boat Services

Thresholds provided by the Utah Department of Transportation (UDOT 2025) identify key elevations required for ferry operations, most notably 3,575 feet. The analysis evaluates whether reservoir elevations under each alternative would sustain these services or require extended closure.

Methods Used to Assess Sport Fishing

Reservoir sport fishing is influenced primarily by habitat availability, shoreline complexity, and thermal conditions. Because no discrete elevation thresholds exist for fishing suitability, DMDU is not used for reservoir sport fishing; instead, the analysis focuses on how general elevation trends under each alternative influence fish habitat.

A more detailed analysis (**TA 8**, Biological Resources – Fish and Other Aquatic Species) using DMDU information was conducted for the Lees Ferry rainbow trout fishery, where water temperature is directly linked to recreational quality and species viability.

Impact Analysis Area

The impact analysis area for recreation aligns with the general analysis area, which encompasses the Colorado River corridor from the full pool elevation of Lake Powell to the SIB. Given the limited flow variability and the constrained nature of water-based recreation downstream of Parker Dam, a detailed analysis below this area not warranted. Potential effects in this area would be negligible and would not differ substantially amongst the alternatives.

Assumptions

- The analysis assumes that the demand for recreational opportunities will either remain constant or increase over time. This assumption forms the basis for evaluating impacts on activities such as reservoir recreation, fishing, and whitewater boating.
- The analysis considers 5,000 cfs and 8,000 cfs as two levels at which commercial and private boaters may experience navigability challenges (Bishop et al. 1987; Stewart et al. 2000; Shelby et al. 1992).
- While HFEs are not directly incorporated into the recreation modeling, actual HFE frequency may differ from that assumed or predicted in other modeling efforts.
- Additional assumptions related to modeling are considered in the analysis, contributing to the accuracy and reliability of the hydrologic models used to anticipate impacts resulting from various actions.

Impact Indicators

- Threshold reservoir elevations
- Threshold river flows
- Water temperatures

Issue 1: How would the management of reservoir elevations affect recreation?

Lake Powell

Shoreline Recreational Facilities

Reservoir elevations exert a direct influence on the operability of Lake Powell's recreational infrastructure. Many of Lake Powell's primary launch ramps, marinas, and courtesy docks become inaccessible or require substantial modification when lake levels fall below the thresholds identified by the NPS (see **Table TA 14-3** in **TA 14**, Recreation). The DMDU results illustrate that in the Full Modeling Period and 2027-2039 subperiod, none of the alternatives would keep at least 60 percent of Lake Powell recreational sites open during the summer months (**Figure TA 14-1** in **TA 14**, Recreation). Based on the planned length of this decision, the Representative Preferred Alternative is unable to meet the preferred minimum performance across the Full Modeling Period and 2027-2039 subperiod, but does so in 30 percent of modeled futures in the 2040-2049 subperiod, and 22 percent of modeled futures in the 2050-2060 subperiod. Under all alternatives, periods of low water would be more likely, which could result in recurring closures of boat launch ramps, restricting marinas to limited operability, and reducing shoreline access for day users, campers, and boaters. Visitors could experience longer wait times, congested remaining ramps, and reduced access to preferred boating destinations. Taken together, the projected reservoir conditions suggest that under most alternatives, the reliability of Lake Powell's shoreline public use facilities would decline from historical norms.

Boating Navigation

Safe boating access at Lake Powell depends strongly on maintaining reservoir elevations above the 3,620-foot threshold. Elevations below this level expose hazards and constrict navigation channels. The DMDU analysis shows that the Enhanced Coordination and Maximum Operational Flexibility Alternatives offer the greatest robustness at maintaining elevations above this threshold in at least 20 percent of months, doing so in roughly 80 percent of modeled futures. These alternatives would support safer boating conditions under a wider range of hydrologic conditions and preserve access to many of the canyon environments that are central to the Lake Powell recreational experience.

The other alternatives perform moderately to poorly in this regard. The Representative Preferred, No Action, and Basic Coordination Alternatives, achieve the threshold in approximately 60 percent of futures, while the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the threshold in approximately 40 percent of futures. Under these worse-performing alternatives, Lake Powell could experience prolonged periods during which safe passage through major navigation corridors is limited, reducing the quality and quantity of recreational boating opportunities across a wider range of hydrologic futures. All alternatives show poor performance in maintaining a Lake Powell elevation of 3,620 feet or above in 20 percent or more futures, indicating that the long-term return to historically common elevation levels is unlikely.

Sport Fishing

Sport fishing in Lake Powell is sensitive to changes in reservoir elevation because habitat complexity diminishes as water recedes. The Maximum Operational Flexibility and Enhanced Coordination Alternatives, which are more robust at achieving higher median elevations around 3,600 feet, would help preserve a more diverse array of shallow-water habitats favored by desirable warmwater sportfish, including largemouth bass, bluegill, and crappie. Conversely, the lower-elevation alternatives cluster around 3,560 feet and would result in diminished shallow-water habitat, promoting conditions that favor smallmouth bass and reducing the productivity of the fishery for many anglers. Thus, the alternatives that sustain higher average reservoir levels would provide more favorable sport fishing conditions throughout the year.

Ferry and Taxi Boat Services

Ferry and taxi boat services at Lake Powell require relatively high reservoir elevations to maintain safe docking and transit conditions. The ferry becomes inoperable at elevations below 3,575 feet. Because all alternatives frequently fall below this threshold across much of the modeled period, ferry service interruptions or full discontinuation would be a near-constant condition under all operational strategies. Only substantial engineering modifications or relocation efforts would restore reliable ferry service under extended drought conditions.

Lake Mead

Shoreline Recreational Facilities

Lake Mead recreational infrastructure is sensitive to threshold elevations. Many of the reservoir's launch ramps, marinas, and shoreline access points become impaired as water levels retreat, and steep, unstable slopes emerge. The DMDU analysis shows that all alternatives perform poorly at maintaining at least 80 percent of recreational facilities open during the summer season in the Full Modeling Period. The Supply Driven Alternative, particularly the Pro Rata approach, is the most effecting at maintaining this preferred minimum, but only succeeds in 14 percent of modeled futures. While this alternative preserves opportunities at Lake Mead, it also reflects trade-offs for Lake Powell. The Maximum Operational Flexibility Alternative performs moderately well, though not at the same level as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches)

Under all alternatives, including the Representative Preferred Alternative, Lake Mead experiences low reliability in maintaining recreational sites. These deficiencies translate into recurring closures, reduced or eliminated launching opportunities, stranded infrastructure, and a substantial decline in the quality of recreational access. As reservoir conditions deteriorate under these alternatives, visitor safety concerns would increase, and more intensive management interventions would be needed to maintain even modest levels of access.

Boating Navigation

Maintaining Lake Mead above the 1,170-foot threshold is essential for preserving upstream navigation into the lower Grand Canyon. The analysis shows that only the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) provides a high likelihood of maintaining Lake Mead above this level for 10 percent or more of months, with success rates approaching 80 percent of futures. This alternative would help reduce navigation hazards, limit mudflat exposure, and sustain limited upstream boating opportunities.

The other alternatives show weaker performance, with the No Action Alternative and CCS Comparative Baseline exhibiting the poorest performance. Under all alternatives, including the Representative Preferred Alternative, it is likely that large areas of the reservoir would expose thick mudflats and shallow delta formations, making it dangerous or impossible for boaters to access several parts of the reservoir. These conditions would also exacerbate congestion at the limited number of remaining deep-water access points.

Issue 2: How would the management of releases from Glen Canyon Dam affect recreation, including from changes in water temperature?

Whitewater Boating

Whitewater boating conditions below Glen Canyon Dam depend heavily on reliable daytime flows that allow large commercial rafts to safely navigate rapids and manage trip logistics. The analysis shows that the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) performs the strongest in maintaining flows at or above the 8,000 cfs minimum threshold, providing favorable conditions in approximately 86 percent of futures. This alternative would make commercial and private boating groups less likely to face low-water hazards, allowing for safer, smoother navigation.

The Basic Coordination Alternative also performs well, while the CCS Comparative Baseline and the No Action, Maximum Operational Flexibility, Representative Preferred, and Enhanced Coordination Alternatives exhibit diminishing performance. The Enhanced Coordination Alternative, in particular, maintains the 8,000 cfs threshold in only 8 percent of futures, indicating substantial vulnerability to flows falling below the preferred safety conditions. As flows weaken, rafting parties could encounter more exposed rocks, shallower rapids, longer portaging distances, and increased risks of boating incidents. These hazards directly affect the quality, reliability, and safety of the Grand Canyon whitewater recreational experience.

When evaluating flows above the 5,000 cfs threshold, below which trip disruption and safety hazards increase, the analysis finds that the Enhanced Coordination, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives maintain this threshold in nearly 100 percent of futures. While these flows may not provide optimal conditions, they reduce the likelihood of severe navigational hazards. The other alternatives perform moderately to poorly, elevating risks for boaters and contributing to unpredictable trip conditions.

Overall, the alternatives that maintain higher flows offer substantially better protection of the whitewater recreational quality. Conversely, the alternatives that produce more frequent low-flow conditions increase safety risks, impede access to campsites, and alter trip durations.

Sport Fish Populations

Recreational fishing below Glen Canyon Dam, particularly at Lees Ferry, is highly sensitive to changes in water temperature. Rainbow trout experience thermal stress when temperatures exceed 20 °C (68 °F), while warmwater species, such as smallmouth bass, benefit from elevated temperatures and potentially expand their range.

The Enhanced Coordination Alternative offers the highest likelihood of maintaining cooler water temperatures, meeting the preferred temperature performance in 56 percent of futures. Under this alternative, conditions associated with maintaining the trout fishery would be most favorable. The Maximum Operational Flexibility Alternative also performs moderately well, while the Representative Preferred, Supply Driven (both LB Priority and LB Pro Rata approaches), and the No Action Alternatives perform poorly, allowing temperatures to exceed optimal thresholds in a large proportion of futures.

Under warmer and drier hydrologic futures, all alternatives become more vulnerable to undesirable temperature increases. Under such conditions, rainbow trout populations may decline, and warmwater species may proliferate, potentially altering recreational fishing patterns and diminishing the unique value of the Lees Ferry fishery. Without management interventions, such as cold-water bypass infrastructure, the ability to maintain high-quality trout fishing will remain constrained across all alternatives.

Summary Comparison of Alternatives

The alternatives vary considerably in their ability to sustain recreational resources over the full analysis period as well as all subperiods. The alternatives that favor higher Lake Powell elevations, such as the Enhanced Coordination and Maximum Operational Flexibility Alternatives, offer the greatest benefits for Lake Powell-based recreational resources. These alternatives help preserve access to boat ramps and marinas, maintain more reliable boating corridors, and sustain more diverse sport fishing opportunities. By contrast, the alternatives that prioritize meeting compact delivery obligations through downstream releases, such as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), perform more poorly for Lake Powell's recreational infrastructure.

At Lake Mead, the pattern is reversed. The alternatives that retain more water downstream, specifically the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), perform best at keeping facilities open and maintaining safe boating conditions. The Maximum Operational Flexibility and Enhanced Coordination Alternatives provide moderate benefits, while the No Action Alternative and the CCS Comparative Baseline offer the least reliable performance for Lake Mead–based recreation. The Representative Preferred Alternative generally performs in the middle of the range of alternatives for both Lake Powell and Lake Mead.

For whitewater boating in the Grand Canyon, the alternatives also yield varying results. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maintains the highest likelihood of meeting the preferred 8,000 cfs flow threshold, supporting safer and higher-quality rafting opportunities. The Enhanced Coordination and Maximum Operational Flexibility Alternatives perform poorly in this regard, creating greater risks for boaters and reducing the reliability of commercial trip planning. The Representative Preferred Alternative generally performs in the middle of the range of alternatives for daytime flows.

In terms of water temperature and sport fishing below Glen Canyon Dam, the Enhanced Coordination Alternative performs most favorably, helping sustain the cold-water conditions that support the rainbow trout population. The Maximum Operational Flexibility Alternative also provides moderate support for cooler temperatures. The alternatives that prioritize downstream deliveries at the expense of upstream storage tend to worsen temperature conditions and increase the prevalence of warmwater predators. The Representative Preferred Alternative generally performs in the middle of the range of alternatives for water temperature for rainbow trout.

Overall, no alternative fully protects all recreational resources throughout the Basin under extended drought conditions. Instead, each alternative presents a unique set of trade-offs. Those alternatives that prioritize upstream reservoir elevations tend to support recreation at Lake Powell but reduce downstream releases needed for whitewater boating and temperature control; those that emphasize deliveries to the Lower Basin improve Lake Mead recreation but may worsen recreation conditions in Lake Powell and Lees Ferry. These trade-offs underscore the Basin-wide challenge of managing limited water supplies while simultaneously supporting diverse recreational resources that rely on adequate water levels and river flows.

3.15 Dams and Electrical Power Resources

3.15.1 Affected Environment

This section provides a summary of the infrastructure, spillway conditions, and hydropower capacity and generation of the four primary dams and reservoirs in the analysis area of the Colorado River corridor from the full pool elevation of Lake Powell to the SIB. These four dams and reservoirs are Glen Canyon Dam and Lake Powell, Hoover Dam and Lake Mead, Davis Dam and Lake Mohave, and

Parker Dam and Lake Havasu. For additional information and the full discussion of the affected environment and environmental consequences, please refer to **TA 15**, Dams and Electrical Power Resources.

This section addresses the interplay between reservoir elevations and dam releases, and how they influence dam spillway use, power generation, and capacity. It also provides the context necessary for evaluating the effects of the alternatives on dams and electrical power resources.

Hydropower output depends on how much water passes the turbines and the 'head' (the elevation difference between the reservoir surface and the turbine). The higher the reservoir elevation, the greater the head the water can exert as it passes through the turbines. Higher reservoir elevations allow greater power production, and conversely, if reservoirs drop below a specified elevation (the minimum power pool), power production is not possible.

Keeping the reservoir water level below the spillway crest reduces reliance on spillway infrastructure, preserves the water supply, and maintains flood storage capacity. Maintaining lower reservoir levels allows inflow to be routed through controlled outlets to respond to spring runoff. This section also provides the context for analyzing the effects of the alternatives on electricity rates. Reclamation operates and maintains the Glen Canyon, Hoover, Davis, and Parker Dams, while the Western Area Power Administration (WAPA) is responsible for marketing and transmitting the power generated at these facilities across the Upper and Lower Basins (Reclamation 2007a).

Glen Canyon Dam and Lake Powell

Glen Canyon Dam is located in Page, Arizona, and is a concrete arch dam rising 710 feet with a 35-foot-wide roadway connecting the dam's spillways. The dam's reservoir, Lake Powell, has a water storage capacity of 25.16 maf and a maximum reservoir elevation of 3,711 feet. The dam and reservoir are operated and maintained by Reclamation's Glen Canyon Field Division in Page, Arizona. Refer to **Figure TA 15-3** in **TA 15**, Dams and Electrical Power Resources.

Dam operations are managed to maintain the water surface elevation near or below 3,700 feet, which is the normal operating level. Operational preference is to maintain a water surface elevation below the top of active conservation, 3,700 feet, to minimize the occurrence of flood operations and the need for additional monitoring. Glen Canyon Dam is designed to safely accommodate the probable maximum flood including operating up to the maximum water surface elevation of 3,711 feet. Another important operational consideration is maintaining adequate vacant storage at or below an elevation of 3,684 feet on January 1, which provides the necessary capacity to preserve space for spring runoff inflows.

The Glen Canyon Dam powerplant has eight generators with a maximum combined capacity of 1,320 MW at a reservoir elevation of 3,700 feet (Reclamation 2016). At minimum power pool, the powerplant has an estimated physical capacity of 630 MW. The powerplant's physical capacity to generate power has recently been affected by decreases in Lake Powell reservoir elevations due to drought conditions. The decreases in elevation have led to lower head, which, combined with reduced annual releases, has reduced power generation since 1997. Refer to **Figure TA 15-4** and **Figure TA 15-5** in **TA 15**, Dams and Electrical Power Resources.

Hoover Dam and Lake Mead

Hoover Dam is located in Black Canyon on the Arizona–Nevada state line, approximately 35 miles southeast of Las Vegas, Nevada. The dam and its reservoir, Lake Mead, are operated and maintained by Reclamation's Lower Colorado Basin Dams Office. Hoover Dam is a concrete gravity-arch structure standing 726 feet high with a crest length of 1,244 feet. Lake Mead has a water storage capacity of 30.2 maf and a maximum reservoir elevation of 1,232 feet. Refer to **Figure TA 15-5** in **TA 15**, Dams and Electrical Power Resources.

Under normal conditions, nearly all Colorado River flow passes through the turbines, with the spillways and outlet works used only in exceptional circumstances. The maximum safe channel capacity is estimated to be 40,000 cfs. Current operations aim to keep Lake Mead below 1,219.6 feet as much as possible. While limited operations above this level have occurred historically, it is preferred to minimize time spent in the flood control space. The elevation of the bottom of the spillway drum gate is 1,205.4 feet. Operating below this elevation is desired because elevations above this point rely on mechanical gate function, where the risk of failure increases. The most critical elevation threshold is 1,226.9 feet. This elevation corresponds to a spillway discharge exceeding 40,000 cfs and represents an imminent emergency.

The Hoover Dam powerplant has 17 commercial generators with a maximum combined capacity of 2,074 MW. The powerplant requires a minimum Lake Mead elevation of 950 feet to produce power. At minimum power pool, the powerplant has an estimated capacity of 117 MW. The power-generating capacity of Hoover Dam has been affected by drought conditions. The drop in Lake Mead's elevation has reduced head, lowering electric power output. At Lake Mead elevation 1,035 feet, Hoover Dam's generating capacity decreases from 1,274 MW to 382 MW. Elevations above 1,035 feet in current market conditions, hydropower can be produced at or above market value. With current turbines, if the elevation drops below 1,035 feet, it is estimated that operating costs will exceed the value of the hydropower produced. Please reference **Figure TA 15-6** and **Figure TA 15-7** in **TA 15**, Dams and Electrical Power Resources.

Davis Dam and Lake Mohave & Parker Dam and Lake Havasu

Davis Dam is a 320-foot-tall, rock- and earth-fill gravity dam, rising 140 feet above the Colorado River. The dam spans the border of Arizona and Nevada in Pyramid Canyon and is 67 miles downstream from Hoover Dam. Its dam crest is 1,600 feet long and 50 feet wide. Its reservoir, Lake Mohave, has a water storage capacity of 1.8 maf and a maximum reservoir elevation of 647 feet. Davis Dam is operated and maintained by Reclamation's Davis Dam Field Division, which is part of the Lower Colorado Basin Dams Office.

Parker Dam, commonly known as the 'deepest dam in the world,' is a concrete arch structure with 73 percent of its height below the original stream bed elevation of the Colorado River. The dam is on the Arizona–California border and lies 88 miles downstream from Davis Dam. The dam has a crest length of 856 feet and a width of 39 feet. The dam's reservoir, Lake Havasu, has a storage capacity of 646,200 acre-feet and a maximum reservoir elevation of 450 feet. Parker Dam is operated and maintained by Reclamation's Parker Dam Field Division of the Lower Colorado Basin Dams Office.

Normal releases from Davis and Parker Dams are made through the powerplant turbines with the spillway and outlet works in the closed position. The safe downstream channel capacity on the river is 40,000 cfs.

The Davis Dam powerplant has four 51.75 MW generators and one 48 MW generator for a total capacity of 255 MW. The Parker Dam powerplant has four 30 MW generators, totaling 120 MW, with a discharge capacity of 22,000 cfs (Reclamation 2023c). Drought conditions have had less impact on the capacity at the Davis and Parker powerplants than at the Hoover and Glen Canyon powerplants because the elevations of Lake Mohave and Lake Havasu reservoirs have remained relatively constant. However, drought-induced reductions in river flow have resulted in a decline in electric power generation at these powerplants. Please refer to **Figure TA 15-8** in **TA 15**, Dams and Electrical Power Resources.

Hydroelectric Power Distribution

This section provides a high-level summary of hydroelectric power distribution. Please refer to **TA 15.1.4**, Hydroelectric Power Distribution, in **TA 15**, Dams and Electrical Power Resources, for a more in-depth discussion of the topic and a variety of associated topics, including: scheduling; load following, generation, and regulation; reliability standards; basin funds; emergencies and outages assistance; transmission system; power marketing; Tribal benefit crediting; and rates.

Hydroelectric power generation can be adjusted operationally through a coordinated effort between WAPA and Reclamation. This operational flexibility allows WAPA to quickly and efficiently increase or decrease generation in response to customer demand. WAPA markets long-term firm capacity and energy; short-term, firm capacity and energy; and non-firm energy. WAPA sets rates for Firm Electric Service from federal hydropower projects in its marketing territory, in accordance with Department of Energy regulations and applicable federal statutes. Customers pay rates that align specifically with the project from which they buy power.

WAPA sets rates through a public process (proposal, comment period, and final notice in the Federal Register). WAPA has various wholesale customers, including municipal utilities, federal and state public power facilities, rural electric cooperatives, and tribal entities. Power rates are set so that revenues are sufficient to cover all costs assigned to power within the required time periods. 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 are normally set to cover system operations and capital costs. As the costs of these individual components change, the retail rates are adjusted to ensure that enough revenue is collected to meet the utility's financial obligations.

3.15.2 Environmental Consequences

This section summarizes the analysis of the effects of the alternatives on the minimum power pool for Lake Powell and Lake Mead; the power capacity of the Glen Canyon Dam and Hoover Dam powerplants; the power generation of the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam powerplants; the spillway use of Glen Canyon Dam and Hoover Dam; and electricity rates and the market value of the electricity.

