DEPARTMENT OF THE INTERIOR

DRAFT
ASSESSMENT OF ENVIRONMENTAL IMPACT

OPERATION OF GLEN CANYON DAM AND LAKE POWELL
COLORADO RIVER STORAGE PROJECT
ARIZONA - UTAH

PREPARED BY
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ARIZONA, UTAH

ASSESSMENT OF ENVIRONMENTAL IMPACT

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ASSESSMENT OF ENVIRONMENTAL IMPACT

1. History and Background

1.1 Legal and Institutional Factors

The Colorado River is a highly institutionalized stream. Use of its water is governed by a treaty with Mexico, two interstate compacts, water laws of seven States, numerous Federal statutes, court decrees, and water and power contracts. Some of the more important documents that are relative to the "Law of the River" are listed below:

- Supreme Court Decree in Winters v. U.S. - 1908.
- Supreme Court Decree in Wyoming v. Colorado - June 5, 1922.
- Colorado River Compact - November 24, 1922.
- Boulder Canyon Project Act - December 21, 1928.
- California Limitation Act - March 4, 1929.
- Seven-Party Water Agreement - August 18, 1931.
- Boulder Canyon Project Water Contracts - February 21, 1930, through the present.
- Boulder Canyon Project Power Contracts - April 26, 1930, through the present.
- Boulder Canyon Project Adjustment Act - July 19, 1940.
- Mexican Water Treaty - November 27, 1945, and subsequent minutes.
- Upper Colorado River Basin Compact - October 11, 1948.
- Colorado River Storage Project Act - April 11, 1956.
- General Principles to Govern, and Operating Criteria, for Glen Canyon Reservoir and Lake Mead During the Lake Powell Filling Period - April 2, 1962.
- Supreme Court Decree in Arizona v. California - March 9, 1964.
- Lake Mead Flood Control Regulations - July 29, 1968.
- Colorado River Basin Project Act (Public Law 90-537, 90th Congress, approved September 30, 1968).
- Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs - July 10, 1970.
- State Water Laws.
- U.S. v. District Court, Eagle County, Colorado - 1971.
- Contracts for sale of water from Colorado River Storage Project Reservoirs.

1.1.1 Compacts and Treaties

Colorado River Compact - This Compact, among other things:

a. Divides the Colorado River Basin into an Upper Basin and Lower Basin at Lee Ferry, Arizona;

b. Divides the beneficial consumptive use of water between the Upper and Lower Basins;

c. Provides for a minimum delivery to the Lower Basin of 75,000,000 acre-feet every 10 years at Lee Ferry; and

d. Provides for sharing equally, by the Upper and Lower Basins, the burden of delivery of any deficiency in water available in the Colorado River to satisfy the water Treaty with the Republic of Mexico.

Mexican Water Treaty. This Treaty provides in Article 10:

"Of the waters of the Colorado River, from any and all sources, there are allotted to Mexico:

"(a) A guaranteed annual quantity of 1,500,000 acre-feet. . .

"(b) . . . in any year in which, as determined by the United States Section, there exists a surplus of waters . . ., the United States undertakes to deliver to Mexico . . . additional waters of the Colorado River System to provide a total quantity not to exceed 1,700,000 acre-feet a year . . . ."

1.1.2 Federal Laws and Regulations

1.1.2.1 Colorado River Storage Project Act-1956. The Colorado River Storage Project Act (CRSP) provides for the development of water for consumptive use within the Upper Basin, control of floods, and as an incident thereto, the production of electrical energy. Section 7 further provides that the operation of CRSP powerplants be integrated with all other Federal powerplants ". . . to produce the greatest practical amount of firm power and energy that can be sold at firm power and energy rates . . . ." Section 8 authorizes the inclusion of facilities for development of recreation and mitigation and enhancement of fish and wildlife. On this basis, minimum flows for fish and recreation below Lake Powell have been established.

1.1.2.2 <u>General Principles to govern, and operating criteria, for the Glen Canyon Reservoir and Lake Mead during the Lake Powell Filling Period - 1962</u>.

The following principles and criteria are based on the exercise, consistent with the Law of the River, of reasonable discretion by the Secretary of the Interior in the operation of the Federal projects involved. The case generally styled "Arizona v. California, et al, No. 9 Original" is in litigation before the Supreme Court of the United States. Anything which is provided for herein is subject to change consistent with whatever rulings are made by the Supreme Court which might affect the principles and criteria herein set out. They may also be subject to change due to future Acts of the Congress.

1.1.2.3 <u>Lake Mead Flood Control Regulations - 1968</u>.

According to the Flood Control Act of 1944 (58 Stat. 890), it is the duty of the Secretary of War to prescribe rules for the use of flood control space on Federal projects. Flood control criteria for the use of up to 5,350,000 acre-feet in Lake Mead have been established and are contained in the Federal Register (Vol. 33, No. 147, July 30, 1968).

1.1.2.4 <u>Colorado River Basin Project Act - 1968</u>.

It is the object of this Act to provide a program for the further comprehensive development of the water resources of the Colorado River Basin and for the provision of additional and adequate water supplies for use in the Upper as well as in the Lower Colorado River Basin. This program is declared to be for the purposes, among others, of upgrading of and preventing the degradation of the quality of water of the Colorado River; of regulating the flow of the river; controlling floods; improving navigation; providing for the storage and delivery of the waters of the Colorado River for reclamation of lands, including supplemental water supplies, and for municipal, industrial, recreational, and other beneficial purposes; improving conditions for fish and wildlife, and the generation and sale of electrical power as an incident of the foregoing purposes.

It is the policy of the Congress that the Secretary of the Interior (hereinafter referred to as the "Secretary") shall continue to develop, after consultation with affected States and appropriate Federal agencies, a regional water plan, consistent with the provisions of this Act and with future authorizations, to serve as the framework under which projects in the Colorado River Basin may be coordinated and constructed with proper timing to the end that an adequate supply of water may be made available for such projects, whether heretofore, herein, or hereafter authorized.

1.1.2.5 Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs - 1970

Criteria for coordinated long-range operation of Colorado River reservoirs pursuant to the Colorado River Basin Project Act of September 30, 1968 (Public Law 90-537) were promulgated in compliance with Section

602 of Public Law 90-537. They are to control the coordinated long-range operation of the storage reservoirs in the Colorado River Basin constructed under the authority of the Colorado River Storage Project Act (hereinafter, "Upper Basin Storage Reservoirs") and the Boulder Canyon Project Act (Lake Mead). The Operating Criteria are administered consistent with applicable Federal laws, the Mexican Water Treaty, interstate compacts, and decrees relating to the use of the waters of the Colorado River.

The Secretary may modify the Operating Criteria from time to time in accordance with section 602(b) of Public Law 90-537. The Secretary will sponsor a formal review of the Operating Criteria, at least every 5 years, with participation by State representatives as each Governor may designate and such other parties and agencies as the Secretary may deem appropriate.

1.1.3 Power Contracts

Power contracts have been executed with preference customers in the Upper Colorado River Basin area for sale of power and energy available from all powerplants. The contracts are executed for a period of not more than about 20 years. The Glen Canyon powerplant supplies three-fourths of all hydroelectric power produced in the Upper Basin with the bulk of its power going south and east into Arizona, Colorado and New Mexico.

1.2 Project Plan

Under the authorization and direction of the Boulder Canyon Project Act of July 19, 1940, the Bureau of Reclamation proceeded with studies and investigations of a comprehensive plan for the utilization of the waters of the Colorado River system for irrigation, electric power and other purposes in both the Upper and Lower Basins. An inventory report published in 1946 described the water resources, needs and problems, and the then present and potential development of the Colorado River for irrigation, power production, flood and silt control, and other beneficial uses in the States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. This inventory was followed by a report in December 1950 on a plan for the development and construction of the Colorado River Storage Project.

1.2.1 Colorado River Storage Project Plan - HD 364

The Colorado River Storage Project Plan developed in the 1950 Report and published as part of House Document 364, 82d Congress, 2nd Session, included Glen Canyon and nine other reservoirs with a total combined storage capacity of 48,555,000 acre-feet and powerplants having a combined installed capacity of 1,622,000 kilowatts as shown below.

Project Unit	River	Height of dam above river(ft)	Total reservoir cap.(ac-ft)	Power installation (kW)
Cross Mountain	Yampa	295	5,200,000	60,000
Crystal	Gunnison	305	40,000	48,000
Curecanti	do	475	2,500,000	54,000
Echo Park	Green	525	6,460,000	200,000
Flaming Gorge	do	440	3,940,000	72,000
Glen Canyon	Colorado	580	26,000,000	800,000
Gray Canyon	Green	445	2,000,000	210,000
Navajo	San Juan	335	1,200,000	30,000
Split Mountain	Green	245	335,000	100,000
Whitewater	Gunnison	255	880,000	48,000
Total			48,555,000	1,622,000

Of the total system storage, 37,530,000 acre-feet, including 20,000,000 acre-feet of storage capacity at Glen Canyon between elevation 3490 and 3700 feet, was planned as active storage that would be released during drouth periods to meet flow requirements at Lee Ferry of the Colorado River Compact. A supplement to the 1950 Report dated October 1953, and included in HD 364, recommended Glen Canyon Dam with a 26,000,000 acre-foot reservoir as an initial unit for construction of the Colorado River Storage Project.

1.2.2 Glen Canyon Dam and Powerplant and Lake Powell

Definite plan studies of the Colorado River Storage Project facilities authorized in 1956 by Public Law 485, 84th Congress, led to the construction of a dam that would provide a reservoir with a maximum normal water surface elevation at 3700 feet m.s.l. and a powerplant rated at 900,000 kilowatts. A resurvey of the reservoir basin revealed that the capacity of such a reservoir to 3700 feet elevation would be 27,000,000 acre-feet of total storage rather than the 26,000,000 acre-feet that had been originally estimated.

1.2.2.1 Filling Operation

On April 2, 1962, the Secretary of the Interior approved "General Principles to Govern and Operating Criteria, for Glen Canyon Reservoir and Lake Mead during the Lake Powell Filling Period" (published in the Federal Register, 27 F.R. 6851, July 19, 1962). These criteria provided, among other things that, while gaining storage in Lake Powell to elevation 3,490 feet, a minimum of 1,000 cfs and 1.0 million acre-feet per year would be released to the river downstream and further that releases from Lake Mead would be restricted to those needed to satisfy downstream uses of water other than for power.

Storage of water was initiated with the closure of the right Glen Canyon Dam diversion tunnel in January 1963; however, only minor amounts were accumulated until the gates in the left diversion tunnel were closed part way on March 13, 1963, to reduce the release to near 1,000 cfs. Releases from Lake Powell were maintainted at approximately 1,000 cfs are such greater amounts needed to meet 1.0 million acre-feet annual release requirement until March 26, 1964, when the level of Lake Mead receded to within one foot of the elevation of the rated head of its powerplant. At this point the release from Lake Powell was increased to avoid having Lake Mead drop below rated head which caused the level of Lake Powell to recede from elevation 3,415 feet to elevation 3,394 feet. On May 11, 1964, the release from Lake Powell was again reduced to near 1,000 cfs. By August 16, 1964, the level of Lake Powell had risen to elevation 3,490 feet, the minimum elevation at which the powerplant can be operated, and Lake Mead had receded to elevation

1,100 feet. Even though after August 16, 1964, all of the inflow to Lake Powell was released, the level of Lake Mead continued to recede until April 3, 1965, when it reached a low of 1,088 feet. By June 23, 1965, the water surface of Lake Mead had risen to elevation 1,123 feet, the rated head of the Hoover Powerplant, and accumulation of storage in Lake Powell was resumed. The content and water surface of Lake Powell at the end of each water year since storage, was initiated is shown in the following table.

Initial Filling of Lake Powell

Water Year ending Sept. 30	Reservoir Content		Water Surface elevation (feet)
	Total (acre-feet)	Live (acre-feet)	
1963	2,535,000	537,000	3,394
1964	6,213,000	4,215,000	3,492
1965	8,464,000	6,466,000	3,530
1966	8,421,000	6,423,000	3,529
1967	8,358,000	6,360,000	3,528
1968	9,512,000	7,514,000	3,545
1969	11,706,000	9,708,000	3,573
1970	14,037,000	12,039,000	3,599
1971	15,607,000	13,609,000	3,614
1972	14,486,000	12,488,000	3,603
1973	19,282,000	17,284,000	3,646
1974	20,009,000	18,011,000	3,652
1975	22,200,000	20,202,000	3,668

1.2.2.2 Long-Range Integraded Operation

Following the publication of "Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs" in the Federal Register on June 10, 1970, the operation of Lake Powell as well as the other reservoirs of the Colorado River system was governed by those criteria. The actual integrated operation of Lake Powell since the promulgation of these criteria is described in the paragraphs that follow.

1971

Releases from Lake Powell during Water Year 1971 were governed primarily by the objective of providing a delivery to the lower basin of 75 million acre-feet for the critical initial filling period 1963-72. A total of 8,558,000 acre-feet was released from Lake Powell during Water Year 1971 with 8,574,000 acre-feet passing the Compact Point at Lee Ferry, Arizona. On September 30, 1970, Lake Powell water surface was at elevation 3,599 feet with an active or live storage of about 12.0 million acre-feet. The high water surface elevation of 3,622 feet occurred on July 11, 1971, when the reservoir had 14.5 million acre-feet of active storage.