Spillway use and hydropower capacity of the Davis Dam and Parker Dam are not analyzed because Lake Mohave and Lake Havasu reservoirs have historically remained relatively constant, and their elevations are expected to remain so under all alternatives. Both Lake Mohave and Lake Havasu would continue to be operated under a rule curve that provides specific target elevations at the end of each month (refer to **Section TA 3.1.8**, Davis Dam to Lake Havasu, in **TA 3**, Hydrologic Resources).

For additional detail and the full analysis of effects, please refer to **Section TA 15.2**, Environmental Consequences, in **TA 15**, Dams and Electrical Power Resources.

Methodology

WAPA's CRSP Python-based (CRiSPPy) model and Reclamation's CRSS model analysis framework informs the basis for the effects analysis. For additional information on the methodology used, please refer to **Section 3.2.6**, Decision Making under Deep Uncertainty; **Appendix A**, CRSS Model Documentation; and **Section TA 15.2.1**, Methodology, in **TA 15**, Dams and Electrical Power Resources.

Impact Analysis Area

The analysis area for Issues 1–4 encompasses the four primary dams in the Colorado River corridor from the full pool elevation of Lake Powell to the SIB: Glen Canyon Dam and Lake Powell reservoir, Hoover Dam and Lake Mead reservoir, Davis Dam and Lake Mohave reservoir, and Parker Dam and Lake Havasu reservoir. The analysis area for Issue 5 consists of the retail electricity customers in Arizona, Colorado, Nevada, New Mexico, Nebraska, Utah, and Wyoming who receive power through local utilities and cooperatives supplied with Glen Canyon Dam power by WAPA. WAPA sells power at the wholesale level, while local utilities and cooperatives distribute that power directly to homes, businesses, and other customers.

Assumptions

All action alternatives except for the Basic Coordination Alternative incorporate mechanisms related to the storage and delivery of conserved water in Lake Powell, Lake Mead, or both (refer to Appendix S, Additional Description of Alternatives). Unless otherwise specified, impacts reflect modeling assumptions about voluntary conservation behavior.

The Lower Basin electrical generation and firm capacity modeling results are direct outputs from CRSS. Refer to **Appendix A**, CRSS Model Documentation, for more details related to model assumptions and documentation. The Glen Canyon Dam electrical generation and firm capacity modeling results are direct outputs from the CRiSPPy model. For additional information and modeling assumptions, please refer to *CRiSPPy: An Advanced Hydropower Scheduling Tool for the Colorado River Storage Project* (Ploussard et al. 2025). The Glen Canyon Dam rates analysis data was developed by Argonne National Laboratory. Information and modeling assumptions for the rates analysis can be found in *Post-2026 Environmental Impact Statement Rate Analysis for the Colorado River Storage Project* (Yu et al. 2025).

Impact Indicators

- Lake Powell and Lake Mead Reservoir elevations
- Firm capacity (MW)
- Energy generation (MWhs)
- Spillway releases

- Electricity rates
- The market value of electricity

Issue 1: How do the alternatives impact the frequency at which reservoir elevations drop below the minimum power pool at Lake Powell and Lake Mead?

Minimum power pool is the lowest reservoir elevation level at which a hydropower plant can produce power. The frequency at which reservoir elevations drop below minimum power pool for Glen Canyon Dam/Lake Powell and Hoover Dam/Lake Mead were measured by calculating the percent of futures in which the elevations of the reservoirs achieve the preferred minimum performance of maintaining elevations at or above 3,490 feet and 950 feet respectively (refer to **Figure TA 15-9** and **Figure TA 15-11**); and by using vulnerability figures that display conditions that could cause Lake Powell and Lake Mead to drop below these thresholds (3,490 feet and 950 feet respectively), representing undesirable performance when elevations fall below minimum power pool in one or more months (refer to **Figure TA 15-10** and **Figure TA 15-12**).

The Maximum Operational Flexibility Alternative would provide the greatest power pool robustness for both Lake Powell and Lake Mead. For Lake Powell, the Enhanced Coordination Alternative would provide the second-highest level of power pool, while the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would provide the lowest. Conversely, for Lake Mead, the Supply Driven Alternative (LB Pro Rata approach) would provide the second-highest level of power pool, followed by the Enhanced Coordination Alternative. For Lake Mead, the least robust alternative is the No Action Alternative.

Under the driest hydrologic conditions, the Maximum Operational Flexibility and Enhanced Coordination Alternatives would provide the most robust outcomes for maintaining Lake Powell elevations above the preferred threshold, whereas the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) and the No Action Alternative would provide the least. For Lake Mead, the Maximum Operational Flexibility Alternative, Supply Driven Alternative (LB Pro Rata approach), and Enhanced Coordination Alternative would provide the greatest robustness, while the No Action Alternative would provide the least.

For Lake Powell elevation power pool robustness, the Representative Preferred Alternative exhibits a better performance than the No Action, CCS Comparative Baseline, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) alternatives for the full modeling period. For Hoover Dam, the Representative Preferred Alternative is more robust than all alternatives except the Enhanced Coordination, Maximum Operational Flexibility, and Supply Driven (LB Pro Rata approach) Alternatives in the 2027-2039 modeling period.

Issue 2: How would the alternatives impact the firm capacity of the Glen Canyon Dam and Hoover Dam powerplants?

Firm capacity is the reliable, guaranteed amount of power output from a powerplant that accounts for operational constraints such as water releases and ramp rates. Firm capacity is measured in MW. This section considers how the different alternatives affect the annual firm capacity of the hydropower plants at the Glen Canyon Dam and Hoover Dam for the month of August. The analysis uses boxplots to display August firm capacity at both dams across five categories of Lees Ferry natural flow conditions based on the preceding 3-year average Lees Ferry natural flow, as shown in **Figure TA 15-**

14 and **Figure TA 15-15** in **TA 15**, Dams and Electrical Power Resources. The boxplots illustrate firm capacity over a 3-year period for each flow category, allowing comparison of alternative performance across a range of hydrologic conditions.

For Glen Canyon Dam, the firm capacity would be highest in the Average Flow Category (12.0–14.0 maf) under the Enhanced Coordination Alternative, followed by the CCS Comparative Baseline, and would be lowest under the No Action Alternative. Under the other action alternatives, in the Average Flow Category there would be a similar capacity of between 675 and 725 MW. In the Critically Dry Flow Category (4.46–10.0 maf), the No Action Alternative, Basic Coordination Alternative, Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), and CCS Comparative Baseline would show a wide range of interquartile values, with all having the potential for capacity to drop to 0 MW. In the Critically Dry Flow Category, the capacity for every alternative and the CCS Comparative Baseline would be below 725 MW.

For Hoover Dam, in the Average Flow Category (12.0–14.0 maf), the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), Enhanced Coordination Alternative, and Maximum Operational Flexibility Alternative would yield the highest capacity, each exceeding 1,250 MW. The CCS Comparative Baseline, No Action Alternative, and Basic Coordination Alternative all would have wide interquartile ranges. The No Action Alternative would result in a lower capacity in the Average Flow Category. In the Dry Flow Category (10.0–12.0 maf), the Supply Driven Alternative (LB Pro Rata approach) would provide the highest capacity and the smallest interquartile range. All other action alternatives would have wide interquartile ranges and varying capacity in the Dry Flow Category. The No Action Alternative and the CCS Comparative Baseline would have lower capacity in the Dry Flow Category. In the Critically Dry Flow Category (4.46–10.0 maf), the Supply Driven Alternative (LB Pro Rata approach) would have the highest capacity but, like the other action alternatives, would have a wide interquartile range under the Critically Dry Flow Category. Under the Critically Dry Flow Category, the Supply Driven Alternative (LB Priority approach) and Basic Coordination Alternative would have the potential to drop to 0 MW. The CCS Comparative Baseline and the No Action Alternative would produce the lowest capacity in the Critically Dry Flow Category, and they both would have the potential to drop to 0 MW.

Issue 3: How would the alternatives impact the energy generation of the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam powerplants?

Energy generation is the amount of energy created over a certain period, measured in MWh. Energy generation is dependent on reservoir head and water release volume. The model inputs used to develop the boxplot figures in this analysis simulated releases and lake reservoir elevations to calculate estimated energy generation for the Glen Canyon Dam, Hoover Dam, Davis Dam, and Parker Dam powerplants. The boxplots summarize results by five flow categories based on the preceding 3-year average Lees Ferry natural flow. Please refer to **Figure TA 15-17**, **Figure TA 15-18**, **Figure TA 15-19**, and **Figure TA 15-20** in **TA 15**, Dams and Electrical Power Resources.

At Glan Canyon Dam powerplant, under the Average Flow Category (12.0–14.0 maf; refer to **Figure TA 15-17** in **TA 15**, Dams and Electrical Power Resources), the Maximum Operational Flexibility and Enhanced Coordination Alternatives performed slightly above the historical average energy generation value. The median energy generation for the other alternatives remain near the historical average energy generation of approximately 3.4 million MWhs. In the Critically Dry Flow Category (4.46–10.0

maf), the Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives would have the highest median power generation (approximately 2 million MWhs) and the smallest interquartile ranges. The Basic Coordination and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), along with the CCS Comparative Baseline, would have larger interquartile ranges and lower levels of power generation.

For the Hoover Dam powerplant (as shown in **Figure TA 15-18** in **TA 15**, Dams and Electrical Power Resources), in the Average Flow Category, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) experience the highest median value that is comparable to the historic median value of 3.3 million MWhs. Most alternatives have interquartile ranges that fall within the historic median value. The No Action Alternative would have the greatest interquartile range and the lowest level of power generation of approximately 2 million MWhs. In the Critically Dry Flow Category, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in the highest median generation, followed by the Maximum Operational Flexibility, Representative Preferred, Enhanced Coordination, and the Basic Coordination Alternatives. In the Critically Dry Flow Category, the No Action Alternative would produce the least amount of power and, like the CCS Comparative Baseline and the Basic Coordination Alternative, have interquartile ranges that have potential to drop to 0.0 million MWh.

For the Davis Dam powerplant (as shown in **Figure TA 15-19** in **TA 15**, Dams and Electrical Power Resources), in the Average Flow Category, the No Action Alternative, and the CCS Comparative Baseline would result in the highest median generation, comparable to the historic median value of 1.1 million MWhs. The Enhanced Coordination Alternative experienced the lowest median value of approximately 0.95 million MWhs. In the Critically Dry Flow Category, the CCS Comparative Baseline, Basic Coordination Alternative, and Supply Driven Alternative (LB Priority approach) result in the highest median generation values. The alternatives with the lowest median generation value are Enhanced Coordination and Maximum Operational Flexibility. The No Action Alternative and CCS Comparative Baseline show the widest interquartile ranges, reflecting greater variability in annual energy generation under these flow conditions. Approximately 25 percent of the values fall at or below 0.75 million MWh.

For the Parker Dam powerplant (as shown in **Figure TA 15-20** in **TA 15**, Dams and Electrical Power Resources), in the Average Flow Category, the CCS Comparative Baseline, No Action, and Basic Coordination Alternatives performed comparability to the historical median generation value of 0.42 million MWhs. Enhanced Coordination Alternative and Supply Driven Alternative (LB Pro Rata approach) would have lowest median generation of approximately 0.37 and 0.38 million MWhs and wider interquartile ranges. In the Critically Dry Flow Category, the Basic Coordination Alternative and Supply Driven Alternative (LB Priority approach) would result in the highest median values of energy generation with the narrowest interquartile ranges. The Enhanced Coordination Alternative would experience the lowest median value for energy generation at approximately 0.32 million MWhs, followed by the Supply Driven Alternative (LB Pro Rata approach) at approximately 0.36 million MWhs.

Issue 4: How would the alternatives impact spillway use?

Spillway infrastructure is affected by the frequency of high reservoir elevations, which vary greatly between the alternatives. High reservoir elevations for extended durations pose a risk to spillway infrastructure. This analysis compares the various action alternatives with the No Action Alternative and the CCS Comparative Baseline for the following metrics:

- Lake Powell pool elevations
- Lake Mead pool elevations

Keeping the reservoir below the spillway crest minimizes the infrastructure wear and tear and, preserves water supply and flood storage. Maintaining lower reservoir levels allows inflow to be routed through controlled outlets and respond to spring runoff. Maintaining Lake Powell elevation below 3,684 feet, the Representative Preferred Alternative is the most robust, meeting the preferred minimum in 86 percent of futures under the full modeling period. For the 2027-2039 model, the CCS Comparative Baseline is the highest performing alternative, meeting the preferred minimum in 91 percent of futures. The Enhanced Coordination, Maximum Operation Flexibility, and No Action Alternatives for the full modeling period and 2027-2039 model performed on average lower than any of the other alternatives (see **Figure TA 15-21** in **TA 15**, Dams and Electrical Power Resources). Maintaining Lake Powell elevation below 3,700 feet, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would be the most robust at meeting the preferred minimum in 66 percent of futures in the full modeling period. For the 2027-2039 model, the CCS Comparative Baseline and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) meet the preferred minimum in 82 percent of futures. The Enhanced Coordination and Maximum Operation Flexibility Alternatives for the full modeling period and 2027-2039 model performed on average lower than any of the other alternatives (see **Figure TA 15-23** in **TA 15**, Dams and Electrical Power Resources). Spillway release avoidance at Glen Canyon Dam for the full modeling period meets the preferred minimum in 78 percent of futures under the Representative Preferred and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives. For the 2027-2039 modeling period, the CCS Comparative Baseline meets the preferred minimum in 90 percent of futures, with Representative Preferred and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives following in 89 percent of futures (see **Figure TA 15-25** in **TA 15**, Dams and Electrical Power Resources).

For Hoover Dam/Lake Mead, maintaining elevation at 1,205.4 feet for spillway crest avoidance, the No Action Alternative and CCS Comparative Baseline, would be the most robust in meeting the preferred minimum under the full modeling period in 85 and 84 percent of futures, respectively. The worst performing alternative in the full modeling period was the Supply Driven Alternative (LB Pro Rata approach) at 43 percent of futures. For the 2027-2039 period, the No Action Alternative and CCS Comparative Baseline met the preferred minimum in 93 percent of futures. The lowest performing was the Supply Driven Alternative (LB Pro Rata approach) at 68 percent of futures (see **Figure TA 15-27** in **TA 15**, Dams and Electrical Power Resources). For Hoover Dam/Lake Mead to not exceed 1,219 feet in the full modeling period, the CCS Comparative Baseline and No Action and Basic Coordination Alternatives meet the preferred minimum in 99 percent of futures, followed by the Enhanced Coordination Alternative in 91 percent of futures. The least robust alternative for the full modeling period was the Supply Driven Alternative (LB Pro Rata approach) at 79 percent. In the 2027-2039 modeling period, the CCS Comparative Baseline, No Action, Basic Coordination, Enhanced Coordination, and Maximum Operational Flexibility Alternatives meet the preferred minimum in 93 percent or more of futures. The Supply Driven Alternative (LB Pro Rata approach) was the least robust at 84 percent of futures (see **Figure TA 15-29** in **TA 15**, Dams and Electrical Power Resources). For Hoover Dam/Lake Mead to not exceed 1,226.9 feet in the full modeling period, the CCS Comparative Baseline and No Action Alternative meet the preferred minimum in 92 percent of futures and followed by Basic Coordination in 91 percent of futures. The least robust alternative for the full modeling period was the Supply Driven Alternative (LB Pro Rata approach) at 70 percent. In the 2027-2039 modeling period, the CCS Comparative Baseline and No Action Alternative meet the preferred minimum in 98 percent or more of futures. The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) was the least robust in 89 and 88 percent of futures (see **Figure TA 15-31** in **TA 15**, Dams and Electrical Power Resources).

Issue 5: How would changes in energy generation impact electricity rates and the market value of electricity?

Glen Canyon Dam

Argonne National Laboratories and WAPA's report, "Post-2026 Environmental Impact Statement Rate Analysis for the Colorado River Storage Project" (Yu et al. 2025), assessed the relative impacts of various Glen Canyon Dam hydrological scenarios on the CRSP's Firm Electric Service rates. This analysis utilized an advanced simulation tool to estimate future generation production along with a stepwise rate adjustment framework. This framework is consistent with CRSP's obligation to remain financially self-sustaining and deliver cost-based power services (DOE, 2025) and was used to evaluate the rate implications of simulated Glen Canyon Dam-only generation outcomes. It is important to note that CRSP's FES rates encompass hydropower generation resources beyond Glen Canyon Dam; therefore, the identified rate impacts are theoretical, representing uncertainty associated with future Glen Canyon Dam hydrological conditions. The report found that the Enhanced Coordination and Maximum Operational Flexibility Alternatives consistently yielded more favorable hydropower generation outcomes, associated with higher electricity production. These alternatives also indicated fewer rate adjustments, smaller average increases per adjustment, and substantially lower maximum rate increases when an increase was identified. Specifically, under wet or average hydrologic conditions, these alternatives led to results similar to or slightly better than other alternatives. Under dry hydrologic conditions, they resulted in substantially smaller rate increases and less frequent rate adjustments. Overall, the Enhanced Coordination and Maximum Operational Flexibility Alternatives are identified as entailing less adverse economic impact on U.S. electricity consumers and providing greater protection against extreme adverse outcomes compared to the other five alternatives. The modeling framework and key methodological choices supporting these findings, as documented in Yu et al. (2025), included comprehensive data on CRSP's plant characteristics, hydrological conditions, Argus forward prices, and CRSP's power purchase and sales transactions. Another important point to note is that the rate adjustment framework used in the study is a simplified version of actual rate-changing processes, as it is based solely on assumed revenue requirements and simulated electricity production. Consequently, it provides a directional analysis for comparing policy scenarios rather than forecasting actual consumer rates, requiring careful contextualization to avoid misinterpretation. Extreme hydrological conditions, potentially leading to very low or even zero simulated electricity production, can result in a non-trivial subset of degenerate results, projecting unrealistic rate increases or decreases. These extreme events, particularly zero electricity production from Glen Canyon Dam, are unprecedented and fall outside the scope of the current analysis framework, as they cannot be resolved through standard rate adjustments.

For the Glen Canyon Dam powerplant, changes in energy generation across the modeled flow categories directly influenced the market value of hydropower production. Under the Wet Flow

Category, the Representative Preferred Alternative achieves the highest median annual generation value (approximately $350 million), while the CCS Comparative Baseline and No Action Alternative have the lowest (approximately $260 million). Under the Average Flow Category, all alternatives perform similarly, although the Maximum Operational Flexibility Alternative produces the highest median value (approximately $230 million). Under Critically Dry Flow Conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives perform best, maintaining the highest median values (approximately $125 million) and lowest variability, whereas the remaining alternatives exhibit greater variability and include outcomes with a 25 percent probability of annual generation values declining to $0 (see **Figure TA 15-34** in **TA 15,** Dams and Electrical Power Resources).

Hoover Dam

Hoover Dam provides federally marketed hydropower to Arizona, California, and Nevada through the Boulder Canyon Project, managed by WAPA. Funding for the project's operation, maintenance, and capital costs is entirely self-supported by these hydropower sales to contracted entities, requiring no taxpayer funding. Historically, cost-based rates kept Hoover power lower than regional wholesale market alternatives. Under this framework, customers pay a fixed annual base charge to cover these costs, allocated by contract share rather than actual generation. However, as declining water levels reduce generation output, the unit cost of the remaining power rises. This creates a financial swing: when generation drops sufficiently, Hoover's unit cost surpasses market rates, making the power uneconomical and potentially forcing contracted entities to abandon their long-term contracts.

Figure TA 15-35, in **TA 15,** Dams and Electrical Power Resources, shows the market value of hydropower at Hoover Dam. The analysis uses a dollar-per-MWh rate from the Lower Basin Dams Office (WY 2027 data), applied to modeled energy generation from CRSS. Market projections are based on the Preceding 3-Year Average Lees Ferry Natural Flow. Values depend on reservoir elevation with value increasing at elevations above 1,035 feet and lower below it. Under Average Flow conditions, most alternatives have median market values around $200 million. The Enhanced Coordination, Maximum Operational Flexibility, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives maintain higher medians with moderate variability. In contrast, the No Action and Basic Coordination Alternatives show lower medians and greater variability. Critically Dry conditions produce the lowest annual values. The Maximum Operational Flexibility, Basic Coordination, Representative Preferred, and Supply Driven (LB Pro Rata approach) Alternatives show the highest medians ($75–$150 million) and least variability, although the Basic Coordination Alternative has a wider spread. Other alternatives and the CCS Comparative Baseline show larger variability, with lower-end values dropping to $0.

Davis and Parker Dam

The Parker Davis Project is a federally operated system combining the Parker and Davis Dam hydroelectric facilities and transmission infrastructure on the Colorado River. Reclamation operates and maintains the dams and powerplants, while the WAPA markets and transmits the generated electricity to customers under long term contracts.

WAPA sets rates using a cost-recovery framework designed to recover annual project costs including operations, maintenance, replacements, and federal investment repayment. WAPA currently markets the project as a firm, fixed monthly delivery obligation, purchasing supplemental wholesale power to meet this commitment. Declining generation has increased the need for supplemental power, driving significant rate increases due to market price volatility. Starting in October 2028, a new marketing plan will align APA's delivery obligations with hydropower availability. This change will potentially create a financial swing. If generation drops sufficiently, Parker-Davis Project rates could surpass market rates, making the power uneconomical and potentially forcing contracted entities to abandon their long-term contracts.

WAPA sets rates using a cost-recovery framework designed to recover annual project costs including operations, maintenance, replacements, and federal investment repayment. WAPA currently markets the project as a firm, fixed monthly delivery obligation, purchasing supplemental wholesale power to meet this commitment. Declining generation has increased the need for supplemental power, driving significant rate increases due to market price volatility. Starting in October 2028, a new marketing plan will align WAPA's delivery obligations with hydropower availability. This change will potentially create a financial swing. If generation drops sufficiently, Parker-Davis Project rates could surpass market rates, making the power uneconomical and potentially forcing contracted entities to abandon their long-term contracts.