1972

A release of more than 9 million acre-feet was scheduled for Water Year 1972 in order to assume a delivery to the lower basins of 75 million acre-feet for the 10-year period 1963-72. A total of 9,310,000 acre-feet was actually released from Lake Powell during Water Year 1972 with 9,330,000 acre-feet passing the Compact Point at Lee Ferry, Arizona. The 10-year, 1963-72, total delivery at the Compact Point was 75,309,000 acre-feet. On September 30, 1971, Lake Powell had a water surface elevation of 3,614 feet, and an active storage of 13,609,000 acre-feet.

The high water surface elevation for the year occurred on June 27, 1972, when the reservoir had 14,198,000 acre-feet of active storage at elevation 3,620 feet.

1973

During Water Year 1973 the plan for operating the reservoir of the Colorado River system including Lake Powell included the storage and release of such quantities of water at Lake Powell to cause the storage in Lake Powell and Lake Mead to be equal at the end of September 1973. The order issued by the Federal District Court in Salt Lake City on February 27, 1973, to limit the storage of water in Lake Powell to a maximum level of elevation 3,606 feet, the boundary of Rainbow Bridge National Monument, resulted in the release to the Lower Basin of about 1,425,000 acre-feet of water that under the existing criteria (promulgated as required by P.L. 90-537) would have been stored in Lake Powell. Consequently, a total of 10,111,000 acre-feet was released from Lake Powell during Water Year 1973 with 10,141,000 acre-feet passing the Compact Point at Lee Ferry, Arizona. On September 30, 1972, the surface of Lake Powell was at elevation 3,603 feet with an active storage of 12,488,000 acre-feet. The high water surface elevation for the year occurred on September 19, 1973, when the reservoir contained 17,306,000 acre-feet of active storage at elevation 3,646 feet.

1974

A minimum water release of 8.23 million acre-feet from Lake Powell was scheduled for Water Year 1974 as provided in the Operating Criteria since the forecasted runoff indicated that with such a release the active storage in Lake Powell would be less than the active storage in Lake Mead at the end of September 1974 with such an operation.

Actual water release from Lake Powell during Water Year 1974 was 8,259,000 acre-feet as measured at the Lees Ferry gaging station. The water passing the Compact Point at Lee Ferry totalled 8,270,000 acre-feet for the year ending September 30, 1974. A year earlier, on September 30, 1973, Lake Powell water surface elevation was at 3,646 feet with an active storage of 17,284,000 acre-feet. During the succeeding fall and winter months, the reservoir remained at a fairly constant level. Releases were scheduled in the early spring to integrate surplus hydroelectric power from the northwest with CRSP power production. The April-July 1974 runoff above the gage at Lees Ferry, Arizona, undepleted by Colorado River Storage Project reservoirs was 7.1 million acre-feet or 85 percent of the 1906-68 average. Although the snowmelt runoff was velow average, a new all-time high water elevation of 3,667 feet was reached on June 30, 1974, when the reservoir contained 20,103,000 acre-feet of active storage.

1975

During Water Year 1975, Lake Powell was operated as part of the Colorado River Storage Project, in accordance with governing compacts and laws to provide river regulation, optimum power production, recreational opportunities, and fish and wildlife benefits.

On September 30, 1974, Lake Powell water surface elevation was at 3,652 feet, with an active storage of 18,010,000 acre-feet. During the fall and winter months, the reservoir water level remained fairly constant. Releases of water for hydropower generation were scheduled in the early spring to integrate surplus hydroelectric power from the Northwest with CRSP power production. The April-July 1975 runoff above the gate at Lees Ferry, Arizona, was 10.4 million acre-feet or 133 percent of the

1906-68 average. A record high-water elevation occurred on July 25, 1975, when the reservoir contained 21,177,000 acre-feet of active storage, with the water surface at elevation 3,675 feet. That was about 8 feet higher than the former record in 1974.

1.2.3 Plan for Coordinated Operation - Lake Powell and Lake Mead

Because Lake Powell and Lake Mead are operated as multi-purpose reservoirs on the Colorado River, a high degree of coordination must be maintained. Each month, a new 12-month operation plan is prepared for Lake Powell, Lake Mead and other reservoirs of the Colorado River system to reflect changes that have occurred during that past month as well as future operating limitations or requirements which have been recognized since the previous monthly plan was issued. The 12-month plan recognizes these purposes and objectives and provides information concerning the following as a basis for day-to-day operations:

Lake Powell

a. Make storage projections for comparison with storage required by Section 602(a) of Public Law 90-537.

b. Control inflow to Lake Powell, including releases from upstream reservoirs.

c. Monitor water surface elevation, surface storage, evaporation, and estimated bank storage resulting from Lake Powell operation.

d. Generate power at Glen Canyon Powerplant as part of the CRSP system.

e. Release from Lake Powell the amount of water available for fish, recreation, and compact delivery requirements.

Lake Mead

a. Store inflowing water for future use in accordance with existing laws, compacts, treaties and contracts.

b. Minimize the waste of stored water while maintaining storage space required for flood control.

c. Release stored water as required to meet downstream water orders for diversion within the United States and for delivery to Mexico in accordance with the treaty.

d. Provide energy in a manner consistent with the pattern and magnitude of needs of the energy allottees.

e. Maintain favorable water surface levels and flows between all reservoirs in the Lower Colorado River Basin.

f. When possible within legislative priorities, provide a stable or rising Lake Mead water surface during the bass spawning season to the extent ongoing studies indicate is necessary to maintain an acceptable bass fishery.

g. When possible within legislative priorities, assist in the maintenance and enhancement of the fisheries downstream of Hoover Dam.

1.2.4 Participating Projects

In connection with the development of the participating projects of the Colorado River Storage Project, the prime purpose is the use of water for beneficial purposes. The operation and maintenance of these projects are not only designed to accomplish this primary purpose but also to conserve the scenery, the natural, historical, and wildlife values, and to provide for public use and enjoyment of water areas created by these projects. The upstream regulation by the participating project reservoirs as well as other CRSP reservoirs will make the magnitude of annual fluctuation at Glen Canyon less and will also cause less flooding and erosion in the Upper Colorado Basin during runoff season.

1.2.4.1. Relationship and Effect on CRSP Reservoirs.

The diversion of water from the Colorado River and its tributaries for transmountain diversion or inbasin use for irrigation, municipal and industrial, and other consumptive uses associated with both participating projects (as defined in the CRSP Act) and nonparticipating projects impair the flow of the Colorado River at Lee Ferry, Arizona, in meeting the obligation of the Colorado River Compact. This impairment is most acute in dry years, or periods of years when without the availability of stored water, which could be released to supplement the flow at Lee Ferry, the uses in the Upper Basin would have to be curtailed. The reservoirs of the Colorado River Storage Project (Lake Powell, Flaming Gorge, Navajo, Blue Mesa, Morrow Point, and Crystal) have been constructed for this purpose. As the use of more and more of the Colorado River water that was allocated to the Upper Basin by the Colorado River Compact is developed by the participating projects less will remain in the river system and less flexibility will remain in the operation of the CRSP reservoirs after institutional constraints have been satisfied.

2. Description of Present Operating Program

2.1 Operation to Meet Long-Range Objectives

Lake Powell in coordination with the other reservoirs of the Colorado River Storage is being operated in accordance with the institutional and legal constraints that govern the storage and release of the runoff for river regulation, domestic use, irrigation, flood control, hydroelectric power generation, fish and wildlife propagation, recreation, and water quality control.

2.1.1 To Satisfy Requirements of Colorado River Compact

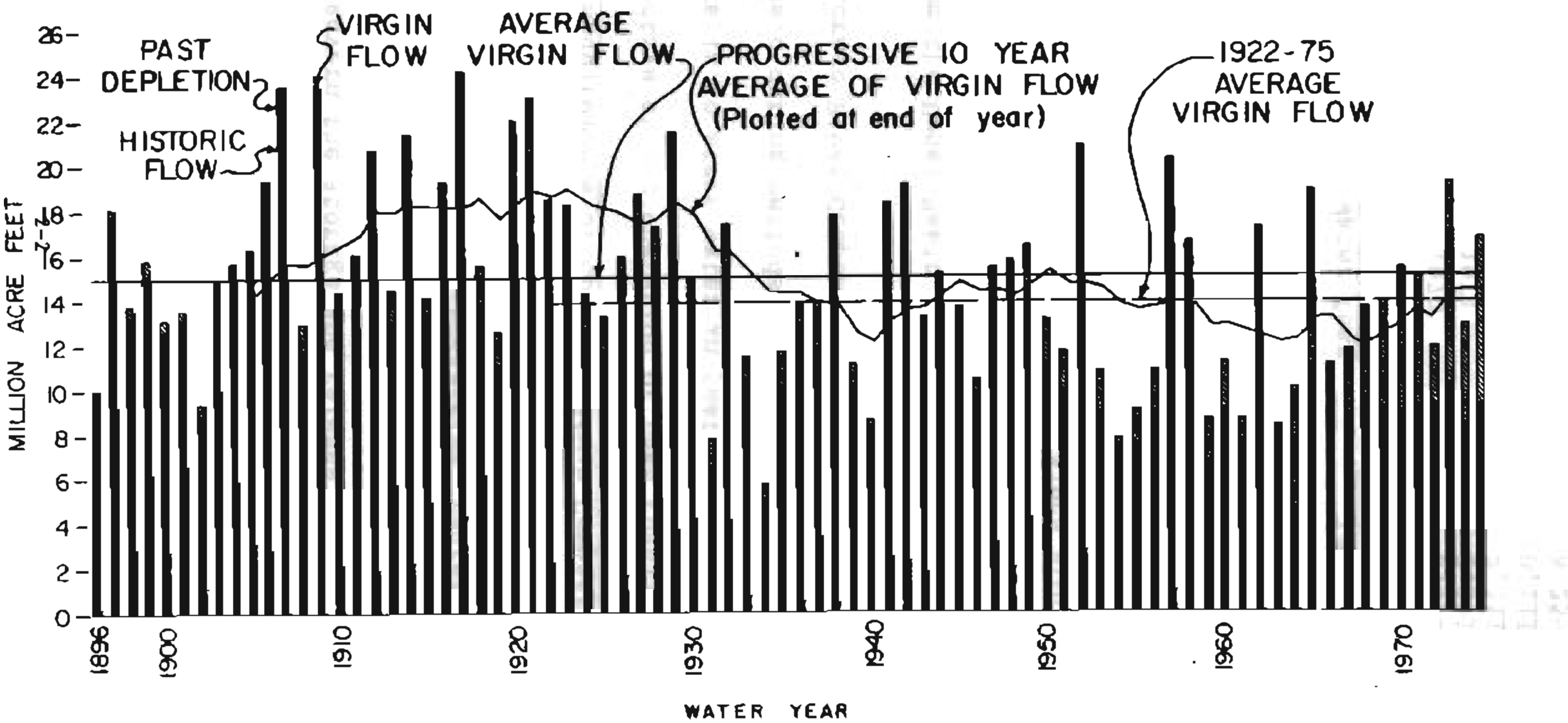
The primary long-range objective of the operation of Lake Powell and the other storage reservoirs is to store water in years of high flow for release to the Lower Basin during periods of low flow to satisfy the requirements of the Colorado River Compact.

Historically the runoff from the Upper Basin as shown in Figure 2-1 has been erratic, varying in its virgin conditions from 5.64 million acre-feet in 1934 to 24.04 million acre-feet in 1917. Since storage was initiated in Lake Powell in 1963, releases from the lake, as measured at Lees Ferry, Arizona, have been as shown in the following table:

Water Year	Recorded Flow at Lees Ferry (ac-ft.)	Water Year	Recorded Flow at Lees Ferry
1963	2,500	1969	8,823
1964	2,414	1970	8,672
1965	10,820	1971	8,591
1966	7,854	1972	9,311
1967	7,797	1973	10,111
1968	8,334	1974	8,259

FIGURE 2 - 1

COLORADO RIVER FLOW AT LEE FERRY, ARIZONA



2.1.1.1 Ten-Year Delivery Requirement

The operation of Lake Powell during initial filling has resulted in a delivery at Lee Ferry, Arizona, the compact point, including the flow of the Paria River for each 10-year period of the following flows:

Period	Flow 1000 AF	Period	Flow 1000 AF
Oct. 1953-Sep. 1963	63,698	Oct. 1959-Sep. 1969	79,334
1954- 1964	90,008	1960- 1970	78,830
1955- 1965	93,535	1961- 1971	80,763
1956- 1966	92,655	1962- 1972	75,309
1957- 1967	83,141	1963- 1973	82,934
1958- 1968	77,240	1964- 1974	88,773

Currently one of the long-range objectives governing the operation of Lake Powell is the scheduling of at least a minimum release of 8.23 million acre-feet of water from the lake which, when added to the flow of the Paria River, is believed to be sufficient to meet the requirements of both Article III(c) and III(d) of the Colorado River Compact.

2.1.1.2 One-Half of the Mexican Treaty Delivery Deficiency

The scheduled minimum release of 8.23 million acre-feet a year from Lake Powell referred to above should be adequate to cover the Upper Basin's obligation over the intermediate to long-term period to "deliver at Lee Ferry water to supply one-half of the deficiency" in surplus waters of the Colorado River System available to satisfy the 1.5 million acre-feet per year requirement of Article 10 of the Mexican Treaty and Protocol of November 27, 1945. This minimum scheduled release is in accordance with the "Long-Range Operating Criteria" which is intended to avoid a critical interpretation of Article III(c) and the Upper Basin's obligation toward the Mexican Treaty delivery requirement.