Figure TA 15-36 in **TA 15**, Dams and Electrical Power Resources, shows the annual market value of hydropower at Davis Dam based on CRSS modeling of generation and an assumed dollar-per-MWhs rate to determine the financial value (in millions of dollars). The results are grouped by preceding 3-year average Lees Ferry natural flow to show how fiscal value is influenced by hydrology for each alternative. Differences in fiscal value are driven by differences in releases across the alternatives (see **Figure TA 3-26** for calendar year releases from Davis Dam). Under the Average Flow Category, the No Action Alternative and CCS Comparative Baseline show similarly high median market values of approximately $47 million and $46 million dollars annually, respectively. The Supply Driven (both LB Priority and LB Pro Rata approaches) and Enhanced Coordination Alternatives have the lowest median value at approximately $42 million. Under the Critically Dry Flow Category, the Maximum Operational Flexibility, Representative Preferred, and Enhanced Coordination Alternatives had the lowest median market values (approximately $35 million), while the Basic Coordination Alternative had the highest median market value at approximately $40 million.

Summary Comparison of Alternatives

No Action

For Glen Canyon Dam and Lake Powell, the No Action Alternative is among the least robust alternatives, with a relatively high likelihood of dropping below minimum power pool and experiencing losses in firm capacity and energy generation under dry conditions. Market values are generally lower and more variable across flow conditions.

For Hoover Dam and Lake Mead, the No Action Alternative is the least robust alternative for maintaining elevations above minimum power pool and for preserving high-head turbine operations. However, it performs favorably for avoiding high Lake Mead elevations and spillway-related risks.

At Davis and Parker Dams, the No Action Alternative generally performs well for energy generation and market value under moderately wet to dry conditions but experiences increased variability and reduced performance under critically dry conditions.

Basic Coordination

For Glen Canyon Dam, the Basic Coordination Alternative provides moderate performance for maintaining minimum power pool but remains more vulnerable to dry hydrologic conditions than the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Firm capacity, energy generation, and market value are generally moderate but become increasingly variable under dry conditions.

For Hoover Dam, the Basic Coordination Alternative performs moderately well in maintaining elevations above minimum power pool protection. Firm capacity, energy generation, and market value remain moderate under wet and average flow conditions but become increasingly variable under dry and critically dry conditions, resulting in less consistent performance.

For Davis and Parker Dams, energy generation and market value remain generally consistent across most flow categories, with performance comparable to many of the other action alternatives. Because reservoir elevations at Lake Mohave and Lake Havasu remain relatively stable, differences among alternatives are modest, although generation and market value decline and become more variable under dry and critically dry conditions. In addition, the Basic Coordination Alternative performs favorably in limiting high reservoir elevations and spillway-related risks at both Lake Powell and Lake Mead, providing a balanced approach between hydropower performance and reservoir management objectives.

Enhanced Coordination

For Glen Canyon Dam, the Enhanced Coordination Alternative is one of the strongest-performing alternatives, maintaining minimum power pool in a high percentage of futures and consistently supporting relatively high firm capacity, energy generation, and market value across all flow categories. It is one of the few alternatives that avoids 0 firm capacity outcomes under critically dry conditions.

For Hoover Dam, Enhanced Coordination provides high robustness for maintaining elevations above minimum power pool and supports relatively stable generation and market value. Although total generation is sometimes lower than the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) under wet conditions, performance remains strong under dry and critically dry conditions.

For Davis and Parker Dams, energy generation and market value are generally comparable to other alternatives under wetter conditions, although performance may be somewhat lower than other alternatives under the driest flow categories. Overall, the Enhanced Coordination Alternative provides a strong balance of hydrologic robustness, generation performance, and market value while minimizing vulnerability to dry conditions.

Maximum Operational Flexibility

For Glen Canyon Dam, the Maximum Operational Flexibility Alternative provides the highest robustness for maintaining minimum power pool and consistently avoids 0 firm capacity conditions. It produces among the highest energy generation and market values under dry and critically dry conditions while maintaining low variability.

For Hoover Dam, this alternative provides some of the highest robustness for maintaining minimum power pool, strong firm capacity, and relatively stable energy generation and market values across hydrologic conditions. While not always producing the highest generation during wet conditions, it consistently performs well as hydrologic conditions become drier.

For Davis and Parker Dams, energy generation and market values are generally moderate relative to other alternatives. Overall, Maximum Operational Flexibility is among the best-performing alternatives for reliability, generation stability, and market value across the system, particularly under adverse hydrologic conditions.

Supply Driven (both LB Priority and LB Pro Rata approaches) Alternative

For Glen Canyon Dam, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) generally provides high firm capacity and energy generation under wet and moderately wet conditions but are more vulnerable to low reservoir elevations than the Enhanced Coordination and Maximum Operational Flexibility Alternatives. Market values are high under favorable hydrology but become more variable as conditions dry.

For Hoover Dam, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) provides some of the highest firm capacity, energy generation, and market value outcomes across most flow categories. The Supply Driven Alternative (LB Pro Rata approach) performs particularly well at maintaining Lake Mead elevations above minimum power pool, although both approaches become more variable under dry conditions.

For Davis and Parker Dams, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) generally produces the highest energy generation and market values under wet conditions. Under drier conditions, performance becomes more comparable to other alternatives, with the Supply Driven Alternative (LB Pro Rata approach) sometimes produces among the lower generation outcomes. Spillway-related performance is strongest at Lake Powell but weakest at Lake Mead, where the alternatives result in more time at high reservoir elevations.

Overall, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) maximizes generation and market value, particularly at Hoover Dam, but involve tradeoffs related to reservoir elevation robustness and performance under increasingly dry conditions.

Representative Preferred Alternative

For Glen Canyon Dam, the Representative Preferred Alternative performs particularly well under wet conditions, producing the highest market values and strong firm capacity. Under dry and critically dry conditions, it continues to provide relatively high energy generation and market values, although performance is generally slightly below the Enhanced Coordination and Maximum Operational Flexibility Alternatives.

For Hoover Dam, the Representative Preferred Alternative provides strong minimum power pool performance, relatively stable generation, and competitive market values across most flow categories. While it does not consistently achieve the highest firm capacity or energy generation, it generally performs in the upper tier of alternatives.

For Davis and Parker Dams, performance is generally comparable to other action alternatives, with moderate-to-high energy generation and market values across hydrologic conditions. From a spillway and reservoir-elevation perspective, it performs among the stronger alternatives at Lake Powell and in the middle range at Lake Mead.

Overall, the Representative Preferred Alternative provides a balanced combination of reservoir protection, power generation, market value, and infrastructure performance. This alternative performs well across all major measures and avoids many of the tradeoffs associated with alternatives focused on a single objective.

3.16 Socioeconomics

3.16.1 Affected Environment

This section briefly discusses key current conditions of economic indicators—such as employment, labor income, and unemployment rates—as well as social and nonmarket values. For additional details on these current conditions, refer to **Section TA 16.1**, Affected Environment, in **TA 16**, Socioeconomics. For overall demographic information, such as population and race and ethnicity data, refer to **Section TA 16.1.4**, Demographics, and **Section TA 17.1**, Affected Environment, in **TA 17**, Population and Land Use. For information on tribal populations and interests, refer to **TA 13**, Tribal Resources**.**

The socioeconomic analysis area includes counties in Arizona, California, Nevada, and Utah (see **Map TA 16-1**). The Arizona analysis area consists of Apache, Coconino, Gila, Graham, La Paz, Maricopa, Mohave, Navajo, Pima, Pinal, Yavapai, and Yuma Counties. The California analysis area consists of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and San Diego Counties. The Nevada analysis area consists solely of Clark County. The Utah analysis area consists of Garfield, Kane, and San Juan Counties. These analysis areas include the following:

- Counties that are directly adjacent to Lake Powell, Lake Mead, or the mainstream Colorado River
- Counties that receive water from the Colorado River and in which impacts from Colorado River shortages would likely occur
- Counties that have ties to recreation-related economic activity on the Colorado River
- Counties where tribal reservations affected by Colorado River shortages are located
- Counties where tribal reservations that have ties to tribal water rights settlements involving CAP water and non-CAP Colorado River water delivered through the CAP are located.

The analysis of impacts on economic and social conditions due to changes in agricultural production includes Arizona, California, and Nevada. The analysis of economic impacts from changes in recreation use includes Arizona, California, Nevada, and Utah. The impact analysis on ecosystem services and nonmarket values includes Arizona, California, Nevada, and Utah.

Baseline Economic Conditions

The following section provides an overview of county-level data for baseline economic conditions, including data on employment, labor income, unemployment rates, poverty, and the market value of agricultural production in the analysis areas. The county-level data do not distinguish between the water sources that were used in support of the economic conditions presented, which may include a combination of the mainstream Colorado River, CAP, and other water sources.

Arizona

In 2022, total employment in the analysis area counties (about 4.2 million jobs) represented approximately 98.1 percent of total employment in Arizona. Farm employment in the 12 counties totaled almost 26,000 jobs in 2022 (about 0.6 percent of total analysis area employment). While total employment in the analysis area increased from 2010 employment levels by about 36 percent, farm employment decreased during the same time period by about 2 percent (see **Table TA 16-1** and **Table TA 16-2**). Employment in the arts, entertainment, and recreation sector totaled approximately 84,000 jobs (or 2.0 percent of the total employment in the analysis area) in 2022, which was an increase of about 27 percent from the number of jobs in 2010.

In 2022, the total market value of agricultural products sold in the Arizona analysis area contributed $4.8 billion to Arizona's economy, which was about 91 percent of the market value of agricultural products sold in the state. Across Maricopa, Pima, and Pinal Counties, the market value of crops sold in 2022 ranged from about $87.1 million in Pima County to about $742.6 million in Maricopa County (USDA 2024; see **Table TA 16-5**). In 2022, the Maricopa, Pima, and Pinal Counties accounted for approximately 55 percent of Arizona's harvested acres of hay and haylage crops, 65 percent of the state's harvested acreage of cotton, and 44 percent of the harvested wheat acreage. The three western Arizona counties that are located along the Colorado River—Mohave, La Paz, and Yuma Counties—accounted for approximately 33 percent of the statewide harvested hay and haylage acreage, 78 percent of the harvested acres of vegetable crops, and 53 percent of the harvested wheat acres in 2022. Yuma County alone accounted for 77 percent of the state's total harvested acres of vegetable crops (USDA 2024). Additional information on irrigated agricultural acreage within the analysis area is provided in **TA 17**, Population and Land Use.

California

In 2022, total employment in the analysis area counties (about 13.9 million jobs) represented approximately 55 percent of total employment in California. Farm employment in the six counties totaled almost 31,000 jobs in 2022 (about 0.2 percent of the total analysis area employment). Farm employment made up a larger percentage of total employment in Imperial County than the rest of the counties in the analysis area, with 4.7 percent of total employment coming from the farm sector in Imperial County (BEA 2024). While total employment in the analysis area increased from 2010 employment levels by about 30 percent, farm employment decreased by about 9 percent during the same time period (see **Table TA 16-7** and **Table TA 16-8**).

In 2022, the total market value of agricultural products sold in the California analysis area contributed $6.1 billion to California's economy. The market value of crops sold in the analysis area was about $4.7 billion, ranging from about $69.5 million in Orange County to about $2.2 billion in Imperial County (USDA 2024; see **Table TA 16-11**). In 2022, the California analysis area counties accounted for approximately 30 percent of California's harvested acres of hay and haylage crops, 16 percent of the state's harvested acreage of vegetables, and 35 percent of the harvested wheat acreage (USDA 2024).

Nevada

In 2022, total employment in Clark County (about 1.5 million jobs) represented approximately 74 percent of the total employment in Nevada. In 2022, employment in the arts, entertainment, and recreation sector totaled almost 47,000 jobs, or 3.1 percent of the total employment in the county. Farm employment represented less than 0.1 percent of total employment, with a little more than 400 jobs (see **Table TA 16-13**).

Approximately 8.4 percent of Nevada's land area in 2022 was used for agricultural purposes (on cropland, pastureland, woodland, or other; USDA 2024). In 2022, the market value of agricultural products sold in Nevada contributed nearly $1 billion to the statewide economy.

Utah

In 2022, total employment in the analysis area counties (about 17,000) represented approximately 1.0 percent of the total employment in Utah. In 2022, employment in the arts, entertainment, and recreation sector totaled approximately 400 jobs (or 2.4 percent of the total employment in the analysis area) and represented 6.0 percent of employment in Kane County (see **Table TA 16-16**).

Economic Contributions from Recreational Use

Total economic output for lake-based recreation in the analysis area was $358 million from Lake Mead NRA and $670 million from Glen Canyon NRA, and the total economic output for river-based recreation was $1,022 million in Grand Canyon National Park (GCNP; see **Table TA 16-19** and **Table TA 16-20**).[17] These amounts reflect total economic output from visitor spending made by local and nonlocal visitors. Spending by nonlocal visitors represents an influx of dollars from outside the local economy. In addition, nonlocal visitors typically have higher levels of spending on food, lodging, and other activities on a per-trip basis. Over 88 percent of recreation spending in Glen Canyon NRA, Lake Mead NRA, and GCNP came from nonlocal visitors (Flyr and Koontz 2024). In 2023, Glen Canyon NRA recreation spending supported 6,300 jobs, Lake Mead NRA recreation supported 3,131 jobs, and GCNP recreation supported 10,064 jobs (Flyr and Koontz 2024; see **Table TA 16-21** and **Table TA 16-22**).

In addition to general recreation sector contributions, visitor use supports concessionaires, including those associated with water-based recreation, such as commercial river trips. In GCNP, commercial river trips hosted about 17,000 passengers in 2023 (a slight decrease from about 20,000 passengers in 2022 and 21,000 passengers in 2021). From these river trips, river concessionaires contributed $63.6 million in 2023 in gross revenue (a decrease from $66.4 million in 2021, in 2023 dollars), representing 29 percent of the total concessionaire revenue at GCNP. River concessionaire franchise fees paid to the NPS in 2023 totaled $6.25 million, of which 80 percent stays at GCNP.[18]

NWRs also support economic contributions through expenditures from recreational visitors, such as entrance fees, lodging near the refuges, and purchases from local businesses for items to pursue their

[17] Economic output for recreation is the total estimated value of the production of goods and services supported by visitors' spending, including the direct, indirect, and induced impacts. Direct impacts occur when businesses sell goods and services to area visitors. Indirect impacts are economic activity supported when businesses purchase supplies and services from other local businesses. Induced impacts occur when employees use their income to purchase goods and services in the local economy.

[18] Laurie Dyer, NPS supervisory concessions management specialist in the Commercial Services Division at GCNP, personal communication provided on September 27, 2024.

recreational experience. In 2017, the Imperial NWR supported about $11.1 million in total economic output (see **Table TA 16-23**).

For additional information on recreation and levels of use in the analysis area, refer to **TA 14**, Recreation.

Social and Nonmarket Values

Nonmarket values refer to resource benefits that are not captured in market transactions or traditional economic measures. Along the Colorado River, these values include the enjoyment of natural scenery, opportunities for recreation and solitude, preservation of landscapes, and the symbolic and ecological importance of the river itself. Such values are important for understanding how river operations affect people's experiences, sense of place, and well-being, even when no direct economic exchange is involved. Place-based communities—such as gateway communities—and non-place-based communities—such as individuals who may never visit but who value the river—derive nonmarket values from the Colorado River, including cultural identity, recreation quality, aesthetics, and existence values. These values often differ by type of community as well as an individual's beliefs. Understanding these values provides important context for assessing potential changes in access and the quality of nonmarket and social values under the post-2026 operational alternatives. For additional details on these social and nonmarket values, refer to **Section TA 16.1**, Affected Environment.

3.16.2 Environmental Consequences

Methodology

Agriculture

Below is a brief summary of the methodology used to analyze economic conditions from changes in agricultural production as a result of a reduction of irrigation water. For additional details on the methodology, refer to **Section TA 16.2.1**, Methodology.

Based on the SAMs and ADMs (see **Appendix C**, Shortage Allocation Model and the Alternative Distribution Model Documentation), Reclamation modeled the change in agricultural revenue from fallowed crops for each priority group by county and state in the impact analysis area due to water shortages at a variety of shortage levels across each alternative and the comparative baseline.

Forgone agricultural revenue from fallowed crops was estimated by multiplying the county-level revenue per acre by the number of acres reduced (or fallowed) for each crop. The county-level revenue was calculated based on the most recent available data on yields and prices. The number of acres reduced for each crop was modeled using an assumed fallowing order based on the crops' profitability and water use, the level of shortages and available water for each priority group by county and state, and the most recent available data on acres harvested. For data that were not available for specific crops grown in the county, estimated data were used based on statewide averages, data from nearby counties, or averages from nearby states or regions for the same or similar crops.

Irrigated crops in the analysis area that were analyzed include field crops, vegetables, and fruit and nut trees and vines, separated out into eight agricultural crop group types that would be affected by the Colorado River shortages and that made up at least approximately 1 percent of a county's harvested acres. The eight crop groups were alfalfa, cotton, crucifer vegetables, field grains, fruit and tree nuts and vines, other hay and haylage, small grains, and small vegetables.

Impacts on economic conditions, such as jobs and income, from changes in agricultural production were analyzed using the IMPLAN input-output economic model. IMPLAN is a regional economic model that estimates how a change in one sector affects jobs, income, and spending in other parts of the economy. For example, the IMPLAN model provides annual average estimates of how a direct change in economic spending (such as through reduced agricultural revenues) would ripple through the broader economy and other industries. Prior to running the model, cost data were converted to a consistent dollar year (2025). Unless stated otherwise, monetary values are reported in the year 2025 dollars.

Recreation

This analysis evaluates how changes in reservoir elevations and river flows may affect recreational use and related economic contributions. The approach integrates visitor use data, spending information, and economic modeling tools to characterize potential changes in both the recreational experience and the regional economy.

For lake-based recreation, the analysis uses visitor statistics from the NPS and Reclamation to estimate changes in visitation levels under different hydrologic conditions. Visitor days are categorized by visitor type, including local and nonlocal trips. Each visit type is linked to an established spending profile that reflects patterns in lodging, food, transportation, recreational services, and other trip-related expenditures. Total spending estimates are then used in IMPLAN to assess potential changes in jobs, labor income, value added, and overall economic output resulting from changes in recreational use.

For river-based recreation, the analysis also evaluates net economic value, which is the value of the benefits that recreationists receive beyond what they spend directly on a trip. Consistent with the approach used in the 2024 LTEMP Final SEIS, past survey research, including that by Gaston et al. (2015), informs models that relate the willingness to pay for boating and angling experiences to the river's flow conditions. These models estimate how changes in hydrologic patterns may affect the value of specific recreational experiences in Glen Canyon and Grand Canyon.

For the action alternatives, potential changes to recreation's contributions are discussed qualitatively, based on the DMDU modeling output and conclusions related to Lake Powell and Lake Mead access to recreation and river-based recreation, as determined by river flow levels and fluctuations, as discussed in **TA 14**, Recreation.

Together, these components provide a qualitative and quantitative framework for assessing how operational changes influence recreational access, the quality of the experience, and economic contributions. Additional methodological detail, including data sources, assumptions, and model parameters, is provided in **TA 16**, Socioeconomics.

Ecosystem Services and Nonmarket Values

The analysis of ecosystem services and nonmarket values uses a qualitative framework to evaluate how changes in Colorado River operations may affect benefits that are not reflected in market transactions but that contribute to community well-being, cultural identity, and the recreational experience. These include values such as scenic quality, sense of place, ecological integrity, and cultural connections to the river corridor. The analysis draws on scoping input, existing literature, and information from other resource sections to understand how various groups interact with and derive value from the Colorado River system. Additional details on information sources, assumptions, and community context are provided in **TA 16**, Socioeconomics.

Impact Analysis Area

Agriculture

The quantitative impact analysis was conducted for the following counties: La Paz, Maricopa, Mohave, Pima, Pinal, and Yuma Counties in Arizona; Imperial, Riverside, and San Bernardino Counties in California; and Clark County in Nevada. The impact analysis area for the qualitative discussions extends to the surrounding communities and tribal reservations.

Recreation

The analysis area is consistent with the general socioeconomic study area defined in **Section 3.1**, Introduction. This includes major recreation hubs, gateway communities, and rural areas where economies rely heavily on river- and reservoir-based recreation. Specifically, the recreation impact analysis area encompasses three primary NPS units: Lake Mead NRA, Glen Canyon NRA, and GCNP.

Ecosystem Services and Nonmarket Values

The analysis area for social and nonmarket values is the Colorado River corridor from Lake Powell to the SIB, consistent with the overall socioeconomic study area. The analysis focuses on communities within the river corridor, but it also includes communities outside of the area for whom the river holds symbolic, ecological, or recreational importance.

Assumptions

Modeling Representative Preferred Alternative Shortage Distributions

Under the Representative Preferred Alternative, two different approaches to distributing shortages are modeled, where (1) 2027-2028 modeling assumes shortage volumes up to 1.5 maf are distributed using the approach developed by the Lower Division States, and shortage volumes from 1.5 maf to 3.6 maf are distributed using the priority system, and (2) from 2029 through 2060, modeled shortage volumes are distributed using the priority system. Refer to **Section 2.4** for additional information. Some impacts are influenced by how the Representative Preferred Alternative distributes Lower Basin shortages in 2027-2028 vs. 2029-2060, and some impacts are either minimally sensitive or not sensitive to this distinction. Impacts discussion will include references to different time periods where relevant.

Agriculture

Below is a list of the key assumptions used in the analysis. For additional details on assumptions, refer to **Section TA 16.2.1**, Methodology.