2.1.2 To Satisfy Long-Range Operating Criteria

The present operating program for Lake Powell, in addition to scheduling releases of water to satisfy the requirements of the Colorado River Compact and Mexican Treaty as described above, recognizes the provisions of the Coordinated Long-Range Operating Criteria that, until sufficient water is in storage in Upper Basin reservoirs to assure delivery of water provided by the Compact and Treaty during critical periods without impairment of uses of water in the Upper Basin, only minimum releases of 8.23 MAF per year will be scheduled from Lake Powell. The present program also recognizes that when such storage has been accumulated in Lake Powell and other Upper Basin CRSP reservoirs, additional water will be released to maintain the active storage in Lake Powell equal to the active storage in Lake Mead.

2.1.2.1 Accumulate and Maintain "602(a) Storage" In Upper Basin Reservoirs

The Colorado River Basin Project Act provides for the development of criteria for the storage of water in Upper Basin reservoirs and the accumulation thereof to the extent the Secretary of the Interior finds it to be reasonably necessary to assure Compact deliveries without impairment of annual consumptive uses in the Upper Basin. Article II of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, pursuant to that Act, provides that the annual plan of operation shall include a determination by the Secretary of the quantity of water considered necessary as of September 30 of the current year to be in storage as required by Section 602(a) of P.L. 90-537 after consideration of all applicable laws and relevant factors, including but not limited to the following:

(a) Historic streamflows;

(b) The most critical period of record;

(c) Probabilities of water supply;

(d) Estimated future depletions in the Upper Basin including the effects of recurrence of critical periods of water supply;

(e) The "Report of the Committee on Probabilities and Test Studies to the Task Force on Operating Criteria for the Colorado River," dated October 30, 1969, and such additional studies as the Secretary deems necessary;

(f) The necessity to assure that Upper Basin consumptive uses not be impaired because of failure to store sufficient water to assure deliveries under Section 602(a)(1) and (2) of P.L. 90-537.

Taking into consideration these and other relevant factors, the Secretary has determined and proclaimed in his fourth annual report to Congress on the 1975 Operation of the Colorado River Basin 1976 Projected Operations that the active storage in Upper Basin reservoirs forecast for September 30, 1976, on the basis of average runoff during the current year, would exceed this "602(a) Storage" requirement under any reasonable range of assumptions which have been realistically applied to those items which he is directed to consider in establishing this storage requirement. On this basis the accumulation of "602(a) Storage" is not to be the criterion that would govern the release of water from Lake Powell during the current year.

2.1.2.2 Maintain Equal Active Storage in Lake Powell and Lake Mead

In application of Article II(3)(b) of the Coordinated Long-Range Operating Criteria releases from Lake Powell are made each year to the extent that such releases can be passed through the powerplant when operated at the available capability of the powerplant. Any water retained in Lake Powell to avoid bypass of water at Glen Canyon powerplant will be released through the powerplant as soon as practicable to equalize the active storage in Lake Powell and Lake Mead. Surplus water released from Lake Powell to equalize storage in Lake Powell and Lake Mead is water which can be used to meet consumptive use demands in the three Lower Division states. The term surpluses as used in These Operating Criteria is not to be construed or applied to the term "Surplus" in the Colorado River Compact.

2.1.2.3 Maximize Power Production and Avoid Spills

Under present operating conditions, when Lake Powell is near maximum capacity, a review of power loads is necessary each month. Flood control activities require monthly water surface estimates so that water can be released soon enough to prevent any water spill. Short-term power contracts are negotiated with private power companies on a month-to-month basis to use the power generated by extra releases during the flood season.

2.1.3 To Implement Colorado River Water Quality Improvement Program

2.2 Annual Operating Plan

2.2.1 Forecast of Water Supply

Operation of the Colorado River during the projected water year is based on a forecast of average runoff from October through December, a forecast from January through June of the April-July inflow related to snowpack and precipitation accumulation and a forecast of average runoff during August and September. Based on an April-July inflow to Lake Powell, a required release of the stored water to meet downstream demands is scheduled for each reservoir through September. Each month, from January through June, the April-July forecast is revised on the basis of precipitation and more snow data collected during the month. Reservoir releases are revised, if necessary, on the basis of the forecast each month pursuant to the criteria of coordinated long-range operation of the Colorado River.

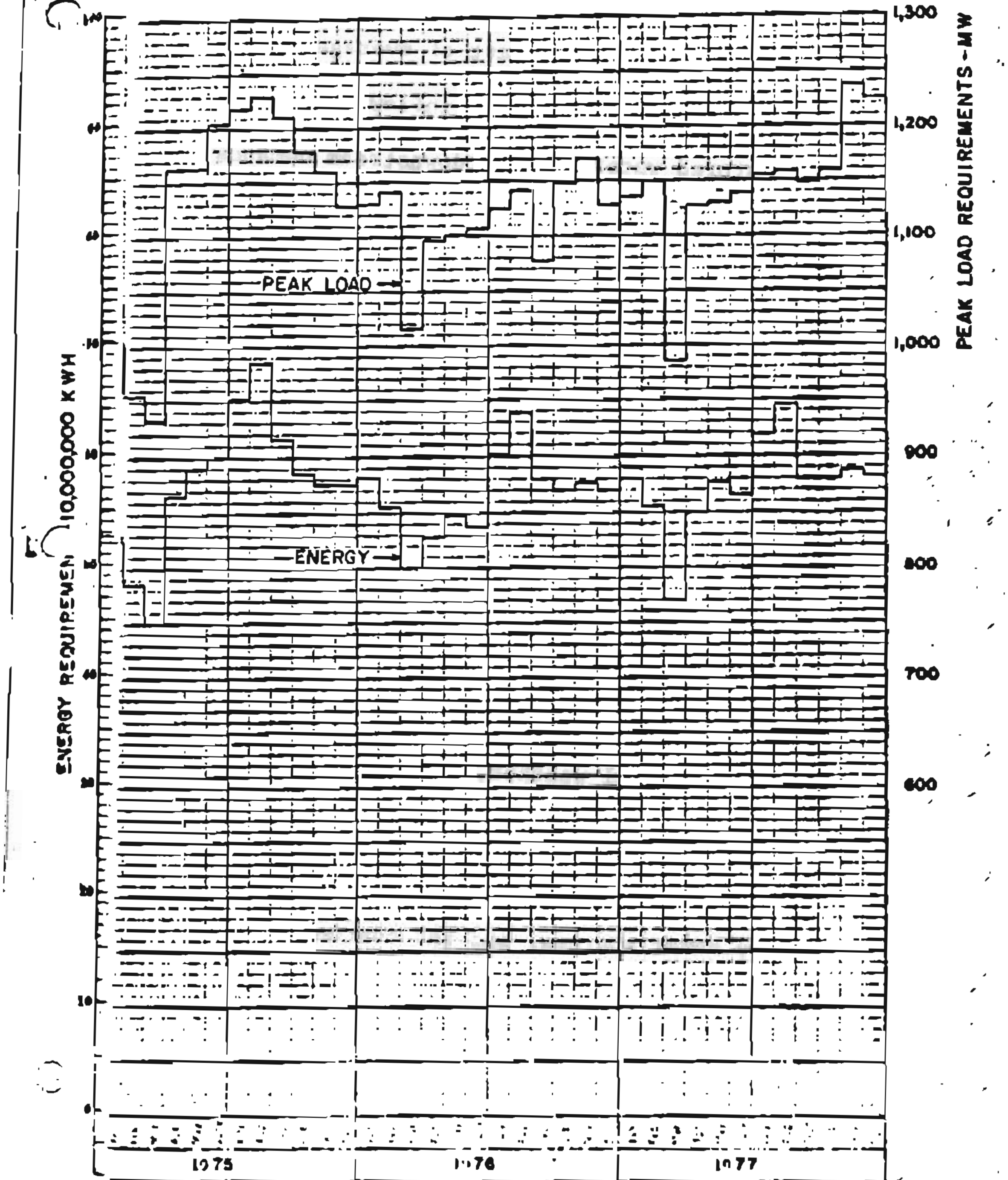
2.2.2 Projection of Power Loads

In developing the CRSP plan of operation, consideration must be given to the amount of power and energy CRSP is obligated to furnish by contract to its customers. The anticipated loads are normally projected based on mean temperatures, normal weather, and economic conditions. Load projections take into consideration historical load growth, present and future commercial and industrial developments, customer-anticipated purchases from auxiliary power sources, and the customers' use of their own generating facilities. Anciticipated CRSP contractual firm power and energy obligations for the next three-year period are shown on the attached graph Figure 2-2. These projections are updated semiannually to more nearly reflect economy and prevailing weather conditions as well as available water supply conditions.

2.2.3 Schedule of Releases from Lake Powell

Water releases scheduled for the Colorado River Storage Project and in particular, Glen Canyon Dam, are planned to accommodate all of the

COLORADO RIVER STORAGE PROJECT
ESTIMATED CONTRACT FIRM POWER & ENERGY OBLIGATIONS



multipurposes for which the Glen Canyon Dam was built, plus many day-to-day demands that develop throughout the year.

2.2.3.1 To Meet Operating Criteria Minimum

The majority of inflow into Lake Mead is regulated by Lake Powell behind Glen Canyon Dam. Regulation of water released from Lake Powell is in accordance with the Colorado River Compact and criteria for coordinated long-range operation of Colorado River reservoirs. At the end of water year 1975 the active storage in Lake Powell and Lake Mead was essentially equal. Based on a current projection of average runoff during water year 1976 a release greater than the minimum of 7,500,000 acre-feet plus one-half of the Mexican Treaty water will be scheduled to the Lower Basin.

2.2.3.2 To Maintain Equal Active Storage in Lake Powell and Lake Mead

The annual plan will show the end-of-month active storage projection for both Lake Powell and Lake Mead. If during the projected year, on the basis of the most probable forecast, Lake Powell's active storage is greater than Lake Mead's active storage, the annual plan will show extra releases from Lake Powell above the 8.23 M.A.F. in order to equalize storage in the two reservoirs.

2.2.3.3 To Satisfy CRSP Customer Load Requirements

Releases for generation of electrical power and energy from Lake Powell are coordinated with other CRSP reservoirs as well as the availability of economical energy from other utilities. The Storage Project's energy resources are less than that required to satisfy our customer contract obligations. In order to meet these energy obligations, purchases are required from other available resources. These purchases are normally obtained from the most economical sources when by so doing it is consistent with the multipurpose operation of the Storage Project facilities. Depending on annual water conditions, energy purchase requirements may vary from about 700,000,000 to 2,300,000,000 kWh per year. In conjunction with other CRSP reservoir release requirements and the current availability of purchase power, the Glen Canyon Powerplant is operated to satisfy anticipated power and energy requirements.

2.2.3.4 To Maintain Adequate Bass Spawn and Survival at Lake Mead

ass spawning success on Lake Mead, until Glen Canyon Dam was constructed, was good. Some biologists feel this success is attributable to rising water levels brought about by natural runoff from the Upper Colorado River watershed. The runoff inundated terrestrial vegetation, primarily Tamarisk, which provided cover and a food source for fry and fingerling bass. Today, with Glen Canyon Dam controlling Lake Mead inflows, bass spawning success appears to have been significantly reduced. Fish biologists have attributed this decline to the somewhat declining water surface on Lake Mead during much of the bass spawning season. During the prime part of this bass spawn releases from Lake Powell are scheduled to enhance the spawning and survival of the bass with the other purposes overriding the schedule of such releases.

2.2.4 Projection of Reservoir Water Surface Levels

Each month, a new annual plan and projection of any water surface levels for Lake Powell and the other reservoirs of the Colorado River system are prepared to reflect the various changes that have occurred during the past month. The updated study reflects the latest forecast of runoff which may change the elevation of Lake Powell each month. Other factors changing the water surface elevation are evaporation, inflow to Lake Powell, bank storage, and releases.

2.3 Monthly Operating Plan

The reservoirs of the Colorado River System are operated to optimize or enhance the multipurpose values that have been created by their construction. One of the methods used as a tool to optimize Lake Powell is a monthly operation plan.

2.3.1 Forecast of Water Supply

Forecasts of inflow to Glen Canyon are made on the first of each month, as described in Paragraph 2.2.1. The forecast is then distributed on a monthly basis by correlating with historical years of the same magnitude. Monthly flows are used in the operation plan at Lake Powell to extract projected monthly data for the purposes for which the projects were authorized, constructed, and operated.

2.3.2 Projection of Power Loads

Each month the annual load forecast for the month is reviewed and updated, taking into consideration the then-existing and anticipated short-term weather projection and available area water or pumping requirements of each CRSP customer. These projections include the current installation of electrical energy consuming equipment not included in the normal load projection. The monthly load projection also reflects the latest available CRSP power customer resources and the utilization thereof. In addition to CRSP customer loads, the projection includes anticipated mutual economic interchange transactions as well as emergency breakdown assistance with other utilities in accordance with contract provisions.

2.3.3 Projection of Power Available from Other Sources

After an evaluation is made of the Project energy requirements, all utilities in the area are canvassed to determine the amount of available surplus energy, the cost of the energy, and the ability of CRSP to utilize the energy to satisfy customer loads in excess of Project generation. To the extent economical energy sources are available below a predetermined rate and within the Project transmission limitations, energy is purchased and/or interchanged from these sources as required to satisfy the annual firming energy requirements. Reference is made to Article 2.2.3.3 for explanation of need of power from other sources.