- Farmers would fallow irrigated crops in response to water shortages rather than using other water sources or switching to more profitable or less water-intensive crops. The assumption that farmers would fallow rather than switch crops is based on the investments and institutional knowledge that have been made in plants, supply chains/relationships, and/or machinery that create barriers for changing crops. Reclamation understands that there could be farmers who are able to switch crops, rather than fallow; however, for the purpose of this analysis, this assumption provides a conservative estimate; if some farmers switch crops or water sources instead, impacts would likely be less severe than discussed below. Impacts on economic conditions due to the use of groundwater to replace the estimated water shortage are discussed qualitatively.

- As discussed above, the analysis assumes that the least profitable crop would be fallowed first, analyzed for each county separately, and crops were assumed to have constant profitability per acre of land and per acre-foot of water.
- Estimated shortages in the agricultural sector are based on the SAMs and ADMs (**Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation). Shortages to individual entitlement holders are measured in terms of consumptive use for a common basis of comparison with state apportionments and volumes of total shortage. Impacts on future opportunities to expand water use due to shortages for irrigation entitlement holders who currently use less than their entitlement are discussed qualitatively.
- In most cases, the contractor, subcontractor, or entitlement holder of an allocation is shown as the entity bearing shortage. In some cases, water allocated to an entitlement holder (for example, a tribal CAP contractor) may lease its allocation to other users (for example, to a non-Indian municipality). The SAMs and ADMs do not attempt to replicate those arrangements, and they only provide approximate estimates at the level of the entitlement holder, contractor, or subcontractor. The entitlement holder, contractor, or subcontractor involved in a leasing arrangement would make specific decisions during Shortage Conditions to administer those arrangements that Reclamation cannot predict with sufficient certainty to analyze in this EIS.

Recreation

- Lake-based recreational spending per visitor trip is based on the most recent NPS Visitor Spending Profiles.
- IMPLAN results represent regional impacts, including direct, indirect, and induced economic activity associated with lake-based recreation.
- Recreational spending per trip for anglers and whitewater rafting (adjusted for inflation) would follow results from willingness-to-pay surveys (Gaston et al. 2015) with variation based on river flows.

Ecosystem Services and Nonmarket Values

- Nonmarket values are not directly quantifiable through market-based indicators; however, they can be described qualitatively based on existing studies, stakeholder input, and related resource analyses.
- Changes in nonmarket values are assumed to be closely linked to conditions evaluated in other technical appendices, such as those for recreation, population and land use, cultural resources, and visual resources.
- Changing hydrology may influence how these values are perceived, particularly where access, scenic character, or ecological conditions are affected.

Impact Indicators

Agriculture

- Change in acres of fallowed cropland
- Change in production value or revenue associated with fallowed cropland
- Change in jobs and income associated with agriculture
- Change in nonmarket values and social conditions associated with changes in agriculture

Recreation

- Changes in direct recreational visitor spending across the affected NPS units and recreation sites
- Changes in regional employment, labor income, value added, and total economic output from lake-based recreation-related activities
- Impacts on the recreational value associated with river-based boating and angling
- Impacts on commercial outfitters, concessionaires, and permittees, especially in areas dependent on rafting, boating, and guided recreation

Ecosystem Services and Nonmarket Values

- Changes in the availability or quality of recreational opportunities not captured by direct spending
- Changes in the river's existence and symbolic values due to shifts in the scenic character or ecological conditions

Issue 1: How would the anticipated water shortages affect the economic contributions and social conditions from agriculture?

Under all alternatives and the CCS Comparative Baseline, anticipated shortages would result in increases in acres of fallowed cropland and agricultural production loss, and the modeled agricultural production loss would result in impacts on the associated jobs, income, and total economic output. Additionally, under the alternatives and the CCS Comparative Baseline, water shortages would likely lead to changes in the quality and access to nonmarket values and social conditions associated with changes in agriculture (Curtis et al. 2023). These values that could be affected by water shortages include the way of life of individuals throughout the surrounding communities, how individuals perceive their sense of place, food and other resources supported by the Colorado River, access to affordable health care, and access to cultural, traditional, and spiritual practices. The magnitude of impacts on economic, nonmarket, and social conditions varies by region, irrigation and tribal entitlement holder, priority group, and the alternatives and the CCS Comparative Baseline. The discussion below provides a summary of impacts on economic, nonmarket, and social conditions across the alternatives and the CCS Comparative Baseline by state and irrigation and tribal entitlement holder. For additional details and the figures with modeling results, including results separated by priority group, refer to **Section TA 16.2.2**, Environmental Consequences, Issue 1.

On average, for non-tribal agriculture entitlement holders in Arizona, the greatest impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Maximum Operational Flexibility Alternative (during a shortage of 4.0 maf), with an annual estimated reduction of about 1,000 jobs,

$56.5 million in labor income, and $237.7 million in total economic output. The lowest impacts on economic conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the No Action Alternative (during a shortage of 0.6 maf), for non-tribal agriculture entitlement holders in Arizona; under this alternative, there would be an annual estimated reduction of about 13 jobs, $0.6 million in labor income, and $2.8 million in total economic output. Under the Representative Preferred (2027-2028) Alternative, during a shortage of 1.5 maf, there would be a reduction of about 40 jobs, $2.0 million in labor income, and $8.9 million in total economic output[19]. Under the Representative Preferred (2029-2060) Alternative, during a maximum shortage of 3.6 maf, there would be a reduction of about 900 jobs, $50.5 million in labor income, and $210.7 million in total economic output.

For non-tribal agriculture entitlement holders in California, on average, the largest impacts on social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Enhanced Coordination Alternative (during a shortage of 3.0 maf). However, the biggest impacts on jobs, labor income, and economic output during a maximum shortage would occur under the Maximum Operational Flexibility Alternative, with an annual estimated reduction of about 11,000 jobs and $824.7 million in labor income, and $1.8 billion in economic output. For non-tribal agriculture entitlement holders in California, there would be no impacts on fallowed lands, the market value of crops, and economic conditions during a maximum shortage under the No Action Alternative (during a shortage of 0.6 maf) and the Basic Coordination Alternative (during a shortage of 1.5 maf). Under the Representative Preferred (2027-2028) Alternative, during a shortage of 1.5 maf, there would be a reduction of about 140 jobs, $8.5 million in labor income, and $36.9 million in total economic output. Under the Representative Preferred (2029-2060) Alternative, during a maximum shortage of 3.6 maf, there would be a reduction of about 9,000 jobs, $718.1 million in labor income, and $1.3 billion in total economic output.

For tribal agriculture entitlement holders in Arizona, during a maximum shortage, the highest level of impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops would occur under the Maximum Operational Flexibility Alternative (during a shortage of 4.0 maf), with an annual estimated reduction of about 1,000 jobs, about $64.7 million in labor income, and $222.6 million in total economic output. The lowest impacts on economic and social conditions during a maximum shortage would occur under the No Action Alternative (during a shortage of 0.6 maf), for tribal agriculture entitlement holders in Arizona, with an annual estimated reduction of about 140 jobs, $10.7 million in labor income, and $34.8 million in total economic output. Under the Representative Preferred (2027-2028) Alternative, during a shortage of 1.5 maf, there would be a reduction of about 400 jobs, $25.2 million in labor income, and $83.3 million in total economic output. Under the Representative Preferred (2029-2060) Alternative, during a maximum shortage of 3.6 maf, there would be a reduction of about 1,000 jobs, $64.0 million in labor income, and $220.0 million in total economic output.

For California and Nevada tribal entitlement holders, the only impacts on fallowed lands, the market value of crops, and economic conditions are expected to occur under the Enhanced Coordination

[19] While the Representative Preferred (2027-2028) Alternative models shortages above 1.5 maf in 2028, consistent with the sideboards, under the Preferred Alternative, Reclamation would consult with stakeholders if Lake Mead elevation is projected below 1,000 feet. (See **Chapter 2** for more details on the sideboards under the Preferred Alternative).

Alternative and Supply Driven Alternative (LB Pro Rata approach). The greatest impacts on economic and social conditions from increases in fallowed lands and reductions in the market value of crops, during a maximum shortage, would occur under the Enhanced Coordination Alternative (during a shortage of 3.0 maf), with an annual estimated reduction of about 63 jobs, $3.9 million in labor income, and $15.9 million in total economic output for tribal entitlement holders in California; for Nevada, there would be an estimated reduction of about 13 jobs, $0.1 million in labor income, and $0.9 million in total economic output for tribal entitlement holders. There are no expected impacts on fallowed lands, the market value of crops, and economic conditions under all other alternatives and the CCS Comparative Baseline for California and Nevada tribal entitlement holders, including under the Representative Preferred Alternative.

Long-term, severe shortages could further affect entitlement holders that have unused water entitlement above their current consumptive use. Irrigation entitlement holders who currently use less than their entitlement (measured in terms of diversion, consumptive use, or both) might not immediately experience impacts on economic contributions from water shortages; however, long-term, continued shortages would limit future opportunities to expand the irrigation entitlement holders' water use, which would result in impacts on economic contributions through reduced opportunities for future developments, expansion of crop production, or additional opportunities to lease water.

If farmers and agricultural producers decide to use irrigation water from other sources—such as other surface water or groundwater sources—instead of fallowing agricultural acreages, the impacts on the economic and social conditions, discussed above, are likely to be lessened in the short term. However, in the event of long-term shortages, if the sustained demand for groundwater results in a reduction in supply from the aquifers, there would likely be increased impacts on economic and social conditions. Additionally, the reliance on more pumped groundwater to offset delivery shortages can lead to substantial additional pumping costs, particularly for electricity, which can affect economic conditions. These impacts on economic and social conditions would affect tribal and non-tribal entitlement holders in Arizona, California, and Nevada, as well as farmers and tribes who rely solely on groundwater for irrigation and domestic needs.

Issue 2: How would operational changes affect economic contributions and the value associated with lake-based and river-based recreation?

Recreation along the Colorado River is a key part of several local economies, supporting thousands of jobs and generating revenue through visitor spending. Lake-based recreation at Glen Canyon NRA and Lake Mead NRA, combined with river-based activities in GCNP, currently contribute approximately 19,000 jobs and $2.1 billion in annual economic output (Flyr and Koontz 2024). These benefits extend beyond direct spending on lodging, food, and equipment and include indirect and induced impacts throughout gateway communities. Stable reservoir elevations and predictable river flows are essential for maintaining these contributions.

Operational changes under the proposed alternatives would influence these conditions in different ways. The alternatives that maintain higher and more consistent water levels would preserve boating access, marina operations, and shoreline recreational opportunities. This stability would support continued visitation and minimize disruptions to businesses dependent on tourism. Conversely, the alternatives that result in greater variability in lake elevations and river flows would affect recreational quality and access and related levels of contributions.

The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) poses the greatest risk to recreation-based economies relying on economic contributions from reservoir-based recreation in Lake Powell, while the CCS Comparative Baseline and the No Action Alternative have the least robust modeled performance for supporting recreational opportunities and spending associated with Lake Mead recreation. In contrast, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more consistent reservoir levels at Lake Powell to support recreation, and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would support the greatest level of contributions from recreation in Lake Mead.

However, under all alternatives, limited launch access and safe navigation routes at Lake Powell, along with navigation challenges in Lake Mead would continue to affect lake-based recreational opportunities and the associated spending. As a result, outfitters and concessionaires operating in these areas would face increased uncertainty, affecting employment and revenue streams under all alternatives. Research indicates that declines in lake elevation can reduce visitation by more than 25 percent, amplifying economic losses for local communities (Johnson et al. 2016). Lake Mead would experience similar constraints, with boating access severely limited during extended drought periods.

River-based recreation is also vulnerable to operational changes. Activities such as angling in Glen Canyon and whitewater rafting in Grand Canyon depend on stable flows to ensure safety and trip quality. Reduced flows shorten rafting seasons and diminish the overall experience, leading to lower recreational value and reduced demand for outfitter services and the associated hospitality sectors. The Basic Coordination Alternative would provide the most support for continued or increased economic value associated with boating and angling and the related economic contributions (see **Figure 16-13** and **Figure 16-14** in **Section TA 16.2.3**). The Enhanced Coordination Alternative would be the least robust at maintaining or exceeding the minimum desired daytime flows to support boating in Grand Canyon; it also would result in the greatest potential for a reduction in the recreational value for whitewater rafting and angling, as well as the regional economic contributions associated with these uses. Impacts would be most pronounced under dry conditions.

Economic impacts extend beyond direct visitor spending. Gateway communities, often small and rural, rely heavily on tourism-related income to sustain local businesses and municipal services. When lake levels drop or river flows decline, these communities experience cascading impacts, including reduced tax revenues and job losses in sectors such as lodging, food service, and transportation. The magnitude of these impacts would depend on the frequency and duration of low-elevation conditions, which would vary significantly across the alternatives.

Maintaining reservoir elevations and river flows within ranges that support recreation is critical for protecting the economic contributions and community well-being. For detailed analysis, including supporting data and tables, see the technical appendix sections for socioeconomics and recreation.

Issue 3: How would anticipated water shortages and changes in water levels in reservoirs and river segments affect access and the quality of nonmarket values?

Nonmarket values, such as scenic quality, opportunities for solitude, and cultural connections, are central to the Colorado River system and its surrounding landscapes. These values are not reflected in direct economic measures but are essential to visitor experiences and the cultural identity of tribes and gateway communities. Stable reservoir elevations and predictable river flows help maintain visual integrity, access to culturally significant sites, and the immersive qualities that define national parks and recreation areas (Flyr and Koontz 2024).

The alternatives that maintain relatively stable reservoir levels and minimize flow variability provide stronger protection for these intangible benefits. Under these scenarios, boating and rafting experiences retain their quality, the scenic character remains intact, and opportunities for solitude and reflection are disrupted less. These conditions also support traditional practices for tribes, which often depend on predictable water levels and access points for cultural and spiritual activities. There may be exceptions to this generalization; for example, alternatives which provide better support for river-based recreation and associated values may result in less preferable outcomes for reservoir-based recreation and vice-versa.

During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on nonmarket values, although this varies by resource. For example, nonmarket values such as scenic integrity, solitude, and cultural connections to the river corridor would be maintained at a level similar to current conditions. Similarly, ecological services, including riparian habitat and wildlife viewing opportunities, remain similar to current conditions and cultural landscapes would retain the factors which are associated with nonmarket values. Recreational experiences for boating, angling, and rafting, however, may be impacted under all alternatives in their quality and support for sense of place for gateway communities and visitor, as modeling indicates that periods of reservoir elevations below thresholds for recreation facility access and navigation would be more likely than that under historic conditions.

As conditions become drier, the No Action Alternative and CCS Comparative Baseline would result in the most modeled futures where impacts could occur to resources with nonmarket values. For example, nonmarket values for recreation and ecosystem services could be reduced in instances of prolonged drought, which could reduce shoreline aesthetics and diminish the opportunities for solitude at Lake Powell and Lake Mead over time. Extended low-flow periods could also impact river-based experiences in Grand Canyon due to changes in setting which could impact perceived naturalness. Cultural and spiritual values tied to iconic landscapes and cultural artifacts could also be affected in low-hydrologic flow periods. Ecological services such as riparian habitat stability may decline, influencing nonuse values related to wildlife and vegetation communities.

Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would be more robust in terms of the support for nonmarket values; particularly for values associated with Lake Powell. Reservoir levels which are maintained at thresholds that support access for boating and camping in more modeled futures, support experiential benefits and cultural connections (see **TA 11**, Cultural Resources). The quality of river-based recreation is expected to remain high, due to increased stability with flow-dependent activities (see **TA 14**, Recreation); however, a lower average flow may impact some values. However, the Maximum Operational Flexibility, Enhanced Coordination, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives include the largest potential shortages to minimize the number of future conditions where dead pool could be reached based on DMDU modeling as described in **TA 4**, Water Deliveries.

More frequent low-elevation conditions would be introduced in the Basic Coordination Alternative, which could noticeably affect the nonmarket values tied to lake-based recreation and scenic quality (see **TA 14**, Recreation) although at a reduced level compared with the No Action Alternative and the CCS Comparative Baseline. Reduced reservoir levels may expose previously submerged areas, altering visual character and diminishing the opportunities for solitude. River-based recreation could experience flow variability that affects trip quality and angling success (see **TA 3**, Hydrologic Resources); however, higher average flows may support some river-based values.

Outcomes produced by the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) vary depending on the hydrology and location. In wet years, the nonmarket values supported would remain similar to those under the CCS Comparative Baseline; however, in dry sequences, reduced reservoir elevations and altered flow regimes would diminish the scenic quality and access for boating and angling at Lake Powell (see **TA 14**, Recreation). At Lake Mead, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) is the most robust at maintaining reservoir levels that support nonmarket values. River-based recreation would experience moderate variability in trip quality, while ecosystem services and the associated nonuse values would fluctuate with water availability (see **TA 8**, Biological Resources – Fish and Other Aquatic Species). Similar to the Basic Coordination Alternative, however, higher average flows may support some river-based values.

Under the Representative Preferred Alternative, as under all alternatives, non-market values associated with recreation would continue to be impacted, by reduced access to recreation facilities and navigation challenges in Lake Powell and Lake Mead. Modeled results show reduced low-elevation outcomes compared to more vulnerable alternatives, but vulnerability remains under drier future hydrologic conditions (see **TA 3,** Hydrologic Resources). The Representative Preferred Alternative generally performs in the middle of the range of alternatives for both Lake Powell and Lake Mead elevations as well as river flow, showing moderate robustness in terms of overall support for recreation associated benefits (**TA 14**, Recreation). Overall, this alternative would provide moderate protection for riverine habitat to support cultural values (see **TA 13**, Tribal Resources).

Summary Comparison of Alternatives

The lowest impacts on economic and social conditions from reductions in agricultural production and increases in fallowed lands due to shortages in irrigation water, across all alternatives, states, and tribal and non-tribal irrigation entitlement holders, would occur under the No Action Alternative due to the low maximum shortage of 0.6 maf; however, across the action alternatives, impacts on economic and social conditions from changes in agriculture would vary across irrigation entitlement groups, based on the maximum shortage levels and water shortage distribution methods. For all irrigation entitlement holders except Arizona tribal, impacts on the economic and social conditions from agricultural activity would tend to be lower under the alternatives with a low maximum shortage level and priority-based shortage distribution methods, and impacts would tend to be higher under the alternatives with a high maximum shortage level or pro rata-based shortage distribution methods, compared with other action alternatives.

However, for Arizona tribal entitlement holders, lower impacts on economic and social conditions due to reductions in agricultural production would occur under alternatives with pro rata shortage distribution methods, and higher impacts occur under the alternatives with priority shortage distribution methods, compared with other action alternatives. Overall, the alternatives demonstrate a trade-off between shortage distributions across irrigation entitlement holders, flexibility in the maximum allowable shortage implementation, and the ability to support stable agricultural production and social well-being.

Operational changes under the proposed alternatives would influence these conditions in different ways. The alternatives that maintain more consistent reservoir levels would preserve boating access, marina operations, and shoreline recreational opportunities. This stability would support continued visitation and minimize disruptions to businesses dependent on tourism. Conversely, the alternatives that result in greater variability in lake elevations and river flows would affect the recreational quality and access and the related levels of contributions. Similarly, the alternatives that maintain consistent and adequate river flow below Glen Canyon Dam would offer continued support for recreational experiences with high value for whitewater boating and angling, and for the related spending in gateway communities and the regional economy.

The Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) poses the greatest risk to recreation-based economies relying on economic contributions from reservoir-based recreation in Lake Powell, while the CCS Comparative Baseline and the No Action Alternative have the least robust modeled performance for supporting recreational opportunities and spending associated with Lake Mead recreation. In contrast, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more consistent reservoir levels at Lake Powell to support recreation, and the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would support the greatest level of contributions from recreation in Lake Mead. However, under all alternatives, access to launch facilities and safe navigation routes for Lake Powell and navigational challenges in Lake Mead would continue to impact lake-based recreational opportunities and the associated spending.

River-based recreation is also vulnerable to operational changes. Activities such as angling in Glen Canyon and whitewater rafting in Grand Canyon depend on stable flows to ensure safety and trip quality. Reduced flows shorten rafting seasons and diminish the overall experience, leading to lower demand for outfitter services and the associated hospitality sectors. While the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would offer more consistent flows than the other alternatives, it would not fully mitigate risks. The Enhanced Coordination Alternative would be the least robust at maintaining or exceeding the minimum desired daytime flows to support boating in Grand Canyon; it would also result in the greatest potential for a reduction in the recreational value for whitewater rafting and the associated regional economic contributions associated with these uses.

Nonmarket values, such as scenic quality, opportunities for solitude, and cultural connections, are central to the Colorado River system and its surrounding landscapes. In general, stable reservoir elevations and predictable river flows support these factors and the value for locals and visitors. As a result, the alternatives that maintain relatively stable reservoir levels and minimize flow variability would provide stronger protection for these intangible benefits. During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on nonmarket values. As conditions become drier, however, the No Action Alternative and CCS Comparative Baseline would result in greater variability in reservoir elevations and river flows. This would result in the potential to expose barren drawdown zones, alter shoreline appearance, and reduce the aesthetic values tied to natural landscapes. Variability in flows can also affect the timing and accessibility of cultural practices, creating challenges for maintaining traditional uses. Visitors seeking a consistent wilderness experience may perceive degraded conditions when confronted with stark elevation changes or shortened seasons, which can influence perceptions of resource stewardship and long-term visitation patterns.

Under drier conditions, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would generally be more robust at maintaining key reservoir and river flow thresholds that support the resources with associated nonmarket values. On the other hand, the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in the most robust preservation of Lake Mead's reservoir levels at thresholds to support resources with nonmarket values.

3.17 Population and Land Use

3.17.1 Affected Environment

This section explores the baseline conditions and potential impacts from different Colorado River operational strategies on analysis area population dynamics and land use changes, with a focus on potential changes in developed lands and lands used for irrigated agriculture.

The full detailed analysis of population and land use can be reviewed in **TA 17**, Population and Land Use. **Sections TA 17.1.1**, **17.1.4**, and **17.1.6** provide comprehensive baseline information to characterize the existing setting and trends related to population, general landownership and management, and developed land patterns. Information is also provided for municipal water, which supports developed land use. Data are provided related to historical agricultural land use to support the discussion of irrigated agriculture.

Due to the influence of municipal water availability on developed lands, the impacts analysis examines changes to water availability for municipal supply and the related impacts on population and land use changes. **Sections TA 17.1.2** and **17.1.3** provide detailed information on industrial and municipal water uses and study area municipalities.

Due to the influence of irrigation water availability on agricultural land use, the impacts analysis examines changes to irrigation water availability and related impacts on acres of lands in agriculture. **Section TA 17.1.5** provides detailed information on agricultural land use within the study area, including irrigated acres of harvested cropland and the percentage of irrigated water from surface water resources.

The analysis area for the population and land-use section is separated by state and is described in **Section 3.17.2**. For a detailed description of the analysis area and rationale for selecting the Arizona, California, Nevada and Utah Counties, refer to **TA 17.1.** A high-level overview of key trends for population and land use is provided below.

Population

Population is one driver of demand for consumptive water use, particularly for municipal water. Communities throughout much of the western U.S. have followed trends of increasing populations over the past decade. In the analysis areas, the population growth rate has generally been positive or stable. **Section TA 17.1.1** provides the historical and projected population for the Arizona, California, Nevada, and Utah analysis area counties.

Population trends varied across the analysis areas over the past decade. Arizona experienced population growth, particularly in urban and suburban settings, due in part to relatively affordable housing and expanding job opportunities in emerging sectors. In Nevada, population growth was concentrated in Clark County and the Las Vegas metropolitan area, where tourism, hospitality, and related services continue to support population growth. California experienced more varied population trends, with urban centers experiencing steady growth while certain rural areas experienced slower growth or population declines.

In Arizona, population growth in some counties has reached over 30 percent, and Nevada's urban centers have seen substantial increases that exacerbate water demand and place stress on existing resource systems. California, with its large and diverse population, faces the challenge of balancing high urban density with water conservation measures, ensuring that residential and industrial growth complies with sustainable water use practices. Projections across the three states indicate continued growth that will necessitate further investments in water infrastructure and resources to meet municipal demands. More detailed information is provided in **Section TA 17.1.1**.

Population growth can increase the demand for water for domestic, agricultural, and industrial use and increase pressure on existing water sources. Studies have shown that population growth can be a dominant driver of long-term municipal water demand (Liu et al. 2025). Insufficient water supply can constrain population growth and development by limiting an area's capacity to support residents.

Industrial and Municipal (Domestic) Water Uses and Trends

The Colorado River is an important water source serving municipalities, industries, and agricultural operations in Arizona, Nevada, and California. **Section TA 17.1.2** provides a detailed overview of industrial and municipal (domestic)[20] water supply, demand, and use trends within the U.S. and the Lower Basin. **Section TA 17.1.3** provides information on the municipalities within Arizona, California, and Nevada with the potential to be affected by changes in domestic water availability. Municipal water systems in these regions face growing pressures from population growth, climate trends, and uncertainties in future water availability, demand, and technological or policy adoption (Liu et al. 2025). Water management strategies—including conservation measures, demand-side management, and technology upgrades—have been implemented to mitigate these pressures and maintain system reliability.

Although existing and ongoing municipal water management strategies do not change domestic water entitlement amounts, they illustrate how municipal systems have adapted—and may continue to adapt—to evolving water supply and demand conditions. This context is important for understanding how communities in the region would respond to variability in water availability under different future conditions. Across the analysis areas, municipal providers employ a range of adaptation measures to manage supply variability and shortages. In Arizona, measures commonly include demand management and conservation; increased reliance on groundwater and stored supplies, including recharge and banking, where available; reclaimed water for non-potable demands; and system

[20] Domestic water use includes the use of water for "household, stock, municipal, mining, milling, industrial, and other like purposes" (1922 Colorado River Compact, section II(h)).

interconnections or operational changes. In California, measures commonly include conservation; recycled water expansion; stormwater capture and local recharge; groundwater management; interties and transfers, where available; and targeted supply or treatment improvements. In Nevada (Clark County), measures commonly include incentives to reduce outdoor water use, extensive reuse and return-flow management, and storage and exchange arrangements coupled with operational and infrastructure modifications to improve drought resilience. Many measures involve substantial capital costs and multiyear implementation timelines and may be constrained by legal or contractual availability, physical system capacity, water quality and treatment requirements, permitting, energy demands, and environmental considerations, which can limit feasibility or timing for some communities.

The availability of and access to domestic water can influence population dynamics and land use patterns in the region (**Section TA 17.1.2**). Peer-reviewed studies have documented the relationships between population growth, land use patterns, and domestic water delivery. Urban sprawl, characterized by low-density development and increased impervious surfaces, has been shown to elevate per capita water demand through higher outdoor water use (Heidari et al. 2021). In contrast, high-density development often reduces water use per capita and can lessen the frequency and severity of water shortages. Rapid urbanization and population growth can also increase pressure on existing water infrastructure, creating challenges in maintaining consistent domestic water delivery.

Municipal water demand within the analysis area depends on more than population or economic growth and can reflect long-term trends in conservation, efficiency, reuse, land-use patterns, climate, and provider policies. Many municipal providers in the Lower Basin have implemented demand management programs and operational practices that have reduced per-capita use over time, such that total municipal demand may remain stable or grow more slowly than population in some communities. Conversely, the magnitude of realized conservation and the remaining potential for additional cost-effective savings vary by provider due to differences in existing program maturity, customer mix, climate, built environment, system losses, regulatory constraints, and local supply portfolios.

Municipal planning and development within the Lower Basin counties in the analysis area rely on assumptions about the reliability, timing, and quality of water supplies used to serve existing and future demands. Within the analysis area counties, local governments and water providers typically integrate water-supply expectations into general plans, zoning and subdivision decisions, capital improvement programs, and long-range utility master planning. These assumptions inform the sizing and sequencing of major infrastructure (e.g., treatment, conveyance, storage, and pressure zones), operational and drought contingency planning, and the ability to maintain service standards under variable hydrologic conditions. Many providers in these counties manage portfolio supplies that may include Colorado River–derived deliveries alongside local surface water, groundwater, conservation, reuse, and interconnections. Because of this, domestic water reliability depends not only on annual volume but also operational availability during peak demand, drought response triggers, and constraints associated with treatment and regulatory compliance. Accordingly, changes in the reliability of Colorado River supplies can be relevant to municipal planning baselines and the context for evaluating potential effects related to domestic water shortages discussed in **Section 3.17.2** (**Section TA 17.2.2** for more information).

Water supply has influenced land use and development within the analysis area. Arizona Department of Water Resources' (ADWR) Assured and Adequate Water Supply programs provide a concrete example of how water availability can constrain development. While not directly tied only to Colorado River water, The ADWR's Assured and Adequate Water Supply programs require developers to demonstrate assured or adequate water supplies before proceeding with new projects. This context provides one example of how planning assumptions for water supply relate to residential and commercial development and helps frame how communities might respond to changes in water availability under future conditions.

Domestic water supply reliability also supports baseline employment and community functions across the socioeconomic analysis area. **TA 16**, Socioeconomics, **Section TA 16.1.2** provides baseline employment by sector for the Arizona, California, Nevada, and Utah counties included in the socioeconomic analysis area for 2010 and 2022 (see **Tables TA 16-1, 16-2, 16-6, 16-7, 16-11**, and **16-14**). These tables provide context for the composition of employment in the analysis area, including sectors that typically rely on continuous municipal water service to support day-to-day operations and public services. Examples of these sectors include but are not limited to information; healthcare and social assistance; retail trade; real estate; arts, entertainment, and recreation; construction; finance and insurance; manufacturing; professional, scientific and technical services; state and local government; and accommodation and food services. While county-level employment data do not distinguish among the water sources supporting certain sectors and associated economic activity and public services, the sector employment helps frame domestic water supply, demand, and use trends in the counties included in the analysis area.

In models of projected water yield and demand in the western U.S. to 2070, data indicate that demands for municipal water are increasing across the socioeconomic analysis area, while projected water availability is decreasing (see, for example, Warziniack and Brown 2019). While this trend is seen throughout the western U.S., the Colorado River region has the largest percentage increases in projected domestic water use and the greatest percentage decreases in projected water yield from all sources, including Colorado River water (Warziniack and Brown 2019).

Study Area Municipalities

The analysis area is informed by the SAMs and includes the counties represented in the SAMs. Further, the Arizona, California, and Nevada municipalities with potential to be affected by the alternatives are described in detail in **Section TA 17.1.3**. and include those represented in the SAMs.

Land Use

This section describes existing land use conditions along the mainstream Colorado River from Glen Canyon Dam to the U.S.–Mexico border. Land use includes recreation, agriculture, tribal land use, conservation and habitat management, residential and urban development, and utility and infrastructure corridors.

Landownership along the Colorado River is highly variable and includes federal (NPS, BLM, FWS, and Reclamation), tribal, state, and private lands. Federal agencies manage much of the land in the upper and middle portions of the river corridor, particularly in areas surrounding Glen Canyon NRA, GCNP, Lake Mead NRA, and multiple NWRs. Tribal lands are prominent in both Arizona and

California. State and private lands are more common in the Lower Basin, especially in urban areas like Bullhead City and Yuma and along agricultural corridors in Arizona and California.

Developed land uses occur in concentrated areas where communities and infrastructure directly rely on the Colorado River. These include recreation sites, marinas, campgrounds, roadways, water delivery systems, hydropower infrastructure, and municipal areas. While most of the corridor remains undeveloped, developed areas have expanded since the early 2000s in several locations due to population growth, recreational demand, and infrastructure upgrades. Agricultural lands are also a major land use along the river's lower reaches, particularly in western Arizona and southeastern California, where irrigated farming depends heavily on surface water deliveries.

Reservoir elevations and river flow conditions strongly influence how land near the river is used and managed. Declining water levels at Lake Powell and Lake Mead have resulted in increased shoreline exposure, changes in recreational access points, and new management needs for erosion control, sediment exposure, and public safety. These hydrologic shifts also affect agricultural land use by altering water availability for irrigation, which can contribute to fallowing or shifts to less water-intensive crops in some areas.

Agricultural Land Use

Agriculture is a major land use along the lower Colorado River, particularly in western Arizona and southeastern California, where irrigated farming relies heavily on surface water deliveries. Key agricultural areas include Yuma, La Paz, and Mohave Counties in Arizona and Imperial and Riverside Counties in California. These regions support extensive production of food, feed, and fiber crops and represent some of the most productive irrigated farmland in the country. Western Arizona counties such as Pinal, Maricopa, and Pima also contain irrigated agricultural lands, although these areas have experienced reductions in irrigated acreage over time due to water availability constraints. Trends in county-level cropland data show shifts in harvested and irrigated acreage across the region, reflecting long-term drought, changes in water deliveries, and adaptation by agricultural producers (Dieter et al. 2018; Presson and Eden 2023; USDA NASS 2024). More detailed information on the location and extent of irrigated agricultural lands is provided in the technical appendix.

3.17.2 Environmental Consequences

Methodology

The analysis of population and land use impacts evaluates a) how operational changes and changes to domestic water delivery could affect overall population and land use patterns, including developed lands for residential and commercial uses, and b) how operational changes and changes to irrigation water could affect lands used for irrigated agriculture.

To analyze how operational changes may affect population and land use patterns (Issue 1), the DMDU analysis was used. The DMDU analysis of domestic water impacts used modeled shortages to domestic users provided by the SAMs and ADMs[21] and proceeded in two main steps. First, domestic priorities were grouped: Arizona CAP non-Indian agriculture [NIA]-A and NIA-B (Group 1), Arizona

[21] There are three unique SAMs and five ADMs to capture the nuances of the alternatives and sensitivity analyses; these are further explained in **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation.

CAP M&I and Priority 4(i) (Group 2), Arizona Priorities 2 and 3 (Group 4), Arizona PPR (Group 5), California Priority 4 (Group 6), California PPR (Group 7), Nevada Priority 8 (Group 8), Nevada Priorities 1–7 (Group 9) to capture variation in modeled shortage by priority across the SAMs. Second, the modeled domestic shortage was analyzed for each priority group to determine the shortage levels at which the group's average percentage shortage equaled approximately 20, 40, 60, 70, 80, or 100 percent of its total entitlement. These thresholds were applied within the DMDU framework to develop **Figures TA-17-2** through **TA-17-9**, which depict the percentage of modeled futures where each priority group maintains the specified fraction of normal water deliveries in 90 percent of years across the action alternatives. For the purpose of this analysis, "normal delivery" is defined as a full Colorado River or CAP entitlement supply. The figures provide a direct comparison of domestic water impacts across priority groups and the alternatives. Additional information on the DMDU robustness and vulnerability concepts used to interpret these results is provided in **Appendix E** (DMDU Overview and Approach). Modeling assumptions and shortage allocation frameworks that inform domestic delivery outcomes are documented in **TA 4**, Water Deliveries. While this section focuses on domestic shortage impacts on priority groups, domestic shortage impacts for each entitlement can be found in **Appendix C**.

To analyze how operational changes may affect agricultural land use (Issue 2), this analysis relied on modeled shortages to irrigation users at the state level, produced by the SAMs. For more detailed information on the SAMs and consumptive impacts on irrigation users, see **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation. For more information on water deliveries and shortage impacts, including those for irrigation, refer to **TA 4**, Water Deliveries.

Impact Analysis Area

The analysis area for the population and land use section is separated by state and is the same for both population and land use issues. The impact analysis area is defined by those counties that may be affected by management direction that could result in water shortages to domestic and irrigation users. As described above, both issue statements rely on the SAMs. As a result, the analysis area is informed by the SAMs and includes the counties represented in the SAMs. The Arizona analysis area consists of Apache, Coconino, Gila, La Paz, Maricopa, Mohave, Navajo, Pima, Pinal, and Yuma Counties. These include counties that are directly adjacent to Lake Powell, Lake Mead, or the Colorado River and counties in which shortages would likely occur. The California analysis area consists of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and San Diego Counties. These counties were selected because they are either directly adjacent to the lower Colorado River, or they are within the MWD service area. Although Ventura County is also in the MWD service area, it does not receive any water from the Colorado River; therefore, it is not included in the analysis area. The Nevada analysis area consists of Clark County. The Nevada analysis area was limited to Clark County because Clark County is adjacent to Lake Mead and encompasses SNWA's service area and other individual water providers. Shortages in Nevada would be limited to SNWA's service area.

Across the states, these counties were selected for inclusion in the analysis area because they represent the counties in which there is potential for direct impacts from shortages, based on modeled domestic (municipal) delivery outcomes and the service areas of major municipal providers. Secondary impacts could also occur in adjacent counties, across states as a whole, in adjacent states, and/or at the national scale (e.g., through economic linkages and supply chains). However, due to analytical constraints and the focus of this analysis on a DMDU-informed assessment of modeled domestic shortage outcomes for selected municipal providers, the population and land use analysis focuses on direct impacts within the counties that correspond to municipal service areas and areas where delivery reductions could most directly influence land-use-related conditions.

This approach is consistent with the socioeconomic framing (**TA 16**, Socioeconomics), which defines analysis areas using counties adjacent to reservoirs and the Colorado River and counties containing major municipal service areas that receive water from the Colorado River (e.g., in California, counties within the MWD of Southern California service area that receive Colorado River water).

Assumptions

- Colorado River operations do not directly control population change, but they may indirectly influence migration patterns.
- Local socioeconomic conditions and demographic trends may also be influenced by factors outside river operations, such as housing costs, infrastructure investment, local attitudes towards water conservation, and regional employment patterns.
- In most cases, the contractor, subcontractor, or entitlement holder of an allocation is shown as the entity bearing shortage. In some cases, water allocated to an entitlement holder (for example, a tribal CAP contractor) may lease its allocation to other users (for example, to a non-Indian municipality). The SAMs and ADMs do not attempt to replicate those arrangements, and they only provide approximate estimates at the level of the entitlement holder, contractor, or subcontractor. The entitlement holder, contractor, or subcontractor to the leasing arrangements would have specific decisions to make during Shortage Conditions to administer those arrangements that Reclamation cannot predict with sufficient certainty to analyze in this EIS.
- Under the Representative Preferred Alternative, two different approaches to distributing shortages are modeled, where (1) 2027-2028 modeling assumes shortage volumes up to 1.5 maf are distributed using the approach developed by the Lower Division States, and shortage volumes from 1.5 maf to 3.6 maf are distributed using the priority system, and (2) from 2029 through 2060, modeled shortage volumes are distributed using the priority system. Refer to **Section 2.4** for additional information. Some impacts are influenced by how the Representative Preferred Alternative distributes Lower Basin shortages in 2027-2028 vs. 2029-2060, and some impacts are either minimally sensitive or not sensitive to this distinction. Impacts discussion will include references to different time periods where relevant.
- Impacts under the Preferred Alternative may be different from what is shown for the Representative Preferred Alternative, as this alternative provides a framework that allows for shortages to be distributed based on agreements among states that may arise, consistent with sideboards described in **Chapter 2**. As a result, the potential for fallowing, crop switching, and other associated long-term land-use patterns in any given area may vary and impacts may be mitigated in part by specific operating guidelines.

Impact Indicators

- Shortage to domestic water users
- Acres of developed land within the analysis areas and the potential for changes based on municipal water availability
- Acres of irrigated agricultural land within the analysis areas and the potential for changes based on agricultural water availability

Issue 1: How would operational changes affect population and developed land use patterns?

This issue examines how modeled changes in domestic (municipal) delivery reliability may influence population and developed land use patterns in communities that rely on Colorado River water for municipal uses. While Colorado River operations do not directly determine population movement or developed land use patterns, long-term changes in water availability and recreational access may influence migration patterns and developed land patterns. This issue statement is analyzed by first synthesizing the DMDU results presented in **TA 17**, Population and Land Use, and then by assessing how domestic water delivery impacts would impact population and developed land use patterns. Modeled domestic (municipal) delivery outcomes are used to understand how reduced reliability may constrain population- and land-use-related conditions, including residential and commercial development, existing communities, and essential services. The DMDU results are interpreted as indicators of potential exposure to domestic shortage and associated impacts, not as direct forecasts of county-level population change, local economic output, or sector-specific impacts. Additional detail on the modeling assumptions and domestic delivery results is provided in **TA 17,** Population and Land Use, **TA 4,** Water Deliveries, **Appendix C, and Appendix E.**

Population is not treated as a direct proxy for consumptive use because conservation, reuse, and local policy can affect per-capita water use. Similarly, municipal-scale economic impacts are discussed qualitatively because comparable economic, utility finance, and sector-specific data are not uniformly available across municipal providers and service areas. **TA 16**, Socioeconomics, provides baseline socioeconomic context, including employment by sector, and **TA 17**, Population and Land Use, uses that context to discuss qualitative pathways by which reduced domestic delivery reliability may affect communities and developed land use.

Figure TA 17-2 through **Figure TA 17-9** in **TA 17**, Population and Land Use, display potential impacts on domestic water deliveries by presenting the percentage of normal domestic water deliveries that can be achieved across a range of modeled futures. Each figure illustrates the percentage of normal domestic water deliveries achieved in 90 percent of years over a 34-year modeling period, representing varying percentages of potential future scenarios for each priority group. The metric of 90 percent of years was selected for this analysis, rather than 100 percent of years, because it better displays variation between the alternatives. For each figure, the rows represent different performance thresholds, as percentages of normal delivery. Higher rows indicate a higher volume of delivery (closer to normal conditions) and are therefore challenging to achieve across a large percentage of potential futures, while lower rows represent lower levels of delivery that are easier to achieve because they allow for more frequent modeled shortages to domestic water delivery. For this analysis, greater than 80 percent of normal delivery in 90 percent of years was selected as the preferred minimum performance level. This row was highlighted because it represents the performance level closest to normal domestic water delivery of the thresholds displayed in the figures, while also representing the earliest point at which differences among alternatives begin to emerge in the DMDU results. In other words, the greater than 80 percent row reflects the least amount of modeled shortage to domestic water users displayed in the figures and is the first row where shortages begin to manifest across alternatives.

In addition, each figure includes a bottom row that shows futures with dead pool–related reductions. These occur when Lake Mead lacks sufficient water to meet downstream demands or when Hoover Dam infrastructure limitations force releases below the required volume, typically when the lake approaches dead pool (895 feet) or even earlier (up to 950 feet). Although this analysis does not address the allocation of reductions related to dead pool, displaying these figures provides important context on the robustness of the alternatives.

Figure TA 17-2 through **Figure TA 17-9** in **TA 17**, Population and Land Use, do not capture individual years within the modeling period, however, they are modeled. The modeling assumptions for the Representative Preferred Alternative in the first two years (2027–2028) are described in **Chapter 2** and the shortages are distributed via LB priority. Therefore, up to 1.5 maf of shortage, in the first two years, impacts to Arizona CAP NIA-A and NIA-B; CAP Indian, M&I, and 4(i); and Priorities 2 and 3; California Priority 4 entitlements; and Nevada Priority 8 (including Balance and Surplus) entitlements, would be more similar to the Supply Driven Alternative (LB Priority Approach). Refer to **Appendix C**, **Table C-28** for domestic shortage impacts for each entitlement holder under the LB Priority distribution (up to 1.5 maf shortage). The results for the Representative Preferred Alternative in 2029–2036, in which Priority distribution is applied, would result in more shortage impacts on Arizona junior entitlements.