2.3.4 Schedule of Release

Releases from Glen Canyon are scheduled on a monthly basis for a variety of reasons. For example, during the boating or river-running season, consideration is given to maintaining riverflows at navigable levels for river running and recreational boating. Power releases are scheduled on the monthly basis, and power interchange in and out of the CRSP system in connection with private power companies is negotiated at times on a month-by-month basis.

2.3.5 Projection of Water Surface Levels

Projection of Lake Powell water surface elevation on the monthly basis is necessary as a function of a multipurpose reservoir. The National Park Service is responsible for recreational aspects of the lake and has many inquiries from boaters, fishermen, and recreationists in general, as to the maximum and minimum seasonal elevation of Lake Powell. Optimum utilization of water for beneficial purposes requires monthly water surface estimates so that water can be released soon enough to prevent any water spill. The Colorado River Compact depends on collection of monthly elevation data as part of its requirement.

2.4 Daily Water Scheduling and Power Dispatching

The Colorado River Storage Project power and energy requirements vary on climatological conditions, customer unit maintenances, energy conservation practices, and economic conditions. The above factors, coupled with other multipurpose operations, affect the daily and hourly demand on the Glen Canyon as well as other CRSP powerplants. Daily water releases are scheduled to reflect and accommodate all of these variables.

2.4.1 Projection of Power Load

On a daily basis a forecast is made of the next day's load requirements. These are normally made in cooperation with each power customer and are based on all prevailing conditions at the time. Loads are normally determined up to 24 hours in advance. Schedules for loads outside the CRSP control area are subject to adjustment hourly between dispatching offices. For loads within the control area, generation control equipment automatically adjusts generation level at the various CRSP plants to meet load requirements.

2.4.2 Allocation of Load to Other CRSP Plants or Other Sources

Allocation of powerplant capacity to CRSP power loads is a function of the available water supply, downstream requirements for irrigation, municipal and other uses, recreation, flood control, decrees and water rights, minimum electrical limits, etc. Within these constraints each CRSP generating unit participates in satisfying the electrical power requirements to produce the most efficient overall generation level. Power from other sources is utilized to satisfy CRSP power and energy obligations when by so doing it will result in maximum optimum utilization of CRSP resources with the least cost to the United States and to conserve other energy resources such as oil. Daily and hourly loading of other CRSP generating facilities vary considerably depending on the month of the year and the prevailing economic and weather conditions. Normally power from other sources is most economical when overall power system requirements are at minimums. This is usually during the hours of 11:00 p.m. through 8:00 a.m. on weekdays and all hours on weekends and holidays. All of these factors are considered in arriving at the participation of other CRSP powerplants and other resources in satisfying the then-existing CRSP power and energy obligations.

2.4.3 Schedule of Releases through Glen Canyon Powerplant

Releases from Glen Canyon Dam are normally so planned that a continuous flow of at least 1000 ft^3/s will be maintained below the Dam. To the extent system conditions will permit, releases will be low during off-peak hours when CRSP loads are low and energy available for purchase or interchange to the system is high. Energy is usually generated during on-peak hours and, therefore, water through the powerplant will be high during the daytime hours.

2.4.3.1 Off-Peak Minimum Requirements

Between the hours of 11:00 p.m. and 8:00 a.m. the electrical load is usually at a minimum. The minimums will vary daily and seasonally depending on the then-prevailing weather conditions, water surface runoff, and the economy. In addition, the minimum load varies each day of the week due to normal electrical usage patterns from a maximum during the middle of the week to a minimum on Sundays and Mondays. We endeavor during weekends whenever possible to maintain the level of releases required for multipurpose use of the river downstream from Lake Powell Reservoir. Normally minimum releases are 3,000 c.f.s. during the months of April through September and 1,000 c.f.s. during the other periods.

2.4.3.2 Projected Maximum

The normal maximum releases from Glen Canyon are a function of the power requirements on a daily basis. The peak releases will usually occur during the hours of 9:00 a.m. through 12:00 Noon, and 5:00 p.m. through 9:00 p.m. daily. The maximum weekly release usually occurs on Wednesday or Thursday with lower peaks on the weekends. The annual high maximum release of about 30,000 c.f.s. ordinarily occurs during the months of July, August, November and December.

2.4.4 Weekend Schedules

Schedules of releases from Lake Powell on weekends also vary quite widely depending on power requirements. During the recreational season schedules are designed to maintain a minimum release of 3,000 c.f.s. and an average of 8,000 c.f.s. during the on-peak hours to accommodate recreational activities below the Reservoir. To the extent that power system conditions will permit, schedules include releases above that required for minimum downstream uses. Occasionally it is very difficult to meet these objectives.

2.4.5 Holiday Schedules

The same criteria and objectives in scheduling usually apply on all holidays that are described above for normal weekends. On some occasions assistance is required to dispose of power and energy that Project requirements are unable to utilize to maintain minimum criteria. Also on occasions it is very difficult to obtain assistance from other utilities to accomplish the desired releases, as they are likewise experiencing very light load conditions and require that their generating facilities be maintained above certain minimum generation levels for security purposes.

2.4.6 During Regular Maintenance

Regular and routine maintenance are scheduled wherever possible so that minimal alterations in normal operating patterns are required.

2.5 Alternative Operations

Within the load requirements on a daily, monthly, and annual basis and the operational constraints of the CRSP hydroelectric system and its interconnected hydroelectric system and its interconnected hydro- and thermal-electric sources of nonfirm energy, alternative plans for optimizing the utilization of the resources must be studied. Through the use of computer models the various alternative operations are analyzed in order to evaluate the benefits and wishes related to each before the selected operation is scheduled and implemented.

3. Description of the Environment

3.1 Glen Canyon Tailwater to Lees Ferry

3.1.1 Physical Environment

3.1.1.1 Physiography

(a) Geology

The inner gorge of the Colorado River between Glen Canyon Dam and Lees Ferry, Arizona, is contained by sheer cliffs and rounded domes of Navajo sandstone. Extending away from the river and capping the Navajo sandstone are sloping benches of the Carmel formation, the softest of the Jurassic beds which forms a comparatively broad and irregularly-bordered platform between the inner and outer gorge. Rising above the Carmel-capped platform are mesas, buttes, and monuments of the Entrada, Summerville and Morrison formations. Overlying the bedrock formation are deposits, located along the river and in the side canyons, composed of river silts, sand dunes, gravel terraces, talus, rock falls and minor amounts of soil. Rising about 25 feet above the river are older stranded alluvial terraces. They were formed by erosion and arroyo cutting following a period of deposition of locally derived silty sands, sand, and gravels containing boulders.

Dunes derived from sand weathered from the sheer faces of cliffs, the stripped Navajo sandstone surfaces and river deposits abound in the canyon and against the cliff faces. Weathering of the canyon walls produces talus slopes several hundred feet in height. Gravels deposited down from the higher terraces lodged in depressions and blow-outs near the river creating bars and benches suitable for establishment of vegetative communities.

(b) Climate

The average annual rainfall for the region as a whole, at elevations between 3200 and 5000 feet (and in part up to 6100 feet), is about seven inches. The average annual temperature in the bottom of Glen Canyon, at elevations between 3200 and 3480 feet, is about 59° F., while in the upland, at about 400 feet, the averages range from 51° to 54° F. Hot summers are common with temperatures ranging from the 80's and 90's in the mountainous areas to from 105 to 115 degrees in the desert areas. Daily ranges are great for all seasons due to the usual clear and dry conditions.

Wind conditions vary according to local storms and topography. Winds generally have an easterly to south-southwesterly flow with the exception of the northerly winds during the winter months. Often, violent thunderstorms during the summer may have gusts of over 100 miles per hour. Spring and fall are generally the driest seasons. Snowfall occurs in the higher elevations of the northern portions of the area.

3.1.1.2 Water in the River

Colorado River water flowing through lower Glen Canyon comes principally from the Rocky Mountains. During the months of April, May, June and July, runoff is high and the Colorado River is at maximum volume. Since Glen Canyon Dam was completed in 1963, the flow of the Colorado River below the dam has been almost completely dependent on the release of water from Lake Powell.

Before Glen Canyon Dam existed, the river gained volume from the spring snowmelt and reached a maximum flow in May or June, then receded during the remainder of the year. Flash flooding in the late summer often resulted in a second peak. During periods of high water, when the river had the greatest transport capability, large quantities of sand and silt were carried through the canyon, scouring the channel. As the water receded in the summer the river slowed and deposited much of its silt and sand load along the channel. The river bars and terraced benches were thus periodically eroded and replenished with sediment.

With the present controlled flow, the higher terraces are no longer flooded, and the lower terraces and bars are eroding. At the same time, elimination of high water discharges has resulted in the rapid development of dense flood plain vegetation in areas which were formerly inundated, and wind deflation is removing large quantities of fluvial sediment above the current high water levels.

The effect of the Glen Canyon Dam on the Colorado's sediment load has been dramatic. At Lees Ferry, the median suspended sediment concentration has been reduced by a factor of about 200. The regulation of flow by Glen Canyon Dam has resulted in a slight increase in median discharge and a great decrease in the number of flood peaks. Since demands for hydro-electric power determine the schedule of discharges, the discharge varies by a factor of about 5 over a 24-hour cycle, resulting in a vertical daily variation of the river by as much as 15 feet. The mean daily high discharge from the dam is about 20,000 c.f.s., and the daily low is 4,600 c.f.s. with extremes ranging from 2,000 to 27,000 c.f.s. Dishcarge during holidays and weekends is low in response to decreased power demand. Arrival of peak flow downstream is, of course, delayed because of the finite water velocity.

3.1.2 Biological Environment

3.1.2.1 General

The lower end of Glen Canyon on the Colorado River is contained within steep cliffs of Navajo sandstone rising 700 feet above the river at Glen Canyon Dam and rising to 1500 feet above the water at Lees Ferry. Throughout this portion the flow of the Colorado River is determined by water released from Glen Canyon Dam.

The fifteen mile stretch of river traverses only 7.5 miles of actual straight line distance. This portion of Glen Canyon is fairly typical of that which is inundated by Lake Powell behind the dam. The predominantly calm waters running beneath high, red cliffs, white sand beaches and verdant benches of willow, tamarisk and arrowweed, combine to allow a wildlands adventure in relative safety. This and the outstanding beauty of the canyon make it popular with rivermen and their fares.

The "green belt" in the canyon bottom forms an ecological complex that is delicately balanced against the harsh and variable desert climate. The presence of permanent water allows a denser community of both plant and animal life. Because of the cold water and the depth of the canyon, a moderate micro-climate exists. This allows animals and plants to live out of their normal life zones. Desert species are found living with those of the high plateaus. Many forms of wildlife have adapted to live in the restricted canyon. The resident animals and birds live in a web of interdependence with their environment.

3.1.2.2 Flora

Within the canyon region, marked changes in vegetation are recognizable and reflect differences in available moisture, aspects of exposure, altitude, soil differences, topography and temperatures. The region is considered as belonging to the upper Sonoran life zone.

Three habitat types are described. These are streamside, terrace, and hillside. Streamside vegetation of phreatophytes, which use large amounts of water, is found on alluvial deposits bordering terraces, along water courses, seeps and springs. This community of tall shrubs and small trees ranges from ten to sixty feet in width and occasionally to 100 yards wide.

The dominant species at the streamside community are the sandbar willow, *Salix exigua*; Goodding willow, *Salix gooddingi*; tamarix, *Tamarix pentandra*; and arrowweed, *Pluchea sericea*. Associated with these major species are others which are occasionally found mixed with them. Local stands of Gambel oak, *Quercus gambelli*; Hackberry, *Celtus douglasii*; and rarely the Fremont cottonwood, *Populus fremontii*; are found with this community on narrow alluvial terraces, steep slopes near the river and in glens. Other shrubs, herbs and grasses are found either scattered or in local dense stands.

Terrace vegetation ranges from ten to 300 feet in width. It includes xerophytic perrenial herbs or desert shrubs growing on dry surface soil which use intermediate supplies of water beyond precipitation, usually receiving it by capillary action from a subterranean water source. The terrace community grows primarily on old flood plains and includes arrowweed; rabbit-brush, Chrysothamnus viscidiflorus; four-winged salt bush, Atriplex canescens; squawbush, Rhus trilobata; shadscale, Atriplex confertifolia; and other shrubs. Trees, including Hackberry and Gambel oak occur with grasses, vines and other trees, shrubs and herbs to make up the community in the main side canyons.

Hillside vegetation composed of xerophytic plants adapted to the sparing amount of water provided by precipitation is found on hillsides, ledges, talus slopes and cliffs, sand dunes, and on higher terraces and mesas above the canyon rim. In this zone the low desert shrub vegetation includes shadscale and saltbush. Other plants, including joint firs, Ephedra sp.; drop seed, Sporobolus sp.; cacti, Opuntia spp.; and black brush, Coleogyne ramosissimum; are conspicuous at the higher elevations. In general, this community varies in numbers and distribution by locality, with the herbaceous plants being quite abundant in species but few in number.

3.1.2.3 Fauna

In Glen Canyon large game animals are scarce owing to the limited food supplies. The numbers of larger animals south of the river are being appreciatively reduced with the continuing grazing of sheep, goats, cattle and horses belonging to the Navajos. Grazing, while more common on the upland mesas on the Reservation side of the river, does extend into Glen Canyon proper where trails provide access to hillside and terrace communities.

The conspicuous animals in the deep canyon are bats, mice, packrats, lizards, water fowl and beaver. Insects, including ants, flies, spiders, gnats and mosquitos, dominate the phreatophytic vegetation. Porcupines occur in some of the side canyons. Gambel quail, golden eagle and Whitewinged dove are resident along the river.