The alternatives with greater robustness would likely result in fewer potential indirect impacts on population growth and developed land. Greater robustness corresponds to a higher percentage of futures in which domestic water delivery remains consistent with normal conditions and shortages occur less frequently. In contrast, less robust alternatives are more susceptible to reductions in domestic water availability because modeled shortages occur more frequently or the volume of shortage is higher. These shortages could manifest as reduced water deliveries, delivery restrictions, or the need for additional conservation measures, which could in turn limit the capacity to meet domestic water demand. A more robust alternative would therefore help ensure that domestic water supplies remain reliable to support existing populations and accommodate anticipated future growth, thereby minimizing potential secondary impacts on development patterns and land use. More detailed information on the nature and type of impacts associated with reductions in municipal delivery reliability is provided in **TA 17.2.2** and **TA 17.2.3**. The SAMs used to inform the DMDU analysis do not incorporate water management measures, such as conservation programs, or demand-reduction strategies. These measures do not change entitlement amounts or shortages; however, as noted in the affected environment section, conservation programs and other management strategies can influence domestic water demand and help mitigate the operational pressures associated with shortages, uncertain supply, and population growth. The potential impacts on domestic water supply for the Lower Division States would also depend in part on existing and future management strategies and conservation measures implemented by the states, local water providers, and individual users. Potential impacts would also depend on other external factors such as environmental and economic conditions.

Communities and municipal providers may respond to shortages through a range of adaptation measures, which could include increased conservation and demand management, use of existing storage or water banking arrangements where available, investments in infrastructure (e.g., treatment upgrades, reuse, interconnections), operational changes, or pursuit of alternative supplies and agreements. The feasibility, timing, and effectiveness of these measures would vary by location and provider, and may be constrained by physical and geographic availability of replacement water, jurisdictional and legal limitations (including state-law and contractual considerations), the time required for planning, permitting, financing, and construction, and constraints related to existing infrastructure configurations and prior investments. Adaptation measures may also involve direct and indirect economic costs to providers and ratepayers, and may require tradeoffs among objectives under different future conditions. Because the DMDU framework tests many uncertain futures, these uncertainties and constraints should be considered when interpreting robustness results and evaluating the extent to which an alternative can reduce both direct delivery impacts and potential secondary effects on development patterns and land use.

Table ES-7, Summary of Potential Effects, Population and Lands, in the Executive Summary provides an overview of impacts on population, lands, and domestic water by alternative based on the DMDU figures discussed in detail in **TA 17**, Population and Land Use. The table demonstrates how the different alternatives perform in terms of the percentage of normal delivery in potential futures. The table with a summary of effects on the population and lands includes two performance indicators: greater than 80 percent of normal delivery and greater than 60 percent of normal delivery in 90 percent of modeled futures, across the full modeling period. The table displays how each alternative performs for these two performance indicators, by priority group. The performance indicators illustrate how each alternative performs in maintaining domestic water deliveries under a wide range of uncertain future conditions. The alternatives that would achieve greater than 80 percent of normal delivery in 90 percent of years demonstrate strong robustness, indicating that domestic deliveries would remain near normal levels across most modeled futures. These alternatives would result in fewer and less severe shortages, which would provide greater reliability for domestic water users. This performance indicator is difficult to achieve under many alternatives.

To show further variation across the alternatives, **Table ES-7**, Summary of Potential Effects, Population and Lands, in the Executive Summary includes greater than 60 percent of normal delivery in 90 percent of years. The alternatives that only meet the greater-than-60-percent-of-normal-delivery-in-90-percent-of-years threshold demonstrate lower robustness. Under these conditions, more frequent domestic delivery reductions or shortages could occur in modeled futures, particularly for junior priority groups. Such outcomes could increase the likelihood of secondary socioeconomic impacts, including constraints on growth or secondary changes in land development patterns.

As described in **Section TA 17.1**, Affected Environment, and **Section 3.1**, Introduction, above, peer-reviewed studies document that domestic water availability significantly influences population dynamics and land use. **Section TA 17.2.3**, DMDU Analysis Summary, provides a detailed overview of potential impacts on domestic water and the associated impacts on population and land use patterns for Arizona, Nevada, and California. Key summaries are also provided below.

Arizona: Across the first decade of the modeling period, the CCS Comparative Baseline and No Action, Basic Coordination, and Supply Driven (LB Priority Approach) Alternatives would result in similar impacts on domestic water supply for Arizona PPR and Arizona Priorities 2 and 3, with greater than 80 percent of normal delivery in 100 percent of potential futures. In other words, there would be no domestic shortage impacts for Arizona PPR and Priorities 2 and 3 under these alternatives. However, potential impacts do vary under the other action alternative for these two priority groups. Under the Maximum Operational Flexibility and Representative Preferred Alternatives, over 80 percent of normal delivery to Arizona Priorities 2 and 3, occurs in 26 percent and 57 percent of potential futures across the first decade of the modeling period, respectively.

In contrast, for Arizona CAP NIA-A, CAP NIA-B, CAP Indian, M&I, and 4i priorities, no alternative achieves the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years across the first decade of the modeling period. Further, under the Basic Coordination, Enhanced Coordination, and Representative Preferred Alternatives, there are no potential futures in which Arizona CAP NIA-A, CAP NIA-B, CAP Indian, M&I, and 4(i)) priority groups receive any percentage of normal domestic water delivery. Under these less robust alternatives, there is a higher frequency of shortage and no potential futures in which normal domestic delivery to these priorities occurs. A higher frequency of shortages and fewer potential futures with normal domestic delivery to these junior priorities could result in potential impacts on municipalities and communities that rely on domestic water delivery under these entitlements. Should shortages result in a reduction or elimination of legal access to municipal water, widespread impacts on social and economic conditions may also be possible. Further, the shortage distributions applied under these alternatives could result in the complete loss of domestic water for these users. However, the Enhanced Coordination and Supply Driven (LB Pro Rata Approach) Alternatives allow for over 60 percent of normal delivery in 100 percent of modeled futures for these priority groups, demonstrating its robustness compared with the other alternatives.

When considering all Arizona priority groups, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives generally demonstrate the most robust performance for domestic water entitlements, based on maintaining greater than 60 percent of normal delivery in at least 90 percent of years across the full modeling period, for the greatest number of users. Compared with the CCS Comparative Baseline and No Action Alternative, under these alternatives 60 percent or more of normal domestic water delivery occurs across the largest percentage of potential futures and for the greatest number of priority groups. While this approach maximizes delivery reliability for more users overall, it involves a trade-off: Some senior entitlements would experience delivery reductions that would not occur under priority distribution, whereas more junior entitlements may continue to receive near-normal deliveries, across the modeled futures. This allocation reflects a balance between broad delivery coverage and the reallocation of shortage risk across the priority groups.

California: For California PPR, all alternatives, excluding the Enhanced Coordination Alternative, achieve the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years, across the first decade of the modeling period. Therefore, under all alternatives, excluding the Enhanced Coordination Alternative, there would be no shortage to California PPR across modeled futures. For California Priority 4, the No Action, Basic Coordination, and Supply Driven (LB Pro Rata approach) Alternatives achieve the preferred minimum performance of over 80 percent of normal delivery in 90 percent of years, across the first decade of the modeling period. The Maximum Operational Flexibility and the Representative Preferred Alternatives demonstrate the most robust performance for California PPR compared with other alternatives. However, for California Priority 4, deliveries greater than 80 percent of normal delivery occurs in no potential futures under the Maximum Operational Flexibility, Supply Driven (LB Priority approach), and Representative Preferred Alternatives. Therefore, under these alternatives modeled delivery reductions could result in impacts on existing residents, economic sectors, and essential services reliant on domestic deliveries. Communities could experience increased constraints on existing and new residential and commercial development, need for additional adaptation measures, and greater pressure to accelerate development of replacement supplies.

When evaluating both California priority groups together, the Supply Driven Alternative (LB Pro Rata approach) is the most robust, compared with the No Action Alternative and all other action alternatives. It provides 100 percent of normal delivery to California PPR and California Priority 4 in 90 percent of years across 100 percent of potential futures. Additionally, considering the dead pool–related reductions, which could affect these users, the Supply Driven Alternative (LB Pro Rata approach) has the third lowest percentage of futures with constrained releases (12 percent), compared with all other alternatives. Reliable domestic water deliveries under the Supply Driven Alternative (LB Pro Rata approach) would support continued population growth and land development in areas served by California PPR and Priority 4.

Maintaining near-normal deliveries reduces the likelihood of constraints on planned and new development, housing availability, and municipal services that rely on water supply. In contrast, the alternatives with lower reliability or greater exposure to dead pool–related reductions could limit opportunities for residential and commercial growth, particularly in high-demand areas, and could influence land use patterns or delay new construction. Ensuring robust water delivery across multiple futures is therefore directly tied to supporting existing communities, sustainable population growth, and land use planning in California.

Nevada: Similar to Arizona PPR, for Nevada Priorities 1–7, all alternatives, excluding the Enhanced Coordination and Supply Driven (LB Pro Rata Approach) Alternatives, achieve the preferred minimum performance level of over 80 percent of normal delivery in 90 percent of years, across the first decade of the modeling period. In contrast, for Nevada Priority 8, the No Action Alternative is the only alternative that meets the preferred minimum performance. For Nevada Priorities 1–7 specifically, the Maximum Operational Flexibility Alternative is the most robust, followed by the Representative Preferred Alternative, compared with the No Action Alternative and the other action alternatives. In contrast, for Nevada Priority 8, these same alternatives are some of the least robust, with deliveries greater than 80 percent of normal occurring in only 1 percent of potential futures (Maximum Operational Flexibility Alternative) and no potential futures (Representative Preferred Alternative).

When considering both Nevada priority groups together, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives, provide the most robust performance. These alternatives deliver greater than 60 percent of normal domestic water across the largest percentage of potential futures and for the greatest number of priority groups. Robust domestic water deliveries are critical to supporting existing communities and population growth and land development in Nevada. The alternatives that maintain more reliable deliveries for both priority groups reduce the risk of constraints on existing and new housing, commercial development, and essential municipal services that depend on water supply. Conversely, the alternatives with lower reliability, particularly for Nevada

Priority 8, could result in impacts on the capacity to support existing residents, economic sectors, and essential services reliant on domestic deliveries. Communities could experience increased constraints on existing and new residential and commercial development, impacts on the capacity of communities to expand, and effects on land-use patterns or delays to new construction projects. Modeled delivery reductions could result in the need for additional adaptation measures, and greater pressure to accelerate development of replacement supplies. By sustaining domestic water availability across a broad range of potential futures, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives may help support existing residents, economies, and essential services; stable population growth and more predictable land use planning across the state, where modeled deliveries remain reliable.

Issue 2: How would operational changes affect irrigated agricultural land use patterns?

Irrigated agriculture in Arizona and California remains sensitive to changes in Colorado River operations. Across all modeled alternatives, reductions in irrigation deliveries occur as reservoir elevations decline and system shortage volumes increase. Differences among the alternatives primarily reflect how shortages are distributed, either according to priority systems or through coordinated or pro rata sharing, and whether conservation and flexibility mechanisms are available to offset impacts.

Arizona experiences the greatest exposure to shortages under most alternatives because many irrigation users in Yuma, La Paz, and Mohave Counites hold junior priority rights. Under conditions without new conservation or shortage-sharing mechanisms, such as the No Action and Basic Coordination Alternatives, Arizona irrigation users face frequent and severe reductions. Literature indicates that these reductions can accelerate fallowing, crop switching, and farmland retirement in western Arizona counties (USGS 2019b; Arizona Extension 2024; Presson and Eden 2023). Even under the CCS Comparative Baseline, modeled shortages still affect Arizona at low to mid-levels of system stress, reflecting ongoing vulnerability despite existing conservation programs.

California agriculture, particularly in senior-rights districts, such as the Imperial Valley, is less affected under priority-based alternatives; however, it faces greater reductions under coordinated or pro rata frameworks. The Enhanced Coordination and Supply Driven (Pro Rata approach) Alternatives distribute shortages more evenly across Lower Basin water users, reducing concentrated impacts in Arizona but increasing exposure for California. Studies show that even modest reductions can influence land use in California's irrigation districts through shifts toward drought-tolerant crops or partial land retirement (Prakash 2023; Lee et al. 2020).

The alternatives that incorporate operational flexibility or large conservation reserves, such as the Maximum Operational Flexibility Alternative and portions of the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), may lessen the severity of shortages during milder hydrologic periods, though long-term reliability still depends heavily on conservation participation and system conditions. Research indicates that agriculture increasingly relies on adaptive practices, such as deficit irrigation and crop switching, to maintain productivity under prolonged water scarcity (USDA ERS 2021).

Up to 1.5 maf of shortage, the Representative Preferred Alternative for 2027-2028 would result in shortages similar to that under the Maximum Flexibility Alternative and the Supply Driven Alternative (LB Priority approach), with impacts concentrated on junior users. In the longer term (2029-2060) modeled outcomes for the Representative Preferred Alternative follow the priority approach for distribution, and indicate potential for fallowing of land as noted under the Basic Coordination Alternative, with impacts concentrated on junior users.

The analysis shows that operational changes to the Colorado River system would continue to influence land use in irrigation-dependent regions. Concentrated shortages under priority-based operations are most likely to drive localized land fallowing and economic disruption in central Arizona, while pro rata or coordinated approaches lead to broader, more evenly distributed impacts in Arizona and California. More detailed modeling results and county-level outcomes are provided in the technical appendix.

Summary Comparison of Alternatives

Population and Developed Land Use: The alternatives vary in how they distribute domestic shortages and in their potential to impact domestic water deliveries and, in turn, indirectly impact population dynamics and land use within the analysis area.

As shown in **Table TA 17-17**, for the No Action, Basic Coordination, Maximum Operational Flexibility, Supply Driven (LB Priority approach), and Representative Preferred Alternatives, which apply a priority-based distribution of shortage, under most modeled futures, water users with senior entitlements would likely continue to experience relatively consistent domestic water deliveries. This is because these entitlements are contractually prioritized during periods of reduced supply. However, junior entitlements could face greater reductions in water deliveries during Shortage Conditions. Consequently, while senior entitlement holders may maintain service levels closer to normal, junior entitlement holders could experience more frequent or severe delivery constraints.

Under the No Action, Basic Coordination, Maximum Operational Flexibility, Supply Driven (LB Priority approach), and Representative Preferred Alternatives, greater than 80 percent of normal domestic delivery to most senior entitlements occurs in all potential futures. The specific Arizona, California, and Nevada senior entitlements vary by alternative (see **Table TA 17-17**). Because these alternatives have greater robustness for senior priority groups, there could be fewer potential indirect impacts on existing communities as well as population growth, and land development. A higher percentage of potential futures with greater than 80 percent of normal delivery could support existing populations, future population growth, water demand, and development in areas serviced by these priority groups.

Under the Basic Coordination, Maximum Operational Flexibility, Supply Driven (LB Priority approach), and Representative Preferred Alternatives, for junior entitlements there are fewer potential futures, and in some cases no potential futures, in which there is any percentage of normal delivery across the first decade of the modeling period. The specific Arizona, California, and Nevada junior entitlements vary by alternative (see **Table TA 17-17**). Under the Enhanced Coordination, Maximum Operational Flexibility and Representative Preferred Alternatives, greater than 80 percent of normal domestic delivery to all junior entitlements occurs in no potential futures, across the first decade of the modeling period. Domestic shortages could manifest as reduced water allocations, delivery restrictions, or the need for additional adaptation and conservation measures, which could in turn limit the capacity to meet domestic water demand. Reduced capacity to meet domestic water demand could impact existing residents and essential services, constrain planned and future development, and create conveyance or treatment system challenges. The extent of these effects would vary by community based on local water portfolios, infrastructure, regulatory context, conservation achievements, financing capacity, hydrologic conditions, and adaptation feasibility. Further, the shortage distributions applied under these alternatives could result in the complete loss of domestic water for these users. Should shortages result in a reduction or elimination of legal access to municipal water, widespread impacts on social and economic conditions could also be possible. For example, in some scenarios, municipalities could even find the need to pursue alternative water sources or hauled water, if available, as an alternative to support continued services. However, adaptation measures (for example, new supplies, infrastructure, treatment, interconnections, and related financing) can require substantial time and resources and may not be available on the same schedule for all communities. While these specific local project decisions would occur outside the scope of this Final EIS, it is important to note the potential for impacts. In addition, indirect social costs could occur as a result of a reduction in ecosystem services; also, indirect social costs could occur from a reduction of benefits to people provided by the environment. For example, trees in urban areas have been shown to provide high levels of benefits to people in the form of shade, which mitigates urban heat impacts (that is, heat-related illness), local air quality improvements, and enhancement of the visual setting. Should a reduction in domestic water supply result in die-offs of urban and suburban area trees, this could represent a loss of value that would take decades to recapture, due to the growth time required for trees (see, for example, Bloome et al. 2016).

As shown in **Table TA 17-17**, the Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives, which apply pro rata distribution of shortage under most modeled futures, would generally allow a larger number of priority groups to receive domestic water deliveries closer to normal conditions. While a pro rata approach would change the distribution of water across all users during shortages, this section solely focuses on the distribution of water to domestic users. This approach would deviate from the priority-based distribution, resulting in some modeled reductions to domestic deliveries for some senior entitlement holders who would otherwise maintain normal domestic delivery under the existing priority system. In contrast, more domestic junior priority water entitlement holders would continue to receive some level of water supply under this approach. In general, the pro rata method would result in more existing users receiving moderate water deliveries during shortages through a redistribution of water from senior entitlements.

Agricultural Land Use: The alternatives vary in how they distribute irrigation shortages and in their potential to influence long-term land use patterns. The No Action and Basic Coordination Alternatives rely on priority-based distribution and result in concentrated impacts on junior priority users in Arizona (primarily in Yuma, La Paz and Mohave Counites, with limited mitigation tools. These conditions increase the likelihood of fallowing, crop switching, and economic stress in affected communities.

The Enhanced Coordination and Supply Driven (LB Pro Rata approach) Alternatives distribute shortages more broadly across the states and users, reducing concentrated impacts on junior priority holders but introducing greater reductions in California, which could lead to more widespread land use changes. The Maximum Operational Flexibility and Supply Driven (LB Priority approach) Alternatives incorporate adaptive tools and conservation reserves, offering potential buffers against extreme shortages; however, their effectiveness depends on stakeholder participation and hydrologic conditions.

Up to 1.5 maf of shortage, the Representative Preferred Alternative for 2027-2028 would result in shortages similar to those under the Maximum Operational Flexibility Alternative and the Supply Driven (LB Priority Approach), with impacts concentrated on junior users. In the longer term (2029-2060) modeled outcomes indicate potential for the greatest level of shortage to junior priority users of any alternative. However, the distribution of shortage under any specific operating guidelines adopted under the Preferred Alternative decision framework may differ from the priority distribution method reflected here for the Representative Preferred Alternative, as a result, the potential for fallowing, crop switching, and other associated long term land -use patterns in any given area may vary and impacts may be mitigated in part by specific operational guidelines.

3.18 Indian Trust Assets

3.18.1 Affected Environment

The U.S. has a trust responsibility to tribes as defined by statutes, court decrees, treaties, or other applicable law.[22] ITAs are legal interests in assets held in trust by the federal government for the benefit of federally recognized Native American tribes or individual Native Americans (Reclamation 1994). ITAs can be located on or off established reservation lands and can consist of land, water entitlements;[23] natural resources; monies, such as trust funds; mineral rights; hunting, fishing, trapping, and gathering rights; and others. Beneficiaries of the Indian trust relationship are tribes and individual Native Americans; the U.S. is the trustee. ITAs are generally restricted against alienation (that is, they cannot be sold, transferred, abandoned, or lost without approval from the Secretary of the Interior). With federal authority and approval, ITAs may be leased to generate income for tribes or individual Native Americans (Department 2025).

It is the general policy of the Department to carry out activities in a manner that protects ITAs and avoids adverse effects whenever possible (Reclamation 1993). In accordance with Reclamation ITA policy and guidance (Reclamation 1994), tribal consultation addressing trust assets should be initiated with appropriate tribal groups and the Bureau of Indian Affairs (BIA), and the presence or absence of ITAs should be addressed explicitly in all NEPA documents. Reclamation has consulted with tribes regarding the proposed Post-2026 Operational Guidelines and Strategies for Lake Powell and Lake Mead Environmental Impact Statement.

The following sections summarize the affected environment for different types of ITAs. See **TA 18**, Indian Trust Assets, for additional detail.

Trust Lands

Indian trust lands are lands that the U.S. holds in trust for the benefit of a tribe (tribal trust land) or for an individual Native American (individual trust land). Trust lands may be located on or off a reservation. While reservations are not always synonymous with trust lands, the exterior boundaries of reservations are used to define the trust land assets for purposes of this NEPA analysis, to be

[22] Nothing in this technical appendix is intended to modify, abrogate, or create ITAs. Any particular ITA remains defined by and subject to applicable authority.
[23] Rights and entitlements may be used interchangeably in this technical appendix for simplicity, and no legal change to any ITA is intended.

inclusive. There are 30 federally recognized tribes in the Colorado River Basin; 29 of these have established reservations. Tribal land uses include, but are not limited to, communal and spiritual uses, domestic use, and agriculture and economic development.

Water Entitlements, Water Deliveries, and Storage and Conservation Options

The management and operation of the Colorado River and delivery of its waters to various users is governed by a complex set of treaties, statutes, Supreme Court decrees, and other settlements and agreements collectively known as the "Law of the River". In general terms, the Law of the River establishes a priority system for the distribution of available water. Higher priority (senior) water entitlements are filled first, and lower priority (junior) entitlements are filled next. Some tribal water entitlements have higher priorities and others are lower priorities. **Appendix C,** Shortage Allocation Model and Alternative Distribution Model Documentation, provides more detail on the priority of each tribal water entitlement in the Lower Basin.

TA 4, Water Deliveries, provides more detail on the Law of the River. **TA 18**, Indian Trust Assets, includes a discussion of tribal mainstream Colorado River water entitlements and CAP contracts.[24] The entitlements included in this analysis are consistent with those in the SAMs and ADMs (see **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation) and other sections of the EIS.[25]

Other Indian Trust Assets

ITAs can also include hunting, fishing, trapping, and gathering rights; mineral rights; and cultural, biological, and other resources. Whether specific rights or resources legally qualify as an ITA is complicated and depends on multiple factors, such as land status (Reclamation 1994). Reclamation consulted with tribes and the BIA to identify ITAs. To date, potential changes in water deliveries and activities affected by potential changes in water deliveries (for example, irrigated agriculture) have been the primary concerns related to ITAs.

Reclamation acknowledges that the 30 Basin Tribes depend on the Colorado River and its tributaries for a variety of purposes, including cultural and spiritual activities, wildlife, instream flows, recreation, and other purposes. See **TA 13**, Tribal Resources, and **TA 11**, Cultural Resources, for analysis of tribal and cultural resources, respectively. In general, those analyses apply to tribal and cultural resources that qualify as ITAs.

Although income derived from ITAs is not an ITA in and of itself, income derived from ITAs, such as agricultural products, water leases, and fees charged for outdoor recreation on tribal land, can be an important source of income for tribes.

3.18.2 Environmental Consequences

Following Reclamation ITA policy (Reclamation 1994), the following analysis discusses actions that affect the value, use, or enjoyment of ITAs.

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[24] While some entitlements are not ITAs, they are included for reference in **TA 18**, Indian Trust Assets.

[25] Tribes may have other sources of water, including groundwater and other surface water, which are not part of this analysis.

Methodology

The methodology varies for each type of ITA. Quantitative metrics are analyzed where possible; otherwise, a qualitative discussion is provided. Refer to **Section TA 18.2.1**, Methodology, for more information on the methodology used. As described in **Section 3.4.1**, the geographic scope of this EIS does not extend above Lake Powell and accordingly does not include an analysis of the impact on Upper Basin water users.

Impact Analysis Area

The impact analysis area includes land within the boundaries of reservations and off-reservation trust land within the Colorado River Basin (29 reservations are listed in **Section TA 18.1**).[26]

Assumptions

- Trust land includes land within the borders of established reservations and off-reservation trust land.
- For the water deliveries analysis, the assumptions of the CRSS modeling (**Appendix A**, CRSS Model Documentation) and SAM modeling (**Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation) apply.
- For potential impacts on agricultural land, the assumptions of the agricultural modeling apply (see **TA 16**, Socioeconomics, for more details).

Impact Indicators

- Percentage of normal water entitlement delivered to Upper and Lower Basin Tribes
- Changes in acres of irrigated tribal agricultural land in the Lower Basin

Issue 1: How would changes in dam operations affect tribal water rights, water deliveries, and water storage and conservation options?

With respect to potential tribal water deliveries, the alternatives can be distinguished based on the following characteristics:

- The maximum shortage, which affects the relative frequency and severity of Lower Basin water shortages, including potential dead pool–related reductions (that is, releases reduced by low Lake Mead levels or outlet limits).
- The approach used to distribute Lower Basin water under shortages.
- Options for tribes and other water users to conserve and store water in Lake Powell or Lake Mead.

Figure TA 18-2 and **Table TA 18-5** in **TA 18**, Indian Trust Assets, summarize the alternatives based on these characteristics. The following sections summarize the anticipated effects of the alternatives on water deliveries and the storage and conservation options.

[26] As discussed in **Section 3.18.1**, one of the 30 Basin Tribes does not have an established reservation; therefore, there are 29 reservations.

Upper Basin

Water Entitlements and Deliveries

No alternative would affect Upper Basin tribal water entitlements or deliveries.

Storage and Conservation Options

The No Action and Basic Coordination Alternatives have no new water storage mechanisms and would not affect water storage and conservation by Upper Basin Tribes. The other four alternatives, including the Preferred Alternative, do have new storage and conservation mechanisms. See **Chapter 2**, Description of Alternatives, and **Appendix S**, Additional Description of Alternatives, for a full description of these mechanisms and how they would operate. Note that in all cases, stored water would be available for water transactions with other Upper Basin water users, both within and across Upper Division States.

Lower Basin

Water Entitlements

The approaches to distributing Lower Basin shortages incorporated in all alternatives are designed to explore a wide range of potential concepts and impacts; they do not reflect an intention by Reclamation to alter apportionments or water entitlements. However, because the concepts would affect a range of users, impacts on deliveries to different entities are analyzed, and addressed in **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation.

Water Deliveries

In this analysis, three main factors combine to determine the potential Lower Basin tribal water deliveries in any given year:[27] (1) the magnitude of potential shortages, (2) the distribution method used to allocate water under shortages, and (3) the frequency of dead pool–related reductions. [28] This analysis focuses on the first two factors. The third factor, dead pool–related reductions, is not a focus of this analysis.

Figure TA 18-3 in **TA 18**, Indian Trust Assets, illustrates how the percentage of normal water delivery changes as shortages become more severe under different distribution methods. For the purposes of this analysis, tribes are aggregated into the following four groups based on entitlement priorities:[29]

- The "AZ CAP NIA" group has the most junior entitlements and includes tribes with Arizona CAP NIA-A and NIA-B priorities. This group consists of four tribes with contracts totaling approximately 177,000 afy.
- The "AZ CAP Indian, CAP M&I, and AZ 4i" group includes tribes with Arizona CAP Indian, CAP M&I, and Arizona 4i priorities. This group consists of 13 tribes and 16 individual entitlements (including mainstream water reserved for future settlement and unallocated), totaling approximately 374,000 afy.

[27] The phrase "potential water deliveries" is intended to recognize that some tribal water entitlements are not fully developed or utilized. For simplicity, this analysis assumes that water deliveries and water entitlements refer to the same quantities of water.
[28] Discussion of dead pool–related reductions can be found in **TA 4**, Water Deliveries.
[29] The number of tribes, water entitlements, and amounts listed below come from the SAM (see **Appendix C**, Shortage Allocation Model and Alternative Distribution Model Documentation, for modeling assumptions and descriptions of priority nomenclature).

- The "AZ 3" includes one tribe with Arizona third priority, totaling 50,000 afy.
- The PPR group is the most senior entitlements; this group includes five tribes in all three Lower Division States. This group of five tribes includes 15 discretely quantified entitlements totaling approximately 503,000 afy.

The DMDU analysis integrates information on the percentage of futures in which different amounts of shortages are estimated to occur under the different alternatives. For tribal water deliveries, deliveries of 20, 40, 60, and 80 percent of normal deliveries are modeled. The results show the percentage of futures in which these thresholds are met in 90 percent or more of the years within each modeled future.

The DMDU figures are presented in **Figure TA 18-4** through **Figure TA 18-12** in **TA 18**, Indian Trust Assets. Solely for the purposes of considering vulnerability within the DMDU modeling framework, a "preferred minimum performance" outcome is defined as a future trace in which at least 80 percent of normal water deliveries are estimated to be delivered in at least 90 percent of the years in a modeled future. In contrast, an "undesirable performance" future means that the preferred minimum performance criteria are not met. The 80 percent threshold was chosen as the preferred minimum performance because it is the model outcome with the largest quantity of water delivered.[30]

Key findings differentiating the alternatives based on the full-period DMDU modeling are listed below. See **Section TA 18.2.2** for additional details, including key findings by priority group.

- There is no alternative that is the most robust across the priority groups in terms of maximizing water deliveries to all tribes. The alternatives perform differently for the priority groups. For some priority groups, the performance depends on the importance placed on results, considering only shortages relative to the frequency of futures with dead pool–related reductions.
- Considering shortages only (that is, not considering dead pool–related reductions), the No Action Alternative is estimated to meet the preferred minimum performance criteria in 100 percent of normal water deliveries to all priority groups except the AZ CAP NIA group. This result is likely due to a lower maximum shortage compared with the other alternatives. However, the No Action Alternative has the highest potential for dead pool–related reductions of any alternative, with 70 percent of futures estimated to have dead pool–related reductions. Therefore, water delivery would be unlikely under the No Action Alternative.
- The CCS Comparative Baseline is similar to the No Action Alternative, except 22 percent of futures meet the preferred minimum performance criteria for the CAP Indian, CAP M&I, and AZ 4i priority group, and 6 percent of futures meet the preferred minimum performance criteria for the CAP NIA group. Dead pool–related reductions are estimated to occur in 50 percent of modeled futures, which is less frequent compared with the No Action Alternative.
- The Representative Preferred Alternative is the second-best performer for the PPR priority group. It is not among the most robust alternatives for any other priority group. Impacts under the Preferred Alternative may be different from what is shown in the DMDU figures for the Representative Preferred Alternative, as this alternative provides a framework that allows for

[30] In this context, "preferred minimum performance" and "undesirable performance" are terms selected to understand a modeling analysis, and they do not imply any policy, legal conclusion, or other conclusions about the analysis or ITAs.

shortages to be distributed based on agreements among states that may arise, consistent with sideboards described in **Chapter 2**.

- The Basic Coordination Alternative is not among the most robust alternatives for any priority group.
- The Enhanced Coordination Alternative has a more complicated pattern of robustness. Twenty-one percent of futures meet the preferred minimum performance criteria for all priority groups; this is less than some other alternatives. This is likely because shortages start relatively early compared with the other alternatives, and there is a high maximum shortage (see **Figure TA 18-2** and **Table TA 18-5** in **TA 18**, Indian Trust Assets). However, this alternative performs well in terms of delivering at least 60 percent of normal water, as it does so in 91–100 percent of modeled futures for all priority groups. This result is likely due, in part, to its use of the pro rata distribution method. Finally, this alternative has 16 percent of futures with dead pool–related reductions, which is among the fewest of the options modeled.
- Considering only shortages, the Maximum Operational Flexibility Alternative is more robust than the Enhanced Coordination Alternative for the two more senior water entitlements groups (PPR and AZ 3) and is less robust than the Enhanced Coordination Alternative for the two less senior water entitlements groups (AZ CAP Indian, M&I, and 4i; CAP NIA). It has the lowest percentage of futures with dead pool–related reductions (9 percent) of all the options modeled.
- The Supply Driven Alternative (LB Priority approach) generally is similar or less robust than the Maximum Operational Flexibility Alternative with respect to shortages for three of the four priority groups and has a higher percentage of futures with dead pool–related reductions (24 percent).
- The Supply Driven Alternative (LB Pro Rata approach) is closest to the Enhanced Coordination Alternative but does not meet the preferred minimum performance criteria as often; therefore, it is less robust.
- It is important to consider the first decadal subperiod, as the Preferred Alternative is a 10-year decision framework. The conclusions above all hold for the first decadal subperiod with the one exception: for the Arizona Priority 3 group, a case could be made that either the Maximum Operational Flexibility, Supply Driven (LB Priority approach), or Representative Preferred Alternatives are the best performing.[31] These three alternatives have various trade-offs between water deliveries considering only shortages and the percentage of futures with a dead pool-related reduction.

Storage and Conservation Options

The No Action and Basic Coordination Alternatives have no water storage mechanisms that would affect Lower Basin Tribes or the quantities of water available to them. Under both alternatives, water conserved under previous mechanisms that remains in Lake Mead in 2027 would be delivered in accordance with existing agreements. The other four alternatives do contain new water storage and conservation mechanisms. See **Chapter 2**, Description of Alternatives, for a full description of these mechanisms and how they would operate. Note that in all cases, stored water would be available for

[31] In the full period results, the Maximum Operational Flexibility Alternative performs better than the Representative Preferred Alternative.

water transactions with other Lower Basin water users, both within and across the Lower Division States. The Enhanced Coordination Alternative is unique in that it explicitly allows for compensating tribes for water used to contribute to a federally managed conservation pool in Lake Mead. See **Section TA 18.2.2** for additional details.

Issue 2: How would changes in dam operations affect Indian trust lands?

Changes in dam operations under the different alternatives would not affect the borders of established reservations or the definitions of any trust lands. Trust land will remain trust land. Future potential acquisitions of land into trust are not limited by the operations. Further, in addition to (uncontrollable) drought conditions in any given year, the different alternatives of various distributions of the available water could add an incremental impact on the use of trust lands. An important aspect of the use of trust lands involves agricultural land, as fluctuations in water levels are estimated to result in some tribal agricultural lands being fallowed. Other changes in the use of tribal land and resources are discussed in **TA 13**, Tribal Resources. The considerations therein generally apply to Trust and non-Trust resources.

Agricultural Land

The potential impacts of changes in dam operations on agricultural land are assumed to be inversely dependent on water deliveries, meaning agricultural impacts are estimated to increase as water deliveries decrease.

Upper Basin

As noted in the Upper Basin water deliveries section above, none of the alternatives, including the Representative Preferred Alternative, would directly or indirectly affect water deliveries to Upper Basin Tribes. However, changes in storage and conservation options under some alternatives could provide opportunities for tribal participation. All else equal, the new mechanisms for conserving and storing water for Upper Basin Tribes (contained in the Preferred, Enhanced Cooperation, Maximum Operational Flexibility, and Supply Driven [both LB Priority and LB Pro Rata approaches] Alternatives) would provide additional options for tribes in the Upper Basin.

Lower Basin

TA 16, Socioeconomics, discusses the potential impacts of changes in dam operations and resulting changes in water deliveries on tribal and non-tribal agricultural economies in the Lower Basin. Estimates are presented for several socioeconomic metrics: acres of fallowed agricultural land, direct market value, jobs, and economic output. Results are presented at the state level and by priority groups for Arizona, California, and Nevada. See **TA 16**, Socioeconomics, for a full discussion of the modeling and results. This section focuses on the acres of fallowed land as an indicator of potential impacts **to** Trust land.

Table TA 18-6 summarizes the modeling results for estimated changes in fallowed tribal agricultural land. Some key findings include the following:

- As indicated in the Lower Basin water deliveries analysis above, the seniority of water entitlements combined with the distribution method makes a large difference in the results.
- Tribal agriculture in Arizona is estimated to experience the largest impacts in terms of the absolute changes in acres of fallowed land. This is likely because the majority of the

reservation land is in Arizona (see **Figure TA 18-1** in **TA 18**, Indian Trust Assets). The Representative Preferred Alternative is would fallow the second-least number of acres in Arizona, relative to the other alternatives.

- No alternative is clearly the most robust for Arizona. The different alternatives and the CCS Comparative Baseline have varying trade-offs between fallowed acreage under shortages and the percentage of futures with dead pool–related reductions.
- In California and Nevada, impacts are only associated with the alternatives that use the pro rata distribution (the Enhanced Coordination and Supply Driven [LB Pro Rata approach] Alternatives). All the other alternatives, including the Representative Preferred Alternative, and the CCS Comparative Baseline use some variation of the priority system and estimate no reductions in water deliveries; therefore, there would be no fallowed agricultural land in these states.
- The Maximum Operational Flexibility Alternative performs the best for California and Nevada; this is because there are zero fallowed acres and the percentage of futures with dead pool–related reductions are minimized. This would be true for PPRs in Arizona as well.

Issue 3: How would changes in dam operations affect other ITAs?

Changes in dam operations would not directly affect the status and corpus of other ITAs. Trust assets will remain trust assets. Future potential acquisitions of assets into trust are not limited by the operations. Further, in addition to (uncontrollable) drought conditions in any given year, changes in dam operations could incrementally affect water levels, vegetation, fish, and wildlife, and therefore could indirectly affect the use of ITAs. General changes in vegetation, fish, and wildlife are discussed in their respective sections of this Final EIS.

Summary Comparison of Alternatives

How the alternatives affect ITAs depends on the type of ITA and other factors. For both irrigated agriculture and water deliveries in the Lower Basin, the most robust alternative depends on the interactions between the priority of water entitlements, the maximum shortages, and the percentage of futures with dead pool–related reductions. See **Section TA 18.2.8**, Summary Comparison of Alternatives, for more detailed summary comparisons of the alternatives by the type of ITA, basin, and priority group.

In general, the action alternatives are more robust than the No Action Alternative for water deliveries and irrigated agricultural land. All else equal, the action alternatives that use a variation of the priority distribution method (the Representative Preferred, Basic Coordination, Maximum Operational Flexibility, and Supply Driven [LB Priority approach] Alternatives) are more robust for more senior water entitlements; the action alternatives that use a variation of the pro rata distribution method (the Enhanced Coordination and Supply Driven [LB Pro Rata approach] Alternatives) are more robust for more junior water entitlements.

3.19 Visual Resources

3.19.1 Affected Environment

Visual resources are the physical features that make up the visible landscape, including land, water, vegetation, topography, and human-made features such as buildings, roads, utilities, and structures. They also include the response of viewers to those features.

Visual resources are important both to visitors to GCNP, Glen Canyon NRA, and Lake Mead NRA and to the Basin Tribes who use these lands for subsistence or ceremony uses. The Grand Canyon Protection Act of 1992 specifically calls for the conservation of visual resources, which are also a key component of federal management of these areas. GCNP, Glen Canyon NRA, and Lake Mead NRA are managed under their general plans which identify management direction for visual resources as part of their general management plan, which is described in **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Lake Powell and Glen Canyon Dam

Landscape Character

The landscapes of the Lake Powell and Glen Canyon area are characterized by sweeping vistas of red rock towers, buttes, and mesas typical of the Colorado Plateau (Fenneman 1931). Navajo Sandstone and desert varnish dominate the existing landscape character with Lake Powell framing these natural features. Lake Powell has deposits of calcium carbonate, which become visible as reservoir levels decrease. At lower lake elevations, the colorful sandstone canyon walls show a light-toned band of calcium carbonate deposit between the full reservoir elevation and the lower reservoir elevation; these deposits contrast with the natural, red-colored sandstone (see **Figure TA 19-1**, in **TA 19**, Visual Resources). Additionally, sediment deltas have formed near the inflow areas of Lake Powell as a result of sediments carried by the Colorado River and the San Juan, Dirty Devil, and Escalante Rivers, resulting in downstream-progressing deltas. These appear as expansive, deep, and eroding mud flats cut by river channels. For more information on existing landscape character, refer to **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Attraction Features

The analysis focuses on Cathedral in the Desert and Glen Canyon Dam, consistent with the 2007 Final EIS and 2024 Final SEIS. These were selected to focus on visibility of specific geologic features and large-scale built structures associated with each reservoir. Note that the discussion of potential impacts on recreation sites and other viewing locations is described under Issue Statement 2. For more information on these attraction features, see **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Lake Mead to Hoover Dam

Landscape Character

The landscapes of the Lake Mead and Hoover Dam area are similar to those described for the Lake Powell area, except the adjacent landscapes are more typical of the Basin and Range region, characterized by parallel, north–south-oriented mountain ranges surrounded by nearly level, typically undrained basins (Fenneman 1931). Similar to Lake Powell, Lake Mead has deposits of calcium carbonate that contrast with the natural rock colors. For more information on existing landscape character, refer to **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Attraction Features

The analysis will focus on Hoover Dam, consistent with the 2007 Final EIS and 2024 Final SEIS. For more information on this attraction feature, see **TA 19.1**, Affected Environment, in **TA 19**, Visual Resources.

Hoover Dam to SIB

The landscapes from the Hoover Dam area to the SIB are characterized by arid mountain ranges and intervening desert plains associated with the Basin and Range region (Fenneman 1931). The availability of Colorado River water has resulted in large areas of irrigated landscapes, including agricultural lands in Arizona, California, and Nevada (Lower Division States), which have altered the natural landscapes. This increased water availability has introduced vivid greens associated with crops and ornamental plantings into these landscapes and has expanded the influence of the Colorado River into adjacent arid lands beyond the narrow, natural riparian corridor.

3.19.2 Environmental Consequences

Methodology

Reclamation used methods similar to those in the 2007 Final EIS and 2024 Final SEIS to analyze potential impacts on visual resources. This analysis assesses the potential effects on attraction features, the extent of the visible calcium carbonate ring, and exposure of sediment deltas at reservoir inflow areas, while incorporating the DMDU framework for this EIS. Additionally, this analysis considers the effects of expanded shoreline exposure on the area's landscape character.

Using modeling and DMDU concepts, the analysis first focuses on the percent of time during the planning window that Lake Powell would decrease below elevation 3,550 feet. At that elevation, Cathedral in the Desert and other geological attraction features—including Gregory Bridge, La Gorce Arch, and other features inundated by Lake Powell—would become visible and accessible. Based on historical averages, Lake Powell was below 3,550 feet approximately 9.9 percent of months between October 2007 and May 2025. The alternatives comparison focuses on maintaining this lake elevation for at least 10 percent of the months during the planning window. Conversely, this analysis also identifies the percentage of preferred minimum performance futures in which Lake Powell would be above 3,550 feet, resulting in less of the upstream side of Glen Canyon Dam being visible, as higher reservoir levels obscure the structure.

The potential height of the calcium carbonate ring was calculated by comparing differing reservoir elevations with the full pool elevations of Lake Powell (3,700 feet) and Lake Mead (1,229 feet) under DMDU concepts. The assessment of effects from sediment deltas and shoreline exposure considers these differing reservoir elevations and references the analysis conducted in the 2007 Final EIS.

Reclamation added two new analysis items, similar to the 2024 Final SEIS, to assess impacts on the Colorado River's landscape character and broader landscape character in the Lower Division States. This assessment is based on changes in modeled hydrologic conditions under the No Action Alternative and CCS Comparative Baseline, as well as management direction associated with the action alternatives. To assess potential changes to the landscape character along the Colorado River (between Glen Canyon Dam and Lake Mead), this analysis includes a qualitative assessment of effects associated with lower flow rates and the potential inability to conduct HFEs from Glen Canyon Dam. For more information on historic flow rates along the Colorado River, refer to **Section TA 19.2.1**, Methodology, in **TA 19**, Visual Resources, and **Section 3.3**, Hydrologic Resources**.**

The assessment of potential impacts on the broader landscape character in the Lower Division States considered changes in annual Colorado River water supplies available to these states. This assessment identifies the extent of large-scale changes in visual character in irrigated landscapes, including changes associated with agricultural production through shortages and the potential for Lake Mead to reach dead pool–related reductions, as described in **Section 3.4**, Water Deliveries. This analysis considers and references assessment items contained in **Section 3.16**, Socioeconomics, including the effect of each alternative's proposed distribution of water on agricultural operations and the effect of increased dust generation from aridification of exposed lands, as described in **Section 3.7**, Air Quality, potentially impacting visibility and views within GCNP and other visually sensitive landscapes.