The river supports some fish life, including Flannelmouth sucker, carp, Rainbow trout, Brown trout, catfish and largemouth bass. After the dam was completed in 1963, the State Game and Fish Department of Arizona actively pursued a fish planting program, which peaked in 1972. The clear, cold waters released from Glen Canyon Dam have been favorable to trout production while fluctuation has not. While the fishery is still relatively young, it shows potential for recreational development. However, both Arizona (above and below the dam) and Utah (above the dam) have curtailed their planting efforts in recent years. Consequently, fishing success has diminished, with a compensating decrease in fishing pressure below the dam. A Rainbow trout fingerling stocking program was initiated in the spring of 1975 at the base of Glen Canyon Dam. A catchable trout stocking program was begun in June 1975.

3.1.3 Human Environment

3.1.3.1 History - Culture

Prehistoric man entered the Glen Canyon of the Colorado only at the few areas where tributary canyons provide access routes to the highlands above. Lees Ferry is one of the few places where the land breaks away sufficiently to allow access. Here two canyon systems meet--the lower end of Glen Canyon and the beginning of Marble Gorge, intersected by the Paria Canyon. That this crossing was well known is evidenced by numerous trails which converge here and the number of archeological sites which have been found. However, the narrow confines of the upstream canyon made access difficult. A complete archeological inventory of the canyon is not available and known sites are restricted to three or four locations where petroglyphs have been found. This is almost always at the point where an access trail would lead down to the river benches below.

Historic knowledge of the area began in 1776 when the Dominguez-Escalante exploration party attempted unsuccessfully to ford the river on their return to Santa Fe. Almost a hundred years passed before this location was again to become of historical note, with the arrival of the government exploration party of Major John Wesley Powell. The Powell surveys covered the entire reach of the Colorado River from Green River, Wyoming, to the present area of Lake Mead. Many of the features of this region were first noted and named by the Powell party.

With the arrival of Powell's second voyage in 1871, Lees Ferry was in its first stage of permanent habitation--John D. Lee had just arrived that year to establish a ferry crossing for the Mormon colonization of northern Arizona.

In 1889, Robert Stanton, an engineer, followed Powell's trail in an effort to survey a railroad route down the Colorado's canyons. Along the way, he became intrigued with the gold-mining possibilities of Glen

Canyon, and later, he returned to pursue this venture. The American Placer Corporation, in 1910, set up a larger hydraulic operation in the Chinle formation at Lees Ferry to extract gold. At considerable expense, boilers were freighted in by wagon from San Francisco, and a boat, a 92-foot stern wheeler, was built on the river bank. It was intended to haul coal for the steam powered hydraulic pumps, from a loading area 25 miles upriver. After considerable work getting the boat into operation they found that the steamboat, Charles H. Spencer, burned nearly all the coal haul for the round trip.

So the largest boat on the Upper Colorado was tied to shore and eventually rotted and sank. The remains of the hull and boiler can still be seen in the shallows just above Lees Ferry development.

Although gold was present, its extremely fine character kept it from being economically mined. The various ventures were abandoned and their many remains are all that is left to remind us of this colorful era in history.

Although there were three crossings at Lees Ferry, the main one was developed upstream, near the mouth of Glen Canyon where the river ran smooth and was relatively free of sandbars. An overhead cable was stretched across the river on which the ferry lead ran. The site was used as a major crossing until 1928, when the ferry boat was lost in an accident. The ferry was never replaced because steel-arch Navajo Bridge was nearing completion on U.S. Highway 89, six miles to the south.

3.1.3.2 Public Use

In 1972, Fort Lee Company, Inc., first offered a one-day float trip on the Colorado River between Glen Canyon Dam and Lees Ferry. In that year 739 visitors floated from the dam to Lees Ferry. In 1973, 1,501 persons made the float trip. 1974 public use increased to nearly 2,450 persons. In addition to the float trips provided by Fort Lee Company, under concession contract to the National Park Service, the river may be navigated upstream from Lees Ferry to the dam by motor-powered boats. Fort Lee Company provides six, twelve-to fourteen-foot open fishing boats for rent with outboard motors in the 10-20 horsepower class, This satisfies the demand for this type of craft at the present time. Float trips operate only from April through September. The rental boats are available year around but demand slackens appreciably after September.

Public recreational boating upstream from Lees Ferry varies in direct proportion to the success of fishermen on the river. The 1972 Labor Day weekend recorded 42 boats on the river in one day. Upstream public use has increased steadily from 1969, when 1,662 upstream boaters were recorded to the peak in 1972, of 2,583 boaters. 1973 boater use dropped to 2,389. 1974 figures reflect a continuing downtrend with 1,350 boaters recorded.

The commercial float trips provided by the Fort Lee Company are one-day trips. The boats make occasional stops along the way to allow visitors (fares) to make short hikes up side canyons and explore many of the river terraces. A lunch break is provided and a convenient sandy beach is utilized.

Upstream is primarily day use although approximately 10 percent of the upstream boaters are overnight campers. These campers utilize undesignated camping sites in clumps of tamarisk and willow growing on sandbars and beaches.

Falling water levels at night force boaters to carefully choose overnight mooring sites. A steeply sloping bottom under the moored boat must be chosen or the dropping water level in the morning will strand the boat on a newly exposed stretch of beach. Boats drawing 24 inches or more of water run a higher risk of becoming stranded upstream. At low water (4 to 6,000 cubic feet per second) boats cannot travel upstream past Three-Mile Bar. Releases above 6,000 c.f.s. allow boats to travel all the way to Glen Canyon Dam. Boating and fishing are the two most popular recreational uses upriver. Camping, while less popular, creates the largest impact on the resources. At the present time there are approximately a half-dozen commonly used campsites. These are mostly primitive in nature and located where a steep bank allows a close in-shore approach by boat without the danger of becoming stranded at low waters. At three of these sites pit toilets have been installed to containerize sewage. Trash facilities are not provided and visitors are urged to carry out all waste material which they carry in. Firewood exists in good supply around most of the camps; however, this will change rapidly since the limited amount of firewood will not be replaced as has been the case in the past when the spring runoff in the Colorado River would re-deposit driftwood on the beaches.

Related to the ecological changes of the inner canyon, vegetation patterns are changing markedly. Tamarisk and willow growths are expanding rapidly on many sites previously used as camping or day use areas. The lack of high flood conditions allow this vegetation to take root and spread into areas not previously occupied. This does restrict the number of accessible beach sites and is presently decreasing available day use and overnight use.

3.2 Colorado River through Grand Canyon National Park

3.2.1. Physical Environment

3.2.1.1. Physiography

The Grand Canyon lies in the physiographic region known as the Colorado Plateau, or the Plateau Province. The Colorado Plateau includes southwestern Colorado, southeastern Utah, northwestern New Mexico and north central and northeastern Arizona. It is characterized by a thick sequence of flat to gently dipping sedimentary rocks that erode into majestic plateaus and mesas separated by deep canyons. The Colorado Plateau is a stable region with few earthquakes and its surface rocks have undergone very little deformation in comparison to other portions of southwestern United States. See page 29 for physiographic map of the Grand Canyon Region.

The mile-deep Grand Canyon is the deepest and most extensive canyon found in the plateau country. It is a geologic timepiece studied by scientists and laymen, and it is a world-renowned scenic spectacle. The exposed rock layers represent all of the eras of geologic time and contain evidence of the evolution of life through more than 600 million years of earth history. The oldest dated rocks in the Inner Canyon approach 2,000 million in age and, thus, the observer comes metaphorically face to face with the beginnings of time.

In a planimetric sense, all of the individual plateaus within the Plateau Province are elongated in a north-south direction and bounded on the east and west by sharp structural breaks and folds. These major zones occur at intervals ranging from 15 to 40 miles apart across northern Arizona.

In carving the Grand Canyon, the Colorado River cut a clean east-west cross section through several of these plateaus providing a window through which the geologic history of the region may be viewed.

The Early Precambrian, Vishnu Schist is the oldest rock formation exposed within Grand Canyon. It consists of 25,000 feet of fine-grained sedimentary rock and 12,000 to 15,000 feet of lava flows; both of which have been metamorphosed into gneiss and schist. In general, the fine-grained clastic rocks of the Vishnu are believed to have accumulated in the relatively shallow waters of an epicontinental sea. The floor of this sea slowly subsided and an enormous thickness of rather monotonous sands and shales was deposited. The apparent thickness of the fine clayey sands exceeds 25,000 feet, but it is not known how much this has been increased by repetition through folding and by injection of granitic material or decreased by compression, recrystalization, and flowage. Considerable quantities of calcite found in some places are interpreted as having been calcareous concretions.

Volcanic activity increased during the later stages of Vishnu time, and basaltic lava flows poured into the ancient sea floor. The basalts were later metamorphosed into schists and layers of sand and silt between the flows were changed into quartzite and quartz mica schist.

The Vishnu Schist is suspended, as it were, in the roof of a much younger batholith of granite, which invaded it in a molten condition. This granite has a radiometric age determination of 1,720 million years, so the older Vishnu may prove to be over 2,000 million years old or older. No traces of life have been found in these ancient metamorphosed rocks.

The long, long episode of sedimentation and volcanism was ended by uplift, compression, and mountain-building on a grand scale; the Mazatzal Revolution. Folding and recrystallization under pressure (metamorphism) profoundly changed the attitude and constitution of the rocks previously accumulated. The Vishnu strata and flows in the Bright Angel Canyon area were folded tightly into a huge geosyncline. Under heat and pressure, recrystallization of the less stable minerals occurred and their directions of easiest growth were oriented in a general northeast-southwest direction more or less parallel to the original bedding planes of the sediments and flow lines of the lavas.

The invasion of the Zoroaster Granite began sometime after deformation and perhaps during later phases of the regional metamorphism and mountain-building. It is a coarse-grained granite of reddish color. Not only was granitic material injected as a melt, but granitic minerals were introduced by permeating gases and schists were granitized. New minerals resulting from contact metamorphism were added to the original mineral assemblages and to their recrystallized regional metamorphic derivatives. The mountains were probably as high as the modern Himalayas or Andes.

The last episode of the Early Precambrian was a long interval of erosion which developed the Arizonan Plain or Ep-Archean erosion surface. The high mountains which had dominated the landscape were worn away by streams and other forces of erosion until a nearly level plain remained. In the Grand Canyon, this surface has a relief not exceeding 20 feet in most areas, and an observed maximum of 50 feet.

A long time elapsed after the conclusion of the Mazatzal Revolution, and before the first Late Precambrian sedimentation began. Inasmuch as there are no rocks representative of this time, it represents a gap in our knowledge of the geologic history of this area. Faulting and fracturing initiated during the Mazatzal Orogeny continued after the cooling of the Zoroaster Granite.

The Unkar Group includes all of the lower, Late Precambrian rocks found in the Grand Canyon region. The Unkar Group has a cumulative thickness of over 5,000 feet. Here and there on the Arizonan Plain up to 50 of the basal Hotauta Conglomerate was deposited. It incorporates angular and sub-angular fragments of quartzite, quartz, granite, pegmatite and schist derived from the underlying and unindated rocks of the Arizonan Plain.

A sea encroached upon the desert plain from the west, removing soil and interstream ridges by wave action and marine abrasion as it advanced. The surface upon which this sea began to lay down its deposits was amazingly flat. It possessed a maximum local relief of 20 to 50 feet. In remnants found over an area that perhaps exceeds 1,000 square miles, the relief is scarcely discernable. No other surface of erosion of such an extent has been reported in the world. The Bass Limestone was the first sea deposit to be laid down upon this nearly level surface. It is dominantly composed of gray dolomites which are dark brown on weathered surfaces. Interbedded shales and sandstone in the upper part, some with ripple marks, indicate fluctuating shallow water as their condition of deposition. The formation is about 200 feet thick in the canyon below Grand Canyon Village where it forms a cliff on exposure. Probable algae deposits found in this formation indicate the existence of primitive forms of life.

The Hakatai Shale overlies the Bass Limestone and consists of some 800 feet of reddish and vermillion mudstones and shales with some sandstone. It is the most vividly colored formation of Grand Canyon. An outcrop north of Pipe Creek may easily be seen from the South Rim. Ripple marks, mud cracks, and raindrop imprints are fairly common. Cubical impressions on upper surfaces of beds may be molds of salt crystals. All these features indicate that the Hakatai was deposited under shallow water conditions with occasional emergence. The formation generally erodes to a smooth slope.

The Rama Intrusives are plugs, dikes, and sills of basalt and diabase which have been intruded into the Bass Limestone and the Hakatai Shale. A 240-foot thick sill occurs in the Hakatai Shale of Bright Angel Canyon, and is also exposed in Hindu Amphitheater. There is no known connection between the Rama Intrusives and the later volcanics of the Cardenas Formation.

The Shinumo Sandstone consists of thick-bedded to massive white, purple, red, and brown sandstone strata which grade into cemented quartzites. The formation is about 1,100 feet thick. Many outcrops are cross-bedded and some show ripple marks. They are deposited under rather uniform shallow water conditions. Where exposed, the Shinumo stands in imposing cliffs.

The Dox Formation (1,700 to 3,000 feet thick) consists largely of reddish-brown sandstones and calcareous sandstones with some green, white, and buff beds. There are some interbedded shales. Ripple marks and cross-bedding indicate shallow water deposition. Where exposed, it stands in steep cliffs and slopes.

The Cardenas formation consists of at least 13 lava flows interbedded with eight very fine grained sandstone beds. Characteristics of the lavas and sandstone beds suggest deposition in standing water that became shallower with time and intermittently disappeared altogether. The shallow water environment was maintained by basin subsidence or rising water level, or both, during accumulation of the lava flows and sandstones. Radiometric dates of 845 ± 15 and 1,150 ± 30 million years have been obtained from lavas in this formation and paleomagnetic pole positions indicate an age range of from 1,000 to 1,200 million years. The formation is nearly 1,000 feet thick in the eastern Grand Canyon. A 70-foot thick sill of probable Cardenas age is found in the upper part of the Shinumo Quartzite in Bright Angel Canyon.

The Nankoweap Group overlies the Unkar Group and is more properly considered a formation which consists dominantly of sandstone. It is separated from both overlying and underlying formations by unconformities. It is found only in the eastern Grand Canyon where it reaches a maximum thickness of 330 feet.

The youngest Precambrian rocks of the Grand Canyon region are found overlying strata of the Nankoweap and Unkar Groups in the eastern part of the park, and are referred to as the Chuar Group. These formations were elevated as fault-block mountains and then eroded from most of the area while the Ep-Algonkian or Grand Canyon Peneplain was being formed.

At the base of Chuar Group is the Galeros Formation. It consists of some 40-80 feet of massive, coarsely crystalline dolomite at the base, with 580 feet of predominantly shale strata above.

The Kwagunt Formation is the middle member of the Chuar Group. It is 1,200 feet thick and consists primarily of shales and mudstones with interbedded, thin limestones and dolomites. The basal 80 feet of this formation is a red sandstone unit which is very prominant on Carbon Butte in the eastern Grand Canyon.

The Sixty Mile Formation is the upper member of the Chuar Group and is mainly composed of breccias and coarse, pebbley sandstones, with subordinate cherty siltstones. It is only 120 feet thick, but its breccias suggest tectonic uplift with erosion of the surrounding outcrops of younger formations in the Chuar Group due to slight warping.

Following the deposition of the Late Precambrian Chuar strata, the Grand Canyon area was subjected to stresses reviving earlier faults and leading to the elevation of block-faulted mountains similar to those now seen in the Basin and Range section of western America. This period of mountain-building is called the Grand Canyon Revolution.

The uplifted block-faulted mountains were then subjected to a long period of subaerial erosion. This erosion produced the Ep-Algonkian erosion surface which, although often referred to as the Grand Canyon Peneplain, actually consists of a series of block-faulted, quartzite ridges, some of which rise 800 to 900 feet above the general base of erosion.

Rocks of the Paleozoic Era began being deposited in Middle Cambrian time in Grand Canyon. The Grand Canyon Peneplain was slowly submerged beneath a sea encroaching from the west. Here and there, thin basal conglomerates, arkoses, and quartzite breccias were deposited as surface debris were reworked by the waves. Then thick, cross-bedded, brown sandstones were deposited. The monadnocks of the Grand Canyon Peneplain projected above the water as islands until successively covered by Tapeats and later sediments. The Tapeats Sandstones averages about 200 feet thick below Grand Canyon Village.

The Bright Angel Shale was deposited on top of the Tapeats Sandstone and grades into thin-bedded sandstones and greenish to buff micaceous shales. Most of the dolomite beds, which weather to a brownish color, occur in the upper part of the formation. During the last part of Bright Angel time the last of the Cambrian islands were buried. The Bright Angel Formation is generally 350-400 feet thick below Grand Canyon Village. Trilobites, small extinct marine crustaceans, are the characteristic fossils. Some primitive brachiopods are also found. The Bright Angel represents an intermediate stage in the west to east transgression of the Cambrian sea.

The Muav Limestone consists largely of gray and buff limestones. The base has layers of impure, mottled limestone interbedded with greenish shale and buff sandstone lithologically similar to the Bright Angel Formation from which it is transitional. The top of the formation consists of brown shales and sandstones. It varies in thickness from 300 to 400 feet below Grand Canyon Village. Trilobites and brachiopods are the characteristic fossils. The Muav Limestone was deposited well offshore as the Cambrian sea advanced from west to east across the Grand Canyon Region.

No beds of certain Ordovician or Silurian age have been found in Grand Canyon National Park. They either were never deposited or were removed by erosion since deposition. An undulating dolomite overlies the Muav Limestone in the western Grand Canyon near the Hurrican Fault. Fossil evidence is yet lacking but this formation may prove to be Ordovician or Silurian in age.

Hollows and channels eroded in the top of the Muav Limestone are filled with a calcareous sandstone and a lavender to purplish colored dolomite limestone. These outcrops of the Devonian Temple Butte Limestone are usually found in cliff faces. Scales from an extinct amored fish have been found in this formation as well as corals, brachiopods, and gastropods. Nearly all of the remnant outcrops of this formation are less than 100 feet thick in the eastern Grand Canyon. In the middle portion of the Grand Canyon, the Temple Butte Limestone is several hundred fee thick and everywhere separates the Muav Limestone from the Redwall Limestone. The formation becomes progressively thick to the west and, toward the lower end of Grand Canyon it attains a maximum thickness of more than 1,000 feet. This difference in thickness is primarily due to erosion in Late Denovian and Early Mississippian time.

The Mississippian Redwall Limestone consists of thick to massively bedded, bluish-gray limestone beds. Various horizons contain irregular white chert nodules. The formation averages 500 feet in thickness below Grand Canyon Village and forms the major part of a cliff generally 600 feet high. It is the most conspicuous cliff above the Tonto Rim. The prevailing red color is a surface feature only, an iron oxide painted over it by rainwash from the overlying Supai redbeds. Various marine invertebrates, including brachiopods, corals, and crinoids, are the characteristic fossils found in this formation.

During a period of erosion following Redwall depostion, caves, solution hollows, cavities, and fissures (karst topography) were eroded in the Redwall Limestone. Erosion probably began in Mississippian time and extended into the Pennsylvanian Period.

The Supai Formation was deposited in Late Pennsylvanian and Early Permian time. It is a thick (1,000 foot) series of alternating red cross-bedded sandstones and shales. The lower fourth of the formation, which includes calcareous sandstones and limestones, may be marine in origin and is Pennsylvanian in age. The upper part, the bulk of the formation, is probably Permian as is the overlying Hermit Shale. It is nonmarine and on bedding plane surfaces, trails of quadrupeds are found. Some of the footprints indicate that the animals making them were the size of small lizards. Some larger tracks, 2-3 inches across, were made by heavier and probably more sluggish creatures. The animals are believed to have been either amphibians or primitive reptiles.

The Permian Hermit Shale is 100-300 feet in thickness, and is a deep red color. The strata are mostly shales and siltstones with a few lenticular sandstones near the base. The red color resulting from iron oxide, mud cracks, and ripple marks, indicate shallow water conditions and intermittent exposure to air. Thirty-five species of fossil plants, mostly ferns, have been described from the Hermit. There are also quadrupedal footprints on some of the bedding planes.

The Coconino Sandstone is a massive, white to buff, cross-bedded sandstone and is 400 feet thick below Grand Canyon Village. It is a rather pure, uniformly fine-grained quartz sandstone. The grains are rounded and commonly pitted and frosted. Eolian cross-bedding on a large scale is characteristic. The formation was accumulated in a huge desert sand dune area. Trails of quadrupedal animals, small primitive reptiles or amphibians, have been found on cross-bedded surfaces.

The Toroweap Formation, deposited by the Toroweap sea, includes red and yellowish sandstones at top and bottom with intermediate gray limestones. The Toroweap sea spread over the Coconino dune area from the northwest while the sand was still fairly loose. The formation is about 290 feet thick below Grand Canyon Village.

The Toroweap sea retreated westward from the Grand Canyon Region, and then returned as the Kaibab sea, advancing across the Grand Canyon Region from west to east.

The Kaibab Limestone is composed of massive, marine limestones. They form the uppermost cliff along the rim. Some of the beds contain admixtures of sand and nodules of white chert. Bedded cherts also occur. Where erosion has not removed the uppermost beds near the rim, it measures 320 feet in thickness. The Kaibab has a rather abundant marine fauna of brachipods, corals, cephalopods, crinoids, and sponges.

After withdrawal of the Kaibab sea, there followed a period of arid erosion. No mountain-building or even slight deformation affected the thick succession of Paleozoic strata. Broad shallow valleys were cut, but nowhere did the downcutting continue long enough to remove much of the upper part of the Kaibab Formation. Some karst erosion took place at the end of the Permian or near the beginning of the Triassic.

The presence of an erosion surface at the top of the Kaibab rimrock of the Grand Canyon indicates that the land was above sea level at the beginning of the Mesozoic Era. Erosion has removed most of the Triassic Moenkopi Formation and almost all of the more recent Mesozoic and Cenozoic rocks from the Grand Canyon region. Their prior existence over the canyon's strata can only be established through inference and extrapolation from outcrops in nearby areas.

Lake Bidahochi formed in Late Miocene to Early Pliocene time in the valley of the Little Colorado River, indicating that no great river such as the Colorado could have passed through there since that time. The middle member of the Bidahochi Formation (the Hopi Buttes volcanics) has a radiometric age of 4.1 million years. Stage 1 volcanics of the San Francisco field began eruption about 2.5 million years ago and eruptions have continued intermittently in that area until 1064 A.D. with the eruption of Sunset Crater. Lava flows have intermittently blocked the Colorado River near Toroweap in Grand Canyon National Monument. There is evidence to indicate that one of the lakes backed up behind the highest of these flows probably extended upstream as far as Lees Ferry and maintained itself until the lava dam was breached. The oldest of these canyon blocking flows has an age of 1.2 million years and shows that at that time the Colorado had excavated the Grand Canyon to within 50 feet of its present depth.

Soils

Within Grand Canyon soil profiles show minimum development. Most soils of the Grand Canyon are residual, being formed from immediate bedrock. Alluvial deposits along the Colorado River combine with colluvial deposits to form the major transported soils of the Inner Canyon. Detailed soils maps of the Inner Canyon have not yet been prepared. It is known that the soils, where present, develop slowly. Combining this with the steep slope makes the soils a fragile resource. Soil textural classes vary from sandy alluvium along the river to silt and clay formed from the weathering of the sedimentary rocks of the canyon walls.

<u>Erosion potential</u>

The large areas of bedrock, shallow soils and sparse vegetation create an ideal situation for sheet wash, flash flooding, and high erosion potential. Once disturbed the soils erode easily and regenerate slowly. Sand beaches immediate to the river suffer greatly from the erosion forces of the Colorado River. Time lapse photography is showing that beaches are being eroded at a high rate. This erosion is an acute problem because the beaches are not being replenished due to the decreased sediment load of the river since the installation of Glen Canyon Dam. There is the possibility that in the future the beaches may totally erode away.

<u>Geologic hazard</u>

Geologic hazards within the canyon are landslides and flash flooding. Camping almost always occurs in landslide zones because of the steep canyon walls. Camping also occurs in flood zones of side canyons. However, neither has caused a fatality recorded by the park except for two deaths occurring in the Indian Gardens flash flood zone in the mid-60's. These, however, were not river campers but hikers from the rim.

Atmospheric quality

Chemical pollution

Currently, the atmospheric quality is excellent, qualifying easily for EPA Class I air. Except for occasional localized pollution from outboard engines and campfires the air quality is some of the best in the world.

Noise

Noise pollution of the Colorado River use zone is caused by two factors, outboard motors used for raft propulsion, also upriver motorboats in lower reaches of Colorado River (below Diamond Creek), and aircraft. Noise levels of outboard motors border on the level shown to have adverse effects on the performance of the user. It also severely limits communication between operator and passengers and masks natural noise. These factors affect the safety and aesthetics of a river trip. Airplane noise affects the quality of the canyons "wilderness river running experience."

3.2.1.2. Climate

The Grand Canyon has many climates depending mainly on the elevation. Average annual precipitation varies from more than 25 inches along the forested North Rim (8,200 feet) to less than 9 inches on the desert of the Inner Canyon (2,400 feet). Intermediate amounts of about 16 inches per year fall on the South Rim (7,000 feet). The North Rim receives more precipitation in winter than in summer; the South Rim and the Inner Canyon receives about equal amounts during the two seasons. The spring and fall are relatively dry in all three areas. Summer precipitation is usually received from thunderstorms that form over the heated canyon walls almost every afternoon from early July until the end of August. Although these storms are capable of producing locally heavy downpours, they rarely last more than 30 minutes and usually cease completely shortly after sundown.