Impact Analysis Area

The visual resources impact analysis area was defined as the area within 5 miles of the Colorado River from Lake Powell to the SIB, including the full pool elevations of Lake Powell and Lake Mead. Visual effects beyond this geographic area were considered where appropriate, including the potential effects on the broader landscape character associated with potential decreased water availability for the Lower Division States. For more details on the impact analysis area, refer to **Section TA 19.2.1**, Methodology, in **TA 19**, Visual Resources.

Assumptions

- The analysis methods are consistent with the 2007 Final EIS and 2024 Final SEIS. Attraction features analyzed include Cathedral in the Desert, Glen Canyon Dam, and Hoover Dam.
- Decreasing flow rates along the Colorado River, and the potential inability to conduct HFEs from Glen Canyon Dam, would modify the river corridor's natural, visual character by limiting natural flooding processes.
- This EIS references the analysis from the 2007 Final EIS and 2024 Final SEIS regarding impacts associated with expanding sediment deltas.
- Decreasing water availability for the Lower Division States would result in large-scale changes to the visual character of irrigated landscapes, including those associated with agricultural production.

Impact Indicators

- Attraction features: Qualitative assessment describing effects on visibility and access to Cathedral in the Desert and effects from increased visibility of the upstream sides of Glen Canyon Dam and Hoover Dam, informed by the CRSS and DMDU analyses. Quantitative analysis showing the percentage of futures that meet the preferred minimum performance level where Lake Powell is below 3,550 feet (and thus Cathedral in the Desert would be visible and accessible) in at least 10 percent of months under each alternative. Conversely, this analysis identifies the percentage of futures that meet the preferred minimum performance level in which Lake Powell is above 3,550 feet, reducing visibility of the dam's upstream face.

- Calcium carbonate rings: Comparison of modeled ring height (feet) at Lake Powell and Lake Mead under each alternative, considering the CRSS and DMDU analyses.
- Exposed shoreline and sediment deltas: Qualitative assessment referenced from the 2007 Final EIS and 2024 Final SEIS, considering differing reservoir elevations under each alternative, to assess receding shorelines and formation of sediment deltas resulting from lower reservoir elevations.
- Colorado River landscape character: Qualitative description of the effect associated with proposed flow rates and the potential to conduct HFEs from Glen Canyon Dam under each alternative, considering modeling presented in **Section 3.9**, Vegetation Including Special Status Species; **Section 3.5**, Geomorphology and Sediment; **Section 3.14**, Recreation; and **Section 3.7**, Air Quality.
- Broader landscape character: Qualitative description of the effects associated with potential decreases in water availability for the Lower Division States on the broader landscape character. This includes considering modeling associated with potential changes to crop production resulting from proposed distribution of water, as described in **Section 3.16**, Socioeconomics, as well as the potential for Lake Mead to reach dead pool–related reductions as described in **Section 3.4**, Water Deliveries.

Issue 1: How would management of reservoir elevations affect visibility of attraction features?

The assessment of impacts on landscape character associated with the elevations of Lake Powell considers two concepts. The assessment notes that some visitors view visibility and access to Cathedral in the Desert and other attraction features inundated by Lake Powell (below 3,550 feet) as a benefit, while others prefer higher water levels. For more information on the first portion of this issue, refer to **Section TA 19.2.2**, Visibility of Attraction Features, in **TA 19**, Visual Resources.

The second part of the analysis focuses on keeping the Lake Powell water levels high, which reduces the visibility of Glen Canyon Dam, specifically when above 3,550 feet. As reservoir levels drop and more of the dam is exposed, its visual prominence increases and can dominate the surrounding landscape. As shown in **Figure TA 19-3** in **TA 19**, Visual Resources, the Enhanced Coordination and Maximum Operational Flexibility Alternatives would result in more preferred minimum performance futures where less of the upstream side of Glen Canyon Dam is visible because higher water levels obscure the structure. Lower flows could keep Lake Powell at higher elevations under the Enhanced Coordination and Maximum Operational Flexibility Alternatives compared with the CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches). Considering the first 10 years (modeled 2027-2039), the CCS Comparative Baseline, No Action Alternative, and all action alternatives would have similar results as during the full modeling period except the Enhanced Coordination Alternative, which would have a smaller percentage of preferable futures over the first 10 years compared to the full modeling period. The Representative Preferred Alternative exhibits a similar performance as the No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives for the first 10 years (modeled 2027-2039 period) with the results being within the range analyzed associated with these alterantives.

As shown in **Figure TA 19-4** in **TA 19**, Visual Resources, comparing DMDU modeling with the driest historic 10-year average flows, the CCS Comparative Baseline, No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would require higher flows to maintain similar elevations, which makes those alternatives more vulnerable to missing the preferred minimum performance level. Specifically, those alternatives would be more vulnerable than the Enhanced Coordination and Maximum Operational Flexibility Alternatives, with over 75 percent of traces in the reference hydrology exhibiting conditions resulting in the potential for Lake Powell to decrease below 3,550 feet for 10 percent or more of months during the planning period. Based on updated modeling, approximately 50 percent of traces in the reference hydrology under the Enhanced Coordination Alternative and Maximum Operational Flexibility Alternatives exhibit conditions that are expected to result in Lake Powell falling below 3,550 feet for 10 percent or more of the planning period. The Representative Preferred Alternative exhibits a similar performance as the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) with the results being within the range analyzed associated with these alternatives.

Modeling of lake levels within Lake Powell and Lake Mead indicates that, under the CCS Comparative Baseline and the No Action, Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives, Hoover Dam visibility follows the same pattern described for Glen Canyon Dam. Under the Basic Coordination Alternative and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), based on managing higher reservoir levels in Lake Mead than in Lake Powell, less of the upstream side of Hoover Dam would be visible, with comparatively more of the upstream side of Glen Canyon Dam being visible, as described above. Therefore, as Lake Mead reservoir levels decrease, exposing more of the dam's concrete structure, its effect on the area's landscape character would increase and further dominate the landscape character.

Issue 2: How would management of reservoir elevations affect landscape character, including visibility of calcium carbonate rings, exposed shoreline, and sediment deltas?

The assessment compares how often modeled futures fall into reservoir elevation ranges relative to full pool, and relates those ranges to changes in landscape character. This difference in reservoir elevations creates a light-toned band of calcium carbonate deposit as well as generating larger sediment deltas and exposing more shoreline. The lower the lake levels become, the impacts on landscape character increase including effects from calcium carbonate rings, exposed shoreline with trash and other debris, and sediment deltas. To compare alternatives, the assessment focused on whether calcium carbonate rings would exceed historic maximums at any time during the planning period.

For Lake Powell, the tallest calcium carbonate ring, which occurred in February 2023, was 179 feet tall. As shown in **Figure TA 19-5**, **Figure TA 19-6**, and **Figure TA 19-7** in **TA 19**, Visual Resources, based on updated modeling, all alternatives would exceed the historical maximum during the modeling period. In looking at a higher threshold of 200 feet tall, the CCS Comparative Baseline and the No Action Alternative, Basic Coordination Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would result in more futures where the calcium carbonate rings would exceed the 200-foot maximum during the modeling period. Only 5 percent, 4 percent, 13 percent, and 18 percent of futures under these alternatives, respectively, would result in calcium carbonate rings being less than 200 feet tall for all the months of modeling. Considering the first 10 years (modeled 2027-2039), the CCS Comparative Baseline, No Action Alternative, and all action alternatives would have similar results as the full modeling period except all the action alternatives would result in slightly higher percentage of preferable futures over the first 10 years compared to the full modeling period. The Representative Preferred Alternative would potentially exceed the 200-foot maximum height, with 45 percent of futures resulting in calcium carbonate rings being less than 200 feet for all months of modeling for the first 10 years (modeled 2027-2039 period) and 24 percent of futures during the full modeling period, with these results within the range analyzed associated with these alterantives.

For Lake Mead, the tallest calcium carbonate ring, which occurred in July 2022, was 180 feet. As shown in **Figure TA 19-8**, **Figure TA 19-9**, and **Figure TA 19-10** in **TA 19**, Visual Resources, based on updated modeling, all alternatives would exceed the historical maximum during the modeling period except for the Supply Driven Alternative (LB Pro Rata approach) which would have a 1 percent of futures where this threshold is not exceeded. In looking at a higher threshold of 200 feet tall, the CCS Comparative Baseline and the No Action Alternative would result in more futures where calcium carbonate rings would exceed the 200-foot maximum during the modeling period, with only 13 percent and 6 percent of futures under these respective alternatives resulting in calcium carbonate rings being less than 200 feet tall for all the months of modeling. Under the Basic Coordination Alternative, Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), these percentages would increase to 16 percent, 14 percent, 20 percent, and 40 percent, respectively. Considering the first 10 years (modeled 2027-2039), the CCS Comparative Baseline, No Action Alternative, and all action alternatives would have similar results as the full modeling period with all alternatives, including the No Action Alternative, resulting in slightly higher percentage of preferable futures over the first 10 years compared to the full modeling period. The Representative Preferred Alternative would likely exceed the 200-foot maximum height, with 23 percent of futures resulting in calcium carbonate rings being less than 200 feet for all months of modeling for the first 10 years (modeled 2027-2039) and 17 percent of futures during the full modeling period, with these results within the range analyzed associated with these alterantives.

As described in the 2007 Final EIS, sediment deltas would continue to build up over time and would be visible as the reservoir elevations decrease, including under the No Action Alternative. The expanding sediment deltas would become populated by vegetation, including tamarisk, which would introduce into the landscape bright greens that would contrast with the arid landscapes adjacent to Lake Powell and Lake Mead. Additionally, the receding shorelines would expose trash and other debris, which would diminish the area's landscape character. The lower the lake levels become, impacts on landscape character associated with calcium carbonate rings, exposed shoreline with trash and other debris, and sediment deltas would increase. Additionally, lower lake levels would facilitate re-emergence of side canyons including public access for recreation (see **Section 3.14**, Recreation). The calcium carbonate ring, exposed shoreline with trash and other debris, and sediment deltas would modify the landscape character along the edge of Lake Powell. These modifications would be visible for motorists on Utah State Route 95, boaters on Lake Powell, recreationists at developed and undeveloped recreation areas, and hikers on trails adjacent to Lake Powell. Similarly, the calcium carbonate ring, exposed shoreline with trash and other debris, and sediment deltas would modify the landscape character along the edge of Lake Mead; these modifications would be visible for motorists on US

Highway 93 (between Boulder City, Nevada, and the Hoover Dam), boaters on Lake Mead (including visitors to Overton Beach and Pearce Ferry), and hikers on trails adjacent to Lake Mead.

Issue 3: How would management of releases from Glen Canyon Dam affect landscape character along the Colorado River?

The No Action Alternative and the CCS Comparative Baseline would include lowering releases from Glen Canyon Dam as Lake Powell elevations decrease; this would result in releases as low as 7.0 maf when elevations drop below 3,525 feet. Since neither the No Action Alternative nor the CCS Comparative Baseline would reduce releases from Glen Canyon Dam under 7.0 maf, including if Lake Powell drops below power pool but remains above dead pool, there would be minor, incremental impacts on the landscape character along the Colorado River, including through the Grand Canyon. The current trend of increasing bank armoring associated with expanding riparian vegetation areas (including tamarisk) would continue under the No Action Alternative and CCS Comparative Baseline. If the elevation of Lake Powell were to drop below dead pool, flows from Glen Canyon Dam could dramatically decrease, resulting in more extensive impacts on the landscape character, including the appearance of river features not visible under current conditions. Additionally, the positive influence of the moving, turbulent Colorado River adds to the existing landscape character, which would be degraded if releases from Glen Canyon Dam were dramatically reduced. The No Action Alternative would result in relatively short and few HFE releases, providing fewer opportunities for sand bar volumes to increase compared with the CCS Comparative Baseline, which would result in longer and more frequent HFE releases with more opportunities for increased sand bar volumes.

The Basic Coordination Alternative would result in impacts similar to those under the No Action Alternative and CCS Comparative Baseline, since it includes a similar range of releases from Glen Canyon Dam, but would include an increased number of futures where HFEs are conducted. The Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches) would include lower releases—as low as 4.7 maf, which is lower than historical minimum flows. Lower releases from Glen Canyon Dam would result in less water flowing along the Colorado River (and through the Grand Canyon), which could increase existing trends of bank armoring associated with more extensive riparian vegetation, including tamarisk. The Representative Preferred Alternative would also include lower releases, as low as 6.0 maf, which would result in similar impacts along the Colorado River as the other action alternatives but since these releases would result in more water flowing along Colorado River, the trends described above would be tempered. Lower releases also could limit the number of times an HFE could be triggered from Glen Canyon Dam; a trigger would only occur when the HFE furthers maintenance of target reservoir elevations.

The Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives would result in the greatest number of futures where HFEs are conducted. These lower flows may also result in the appearance of river features not visible under current conditions and less movement of the river's natural sandbars. If yearly elevations facilitate releases of 7.0 maf or more under the Enhanced Coordination, Maximum Operational Flexibility, Supply Driven (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternatives, the impacts under these alternatives would be similar to those described under the No Action Alternative and CCS Comparative Baseline as the lower releases from Glen Canyon Dam would be avoided. If the elevation of Lake Powell were to drop below dead pool, flows from Glen Canyon Dam could dramatically decrease, resulting in impacts similar to those described under the No Action Alternative and CCS Comparative Baseline. For more information on the impacts on riparian vegetation, refer to **Section 3.9**, Vegetation Including Special Status Species; for impacts associated with sand bars, including their volume, refer to **Section 3.5**, Geomorphology and Sediment; and for impacts on recreation, including the visibility of river features, refer to **Section 3.14**, Recreation.

Issue 4: How would management of water availability for the Lower Division States affect landscape character?

Since the No Action Alternative would include minor (0.6 maf) adjustments to the distribution of water for Arizona and Nevada (but no adjustments for California) based on lowering Lake Mead elevations, there would initially be a limited incremental effect on irrigated landscapes, including those in agricultural use. If elevations in Lake Mead were to drop to dead pool (895 feet), flows from Lake Mead would dramatically decrease, resulting in lower water deliveries than currently allocated, affecting all three Lower Division States. As described in **Section 3.4**, Water Deliveries, the No Action Alternative would result in the most futures where dead pool–related reductions may be reached during the modeling period. Depending on the duration of these decreased water deliveries, the character of irrigated and agricultural landscapes within the Lower Division States would be modified through aridification of these areas; this would diminish the vivid greens associated with crops and ornamental plantings. The influence of the Colorado River on adjacent lands would narrow as these areas transition to their natural, arid condition. This would result in large-scale changes to the landscape character compared with the existing condition. The aridification of these lands could also result in more exposed soil, generating fugitive dust affecting visibility within the region, including from GCNP and other highly valued viewsheds. For more details on the impacts related to fugitive dust, please see **Section 3.7**, Air Quality.

The following alternatives all include shortages designed to avoid reaching dead pool, temper the impacts on the character of irrigated and agricultural landscapes within the Lower Division States, and avoid more extensive impacts if Lake Mead reached dead pool. If Lake Mead reaches dead pool elevation during the planning period, impacts for all alternatives would be similar to those described under the No Action Alternative.

The CCS Comparative Baseline would include a series of water supply adjustments for the Lower Division States based on lower elevations of Lake Mead. If water levels in Lake Mead drop below 1,075 feet, effects similar to those described under the No Action Alternative would occur, with conservation measures tempering these effects. As Lake Mead approaches dead pool, to avoid a dramatic decrease in water releases from Hoover Dam affecting all three Lower Division States, more reductions (up to 1.38 maf) could occur. These reductions to avoid reaching dead pool would temper the impacts on the character of irrigated and agricultural landscapes within the Lower Division States, as described under the No Action Alternative.

The Basic Coordination Alternative would have impacts similar to those under the No Action Alternative, as there would be adjustments to the distribution of water for Arizona and Nevada, but no adjustments for California, based on lowering Lake Mead elevations. As the Lake Mead elevation drops below 1,160 feet, shortages would begin; they would increase to 1.48 maf when Lake Mead is below 1,110 feet. Due to increased shortages under this alternative, the Basic Coordination Alternative would result in the second most futures where dead pool–related reductions may be reached during the modeling period, as described in **Section 3.4**, Water Deliveries.

Under the Enhanced Coordination Alternative, there is a potential for greater shortages than under the No Action Alternative, CCS Comparative Baseline, and Basic Coordination Alternative, with shortages (up to 3.0 maf) being distributed pro rata among mainstream lower Colorado River water users independent of state. These shortages would occur in all three Lower Division States and incrementally affect irrigated landscapes, including those in agricultural use, based on the extent of the shortage. As described in **Section 3.4**, Water Deliveries, the Enhanced Coordination Alternative would result in the second least number of futures where dead pool–related reductions may be reached during the modeling period.

Under the Maximum Operational Flexibility Alternative, there is a potential for greater shortages than under the CCS Comparative Baseline and the Enhanced Coordination, No Action, and Basic Coordination Alternatives, with shortages being based on priority. These shortages would occur based on the total system effective storage and capacity, as described in Appendix S, **Section S.4.1.1**, Shortage Conditions, with shortages up to 4.0 maf. These shortages would occur in all three Lower Division States and incrementally affect irrigated landscapes, including those in agricultural use, based on the extent of the shortage. As described in **Section 3.4**, Water Deliveries, the Maximum Operational Flexibility Alternative would result in the least number of futures where dead pool–related reductions may be reached during the modeling period.

Under the Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), there is a potential for larger shortages (up to 2.1 maf) than under the CCS Comparative Baseline and the No Action and Basic Coordination Alternatives, with shortages being distributed based on priority within a state or pro rata within that state as described in Appendix S, **Section S.5.1.1**, Shortage Conditions. If water levels in Lake Mead drop below 1,145 feet, effects similar to those described under the No Action Alternative are anticipated, with conservation measures tempering these effects. As lake levels continue to drop toward 1,000 feet, all three states would receive less water from the Colorado River under this alternative through proposed shortages, up to 2.1 maf, and conservation measures.

The Representative Preferred Alternative would result in shortages up to 3.0 maf, distributed based on Lower Basin consensus arrangements, if they exist, or otherwise distributed based on the priority system, with initial shortages beginning at 1.5 maf in 2027 and 2028. Consultation would occur if Lake Mead elevation were projected to be less than 1,000 feet to determine if additional reductions are needed in the Lower Basin (including Mexico). As described in **TA 4**, Water Deliveries, the Representative Preferred Alternative, similar to the Enhanced Coordination and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives, would be in the group of alternatives with the second-fewest futures involving dead pool–related reductions during the modeling period (Maximum Flexibility has the fewest futures). If Lake Mead reaches dead pool elevation during the planning period, impacts would be similar to those described under the No Action Alternative. These results are within the range analyzed across the other alternatives.

For more information on the impacts on agricultural operations, refer to **Section 3.16**, Socioeconomics, and for more information on the specific, state-level water deliveries, refer to **Section 3.4**, Water Deliveries.

Summary Comparison of Alternatives

In general, alternatives that facilitate higher reservoir elevations, maintain higher flows along the Colorado River, including through Grand Canyon, and support full water deliveries to the Lower Division States would result in the lowest impacts on visual resources and landscape character. While some users may prefer lower lake levels in Lake Powell, to allow Cathedral in the Desert and other attraction features inundated by Lake Powell to be visible and accessible, in general higher water levels would result in lower impacts on landscape character because there would be shorter calcium carbonate rings, less exposed shoreline (including trash and other debris), and smaller sediment deltas.

During wet hydrologic conditions, the range of alternatives would generally produce conditions where lake levels and flows along the Colorado River would result in minimal impacts on landscape character.

Under drier conditions, the Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives would facilitate more futures with higher reservoir elevations and lower flows along the Colorado River to minimize the risk of reaching dead pool. These alternatives also include larger water delivery shortages to the Lower Division States, which were designed to avoid reaching dead pool. These alternatives would result in shortages up to 3.0 maf and 4.0 maf, depending on the alternative, which would incrementally affect irrigated landscapes, including those in agricultural use, as shortages occur.

The CCS Comparative Baseline, No Action, Basic Coordination, and Supply Driven (both LB Priority and LB Pro Rata approaches) Alternatives would result in the most futures where landscape character is affected by lower water levels in Lake Powell and higher flows along the Colorado River, which would increase the risk of reaching dead pool. Based on management to keep water levels higher in Lake Mead than Lake Powell, under the Basic Coordination Alternative and Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), impacts associated with lower Lake Mead reservoir levels would be reduced and impacts would be similar to those under the Enhanced Coordination, Maximum Operational Flexibility, and Representative Preferred Alternatives.

The CCS Comparative Baseline and the No Action and Basic Coordination Alternatives would include smaller shortages in water deliveries to the Lower Division States—0.6 maf, 1.38 maf, and 1.48 maf, respectively—resulting in limited initial effects on irrigated landscapes compared with the Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, Supply Driven Alternative (both LB Priority and LB Pro Rata approaches), and Representative Preferred Alternative. If dead pool is reached, however, the character of irrigated and agricultural landscapes within the Lower Division States would be more dramatically modified through aridification of agricultural and other irrigated landscapes. The Enhanced Coordination Alternative, Maximum Operational Flexibility Alternative, Supply Driven Alternative, and Representative Preferred Alternative would result in the least number of futures, with Maximum Operational Flexibility resulting in the fewest, where dead pool-related reductions may be reached during the planning period.