Winter precipitation is not as consistent as that of summer, varying greatly from year to year in both amount and frequency of occurrence. It is associated with middle latitude storms moving eastward from the Pacific Ocean and normally falls in gentle to moderate showers which may persist for several days. When these storms intensify over the California Coast, move directly into Northern Arizona from the west, and meet a cold wave sweeping down from the northwest, severe storms with heavy snow and strong winds can strike. Practically all of the winter precipitation on the North and South Rims occurs as snow. An annual average accumulation of more than 150 inches on the Kaibab Plateau is not unusual and has kept the road to the North Rim closed from November until mid-May in the past. Snowfall is a rarity in the Inner Canyon and averages less than 1 inch per year.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN MAXIMUM TEMPERATURES (°F)												
INNER CANYON	56	62	71	82	92	101	106	103	97	84	68	57
DESERT VIEW	40	43	48	57	69	78	84	80	73	61	49	39
SOUTH RIM	41	45	51	60	70	81	84	82	76	65	52	43
NORTH RIM	37	39	44	53	62	73	77	75	69	59	46	40
MEAN MAXIMUM TEMPERATURES (°F)												
INNER CANYON	46	52	59	69	77	86	92	89	83	72	57	47
DESERT VIEW	31	34	37	44	56	64	72	68	61	50	39	30
SOUTH RIM	30	33	38	46	54	64	69	67	61	50	39	31
NORTH RIM	26	29	33	41	48	56	62	60	54	45	35	30
MEAN MINIMUM TEMPERATURES (°F)												
INNER CANYON	36	42	48	56	63	72	78	75	69	58	46	37
DESERT VIEW	21	24	26	32	42	50	59	56	49	39	30	21
SOUTH RIM	18	21	25	32	39	47	54	53	47	36	27	20
NORTH RIM	16	18	21	29	34	40	46	45	39	31	24	20
MEAN PRECIPITATION (Inches)												
INNER CANYON	.68	.75	.79	.47	.33	.39	.80	1.36	.88	.70	.51	.87
DESERT VIEW	.85	.92	1.45	.74	.56	.36	1.25	1.45	1.01	1.70	.81	1.80
SOUTH RIM	1.32	1.53	1.13	.92	.65	.46	1.87	2.28	1.50	1.21	.95	1.61
NORTH RIM	3.17	3.22	2.63	1.73	1.17	.86	1.93	2.85	1.99	1.38	1.48	2.83

3.2.1.3. Water in River

As shown in the following tables, springs and tributaries between Lees Ferry and Lake Mead contribute approximately 0.5 million acre-feet of water to the Colorado River. Because of the remoteness of most of the minor tributaries, many of these figures are based upon short-term observations and must be considered only approximate maximum values.

TRIBUTARIES
LEES FERRY TO LAKE MEAD

Major Tributaries	Flow in A.F./Yr.	Total Dissolved Solids mg/1	Salt in Tons/Yr.
Paria River	18,000	1,173	30,000
Little Colorado River	134,000	712	130,000
Blue Springs	161,000	2,499	547,400
Bright Angel Creek	25,630	300	10,457
Tapeats Creek	58,000	147	12,000
Kanab Creek	3,000	1,103	4,500
Havasu Creek	50,000	500	34,000
Total	450,430	-----	768,357
Minor Tributaries			
3-Mile Wash	360	---	---
Vaseys Paradise	3,000	198	800
Nankoweap Creek	2,920	500	1,986
Lava Canyon Creek	1,095	750	1,117
Red Canyon Spring	2	44,835	122
Hance Canyon	2	---	---
Cottonwood Spring	8	387	4
Grapevine Spring	16	334	7
Clear Creek	1,460	309	613
Indian Gardens	480	305	197
Monument Creek	150	1,470	300
Hermit Creek	438	441	263
Boucher Creek	183	786	195
Crystal Creek	2,920	735	2,920
Shinumo Creek	5,000	200	1,360
Elves Chasm	200	588	160
Galloway Canyon	200	---	---
Stone Creek	250	367	125
Deer Creek	8,800	350	4,189
Matkatamiba Creek	44	1,139	68

TRIBUTARIES
LEES FERRY TO LAKE MEAD
(Continued)

Minor Tributaries	Flow in A.F./Yr.	Total Dissolved Solids mg/l	Salt in Tons/Yr.
Green Alcove	100	---	---
National Canyon	700	---	---
Fern Glen Canyon	360	---	---
Gateway Canyon	360	---	---
Lava Falls Springs	4,380	845	5,037
Vulcan Springs	3,650	684	3,395
Spring Canyon	95	478	62
205 Mile Canyon	5	728	115
3-Spring Canyon	15	426	9
Diamond Creek	2,555	470	1,635
Travertine Canyon	365	742	369
Travertine Falls	37	937	47
Separation Canyon	10	441	6
Spencer Canyon	1,095	426	635
Lost Creek	50	---	---
Reference Point Creek	10	---	---
Total	41,315	---	25,626

For many years the developed area on the North Rim at Bright Angel Point had obtained its water through a pipeline from Roaring Springs, a major source of Bright Angel Creek. In August 1970, a 16-mile long transcanyon pipeline was completed which connects Roaring Springs with the pumping facilities at Indian Gardens. The pipeline operates continuously except for shutdowns due to breaks in the line. The waterline has a maximum carrying capacity of 208.8 million gallons of water per year. Water in excess of pumping capacity or of needs on the South Rim is released into Garden Creek to return to the Colorado River. The springs at Indian Gardens are now allowed to flow freely into Garden Creek.

Bright Angel Creek is the fourth largest tributary to the Colorado River between Glen Canyon Dam and the Virgin River. The waters of this creek are low enough in total dissolved solids to dilute the salinity of the Colorado

River by 1 to 2 parts per million. As Roaring Springs is one of the major sources of water for Bright Angel Creek, any reduction in their flow in effect increases the salinity of the Colorado River drainage. Water removed from Roaring Springs for use on the South Rim reduces the amount available for downstream users and increases the need for such downstream storage facilities as dams.

The extracting capacity of the transcanyon waterline amounts to 641 acre-feet per year which is 2.5 percent of the normal flow of Bright Angel Creek. The flow of Bright Angel Creek consists of the flow from numerous other springs (contributing approximately 61 percent of the total flow) and the runoff from 98 square miles of drainage basin which receives from 8 to 26 inches of precipitation a year. If the flow from Roaring Springs is as much as 10 cubic feet per second, then the waterline at capacity would consume 10 percent of its flow averaged out over the year. During the winter months, the entire flow of Bright Angel Creek normally drops from 13 to 15 cubic feet per second.

Water commitments within the park will probably stabilize at approximately 162.3 million gallons per year by the late 1970's. The unincorporated village of Tusayan, just outside the south entrance to the park, on private property, does not have an adequate water supply and must haul its water by truck from Williams, Arizona. Businessmen within that community have proposed that a pipeline be constructed to Tusayan for their use. As this proposal would have far ranging effects if it were implemented.

High levels of dissolved mineral salts in the Colorado River are a major water quality problem in Arizona. The Colorado River enters Grand Canyon with a total dissolved solids concentration averaging 586 milligrams per liter. This amounts to 8.7 million tons per year. These solids are primarily of the calcium-sodium-sulfate type. Grand Canyon contains several springs which are high in total dissolved solids and thus contributes to the total load of the Colorado River. Water quality is also affected by large amounts of sediment entering from flooding tributary streams. The watershed areas drained by streams tributary to the Colorado River through Grand Canyon contribute from 0.5 to 1.0 acre-feet of sediment per square mile per year. Long-term records show an average annual sediment discharge of about 10 million tons into the Colorado from the Little Colorado River. Heavy loads of sediment occasionally are carried into the Colorado River at Lees Ferry by the Paria River. Recorded sediment concentrations in Kanab Creek at Fredonia, Arizona, north of the park, have reached 700,000 parts per million and concentrations of up to 500,000 parts per million may often be found in this stream during periods of intense rainfall.

Substantial amounts of oil and gasoline can be spilled into the Colorado River at Lees Ferry from boat service facilities. Ruptured gasoline tanks can also leak during motorized trips through the canyon. On the average, an estimated 20 to 35 percent of the fuel used in outboard motors is wasted in the exhaust. Laboratory studies of pollutants from outboard motors exhaust indicate that approximately 0.23 pounds of oil, as measured by nonvolatile suspended solids, are wasted per gallon of fuel consumed. The turbulence caused by the propeller creates conditions ideal for dispersion of the waste material into the water. The rest enters the air as an air pollutant in the canyon. No estimate is available for the total amount of fuel used within the Grand Canyon by motorized trips each year. However, the scale of the problem may be visualized by using the National Park Service patrol boat as an example. This boat uses approximately 50 gallons of fuel for a run from Lees Ferry to Diamond Creek, and makes the trip about 10 times a season. In one year's time, the boat thus will leave approximately 115 pounds of unconsumed oil and gasoline in its wake. It is not known if this significantly affects the aquatic ecosystem of the Colorado River.

Preliminary chemical and bacteriological surveys have been made in the Grand Canyon section of the Colorado River to assess possible health hazards to river travelers and hikers. The water quality of the amin Colorado River channel is relatively stable with only slight increases in ionic concentraction and bacterial load with respect to distance from Lees Ferry. The bacteriological contamination in the main river channel is normally at or below the standards set for drinking and recreational use set by the States of Arizona and Nevada and by the Federal Water Pollution Control Administration. This does not preclude the necessity of treating water taken from the main channel for drinking purposes but it does indicate that proper chlorination, boiling or other treatment will easily make the water safe for drinking.

Many of the side streams present quite another picture, at least with respect to recreational primary contact. The bacteriological contamination in most of the popular streams and swimming pools is in excess of the levels recommended for primary contact. The tributary streams show extreme temporal variability in chemical water quality and bacteriological contamination as a result of the summer rain and flood patterns. Bacterial contamination of Havasu and Kanab Creek may be the result of poor domestic waste treatment practices. Fredonia, Arizona, and Kanab, Utah, are the probable sources of fecal contamination load in Kanab Creek. The 2,500 inhabitants of Kanab use a single trickling filter unit for secondary treatment of fluid wastes. The 800 persons in Fredonia use septic tanks for the disposal of domestic wastes. Tremendous increases in bacteriological activity in the waters of Kanab Creek occur during flood periods.

Water samples from Havasu Creek show evidence of human fecal contamination. The source of this contamination is the village of Supai on the Havasupai Indian Reservation. There is a significant increase in bacteriological activity in Havasu Creek as it passes through the village of Supai. Supai lacks waste treatment facilities and has a considerable population of domestic animals. The waters of tributary streams must be considered to pose a potential health hazard to hikers and river travelers.

3.2.2. Biological Environment

3.2.2.1. General

North America has been divided into seven major temperature zones according to latitude, ranging from Tropical at the Equator, to Arctic in the polar region. Biologists, observing that plants and animals typical of each zone differ appreciably from those in adjacent temperature zones, have called them "life zones." The same zoning as to temperature, plants, and animals, also can occur at a single latitude in areas that extend from low to high elevations. Thus, in the Grand Canyon Region, at a single latitude, the elevation range from 2,000 to 9,000 feet creates a wide climatic variation and five different life zones.

The Lower Sonoran Zone, the next zone north of Tropical, has the climate of Southern Sonora, Mexico. In Grand Canyon, it occurs at river level (2,000 feet elevation). Typical plants are cactus, agave, and yucca; animals are also those of the desert--Chuckwalla and Desert Spiny Lizards, Rattlesnakes, and Black-throated Sparrows. Part way up the ascent to the South Rim, the climate, vegetation, and animals become typical of the next zone north, the Upper Sonoran, which is characterized by the pinon and juniper belt.

The Transition Zone, the next zone still farther north, appears on the South Rim at 7,000 to 8,000 feet elevation. Here, in the ponderosa pine forests, are birds such as Steller's Jay and Mountain Chickadee.

Familiar flowers of the South Rim from spring to autumn, include phlox, blue penstemon, springbeauty, mahoniá, cliffrose, and rabbitbrush.

The Canadian and Hudsonian life zones are found in isolated portions of the North Rim of the Canyon. Spruce and fir are characteristic of these zones. Since they occur in restricted areas, many of the animals characteristic of the Transition Zone appear in these areas.

The river itself is a barrier to the smaller creatures, but climatic differences between life zones also prevents many animals from crossing from rim to rim. Some birds go from zone to zone briefly, but each bird species is at home in that life zone where climate, plants, and food supply are most suited to its habits.

From Lees Ferry to Lake Mead, the Colorado River flows a distance of 285 miles; in traveling this distance, it drops from an elevation of 3,090 at

Echo Cliffs to 870 feet at Lake Mead. This produces a change of communities as the organisms change to meet environmental differences. This represents a transition from Upper to Lower Sonoran Life Zone.

The riparian zone of the Colorado River and its tributaries present a complex of collinearly-arranged belts of vegetation, quite different today than before Glen Canyon Dam was built. Regulation of water flow stopping the periodic flooding has led to the stabilization of previously barren soils, as well as a structural rearrangement of organisms below the historic floodline. Only 12 years have elapsed since the new water regime was established, this time period is less than necessary to cause a major successional change, so the change is ongoing.

This zone including the Colorado and its tributaries and the collinearly-arranged vegetation to the point impassable by cliffs in climbing and hiking from the river is the "Colorado River use zone," and the area delt within this environmental assessment.

Nominclature and description of the six topographical divisions along the Colorado River and its tributaries.

Rocky outcroppings, cliff faces, and upper talus slopes: These areas generally provide the minimum of the essentials to the survival of many animals as nesting areas.

Lower talus slopes and bench: Erosion of upper areas provides sufficient soil for sparse plant growth, which is limited by the lack of enduring moisture within the root zone. This zone exists above the historic flood-line, and can be divided into talus and bench as separate entitites.

Upper terraces: Commonly called "benches," these pre-dam fluvial deposits just below the old high waterline are no longer eroding due to the absence of flooding. They provide one of the most fertile habitat types within the canyon. These areas show high incidence of invasion by native and exotic plant species of plants.

Lower terraces: Fluvial deposits formed prior to the construction of Glen Canyon Dam are now eroding away because of the reduced sediment load of the river. This may cause a stablized condition where marsh species will increase in numbers. These post-dam areas increase the size of the cat-tail marsh habitat and are the sole nesting sites for some riparian animals of the canyon.

Side canyons, seeps: With permanent to seasonal water regimes separate from the main flow and with protection from wind and sun not offered by the open river banks, the tributaries, seeps, and alcoves provide an additional habitat type within the canyon.

Sand and gravel bars: These areas receive enough disturbance presently to keep them free of vascular plant vegetation of sizable amount. Frequently submerged, this is the interface between river and lower terrace.

3.2.2.2. Flora

The topographical habitat divisions provide for 14 vegetational habitats or plant associations. In the 14 vegetational habitats, eight major vegetation types can be found.

Sparse vegetation. This zone is characteristic of rock outcroppings, cliff faces, upper talus, and sand and gravel bars.

Deciduous forest. Found in side canyons, seeps and upper and lower terraces. Characterized by mature Cottonwood (Populus), Box Elder (Acer), Willow (Salix), and Cercis, dense to sparse ground cover as herbaceous understory.

Evergreen scrub found in side canyons, seeps, and lower terraces, and upper terraces characterized by Arrow weed (Pluchea), Seep Willow (Baccharis), Brickelbush (Brickellia), immature willow (Salix), and Salt Cedar (Tamarix), stands often dense.

Deciduous scrubs found in upper terraces and lower talus slopes and bench with Acacia (Acacia), Mesquite (Prosopis), Apache Plume (Fallugia), with closed ground cover.

Deciduous dwarf scrubs found in upper talus, lower talus, and bench, Encelia, Mormon Tea (Ephedra), Cheat-grass (Bromus), Chaenactis.

Seasonal marshs often found in a transition between the river and lower terrace includes plant species of Scarlet Monkey flower (Mimulus), Cat-tail (Typha), Horse-tail bush, Equisetum.

Evergreen stuanna found in upper talus slopes, lower talus slopes, and benches characterized by Yucca (Yucca), Agave (Agave), Cholla (Opuntia), Barrel cactus (Ferrocactus), has a sparse to moderate ground cover.

Desert scrub found in upper talus slopes, lower talus slopes, and benches, Larrea, Sage (Franseria), Blackbrush (Coleogyne), Ocotillo (Fouguieria), are found here with a sparse ground cover.

Sensitive Areas. Most of the plant life in the river use area is sensitive with the exception of a few species like Tamarix and Pluchea. Harsh growing conditions inhibit regeneration once an area is disturbed.

Biologically sensitive areas within the canyon can be defined as "places with high densities and/or diversities of plant and animal life and/or provide a unique element required for reproduction and survival of indigenous populations." A list of sensitive areas has been prepared.

Name	Mile	Side of River or Location
	17.5	south
Stantons Cave	31.8	north
Vasey's Paradise	31.9	north
Buck Farm Canyon	40.8	north
Spring Canyon	41.2	north
43-Mile	43.2	south
Saddle Canyon	47.5	north
Nankoweap	52.0 - 53.0	north
Kwagunt Canyon	56.0	north
Little Colorado River	61.5	south
Hopi Salt	62-64	south
Furnace Flats	65.6	south
Cardenas Crimarsh	71	south
Red Canyon	76.6	south
Clear Creek	84	north
Phantom Ranch	87.5	north
Garden Creek	89	south
Monument Creek	93.5	south
Hermit Creek	95	south
Boucher Creek	96.5	south
Shinumo Creek	108.8	north
Elves Chasm-Royal Arch Creek	116.5	south
(Blacktail) 122 Mile Creek	122.0	north
Stone Creek	132.0	north
Tapeats Creek Thunder River (Mi. Tapeats & Thunder River caves)	133.7	north
Deer Creek	136.2	north
Kanab Creek	143.5	north
Matkatamiba	147.9	south
Havasu Canyon	156.8	south

Name	Mile	Side of River or Location
National Canyon	166.5	south
Fern Glenn	168	north
Mohawk Canyon	171.5	south
185-Mile	185.5	north
Granite Park	208.6	south
Spencer Canyon	246	south
Grapevine Wash	279.0	south

(S. Carothers, et al 1974)

(Revised S. Martin, 1975)

Today four visually different vegetation belts are found from Lees Ferry to Mile 240. The lowest is characterized by a Salt-Cedar-Willow-seep willow zone; above this is the zone of ephemeral plants which is heavily used by man. Next is a Mesquite-Acacia-Apache plume belt and beyond this are communities of typical desert species on the talus slope.

Vascular plants. More than 600 species of vascular plants are known to exist within the Colorado River use area. A number such as Tamarix and Camelthorn have been introduced from the eastern hemisphere and are known as exotics. Others are endemic and known only to the Colorado River like Schribner's Needle Grass (*Stipa scribneri*) and Buttercress (*Cardamine parviflora*). Most are of wide geographic distribution and plants common of the Upper and Lower Sonoran Life Zones and their related riparian communities.

List of abundant vascular plants:

Catclaw	*Acacia greggii*
Cottonwood	*Populus fremontii*
Grapevine	*Vitis arizonica*
Mesquite	*Prosopis juliflora*
Sacred datura	*Datura meteloides*

Tamarix	Tamarix chinensis
Willows	
Narrowleaf (coyote)	Salix exigua
Dudley (goodding)	Salix gooddingii
Agave or mescal	Agave utahensis
Black brush	Coleogyne ramosissima
Wolfberry (desert thorn)	Lycium pallidum
Greasebrush	Forsellesia nevadensis
Milkvetch (loco weed)	Astragalus spp.
Spanish bayonet	Yucca angustissima
Prickly pear cactus	Opuntia sp.
Princess plume	Staneeya pinnata
White brittlebush	Encelia frutescens or forinosa
Arrow weed	Pluchea sericea
Snake weed	Gutierrezia sarothrae
Seep willows	Baccharis glutinosa
Desert broom	Baccharis sarothroides
Plantain (cheat grass)	Plantago insularis
Ocotillo	Fouquieria splendens
Whipple cholla	Opuntia whipplei
Barrel cactus	Ferocactus acanthodes
Box elder	Acer nequndo (few)
Creosote bush	Larrea divaricata
Cliffrose	Cowania mexicana
Peppergrass	Lepidum montanum
Sand verbena	Abronia elliptica

Russian thistle	Salsola kali
Four wing salt brush	Atriplex canescens
Net leaf hackberry	Celtis reticulata
Spanish bayonet	Yucca angustissima
Bear grass	Nolina microcarpa
Sheep fescue	Festuca ovina
Six weeks fescue	Festuca octoflora
Mormon tea	Ephedra viridis
Maiden-hair fern	Adiantum capillus-veneris

3.2.2.3. Fauna

Reptiles and Amphibians

Due to the arid surface conditions existing only a few meters from the edge of the river or any of its tributaries, the riparian areas offer a restricted environment for amphibians. Because of this situation, few species are present although those which do exist there seem well adapted to their particular environment as evidenced by their high densities.

Reptilian species, especially lizards, appear to flourish in the riparian habitats of the Grand Canyon. Expansion of the Salt Cedar (Tamarix) seem to be beneficial to the populations of such species as Sceloporus magister (spiny lizard), Cnemidophorus tigris (western whiptail) and Crotalus viridis (western prairie rattlesnake).

List of common reptiles and amphibians:

Red-spotted toad	Bufo punctatus
Woodhouse's toad	Bufo woodhousei
Chuckwalla	Sauromalus obesus

Desert spiny lizard	Sceloporus magister
Side blotched lizard	Uta stansburiana
Western whiptail	Cnemidophorus tigris
Gopher snake	Pituophis melanoleucus
Common kingsnake	Lampropeltis getulus
(Grand Canyon) Western rattlesnake	Crotalus viridis (Abyssus)

Birds

In general, the populations of resident birds of the Colorado River and its tributaries are smaller than what has been found in more stabilized and well developed riparian systems of the southwest. It may be expected, however, with the controlled water release from Glen Canyon Dam and the absence of vegetation scouring floods, the Grand Canyon riparian habitats will continue to flourish and expand, thus providing more habitat for the indigenous breeding species. Also, as this habitat proliferates new breeding species may be attracted to the region.

A list of common birds of Colorado River system.

Cinnamon teal	Anas cyanoptera
*Mourning dove	Zenaida macroura
*Violet-green Swallow	Tachycineta thalassina
*White-throated Swift	Aeronautes saxatalis
White-crowned Sparrow	Zonotrichia leucophrys
*Sparrow Hawk	Falco sparverius
*Spotted Sandpiper	Actitis macularia

*Black Phoebe	Sayornis nigricans
*Say's Phoebe	Sayornis saya
*Common Raven	Coryus corax
*Canyon Wren	Catherpes mexicanus
*Rock Wren	Salpinctes obsoletus
*Blue-gray Gnatcatcher	Polioptila caerulea
*Bell's Vireo	Vireo bellii
*Lucy's Warbler	Vermivora luciae
*Yellow Warbler	Denbroica petechia
*Yellowthroat	Geothlypis trichas
*Yellow-breasted Chat	Icteria virens
*Brown-headed Cowbird	Molothrus ater
*Blue Grosbeak	Guiraca caerulea
*House Finch	Carpodacus mexicanus

* Nesting species

Mammals

The riparian zone of the Grand Canyon displays a high density of small mammal species. The exact reasons for these are not completely known. It is believed that certain phreatophyte species such as Tamarix, Pluchea, Salix, and Baccharis provide a key role in supplying cover and possibly food.

The densities of the canyon's larger species are, not surprisingly, lower than those of the small rodent species. Although the riparian zone is highly productive it is usually too narrow to accommodate the range and requirements of larger species. Thus, many of the larger species range through a great portion of the Inner Canyon coming to the riparian zone to feed and water.

Bat populations are large and diverse in Grand Canyon. This is due to the excellent forage provided by the Colorado River and its associated riparian vegetation, as well as an abundance of roosting area which exists in the rocky canyon walls and caves.

List of common mammals:

Yuma Myotis	Myotis yumanensis
California Myotis	Myotis californicus
Western Pipistrelle	Pipistrellus hesperus
Pallid bat	Antrozous pallidus
White-throated wood rat	Neotoma albigula
Desert wood rat	Neotoma lepida
Rock pocket mouse	Perognathus intermedius
Cactus Mouse	Peromyscus eremicus
Canyon Mouse	Peromyscus crinitus
Feral Burro	Equus asinus
*Coyote	Canis latrans
*Bighorn sheep	Ovis canadensis
*Beaver	Castor canandensis
*Mountain lion	Felis concolor
*Bobcat	Lynx rufus
*Mule deer	Odocoileus hemionus
*Ringtail cat	Bassariscus astutus

*Of special interest to visitors but uncommon or rare, according to recent park ecological study (Carothers, et al 1973).

Fish

The Colorado River has only a few species native to its waters. Because of the change in the river environment, due to the dam at Glen Canyon, such fish as the Colorado River squawfish (*Ptychocheilus lucius*) as the humpback chub (*Gila cypha*) may possibly be nearing extinction. The native fish depended on the seasonal fluctuation of temperatures to breed. The stabilized temperature of the waters now limit breeding to warm side streams.

Carp and various chubs, shiners, minnows, bullheads, bass, and other fish have been introduced to the Colorado in varying quantities. Rainbow, Brook, and Brown Trout have been introduced into Bright Angel, Clear Creek, Shinumo, Garden Creek, and Tapeats Creek. Plantings have been made as recently as 1967 in cooperation with the Arizona Fish and Game Department. Earlier efforts to establish trout in Havasu Creek were not successful.

Stocking still occurs at Lees Ferry, Arizona. Five- to seven-inch Rainbow Trout are planted from one to two times a year. Lees Ferry is 1/2 mile from the park boundary on the Colorado River. Trout when planted are known to migrate along the length of the Colorado in the park. Being carnivorous, they place pressure on the young of the endangered native species, but the impact of this factor is not known at this time.

Stocking has also occurred and will continue at Lake Mead. Coho Salmon, Rainbow Trout, Striped Bass, and Walleye have been stocked since 1968. Coho Salmon, Rainbow Trout, Smallmouth Bass, Walleye, and Striped Bass all move from the lake into the lower park and possibly as the river continues to alter from predam system, they will increase in abundance.

Known fish species of Colorado River in Grand Canyon and Tributaries:

<u>Native species</u>

Flannel mouth sucker	<u>Catostomus latipinnis</u>
Bluehead sucker	<u>Pantosteus discobolus</u>
Bonytail	<u>Gila elegans</u>
Humpback Chub	<u>Gila cypha</u>
Colorado Squawfish	<u>Ptychocheilus lucius</u>
Speckled dace	<u>Rhinichthys osculus</u>

<u>Exotic species</u>

Threadfin Shad	<u>Dorosoma petenense</u>
Rainbow Trout	<u>Salmo gairdneri</u>
Brown Trout	<u>Salmo trutta</u>
Coho Salmon	<u>Oncorhynchus kisutch</u>
Carp	<u>Cyprinus carpio</u>
Fathead minnow	<u>Pimephales promelas</u>
Red shiner	<u>Notropis lutrensis</u>
Channel catfish	<u>Ictalurus punctatus</u>
Black bullhead	<u>Ictalurus melas</u>
Plains fillifish	<u>Fundulus zebrinus</u>
Green Sunfish	<u>Lepomis cyanellus</u>
Large mouth Bass	<u>Micropterus Salmoides</u>
Bluegill	<u>Lepomis macrochirus</u>

<u>Rare or Endangered Species</u>

No endangered or threatened species of plants are known to exist with the enlarged park. Plant communities containing species endemic to the complex or species much diminished in range or habitat by definition rare, are known from the area, but systematic tabulations of these plants are not yet available.

The following animals, observed within the Grand Canyon Complex, are on the Official List of Endangered Native Fish and Wildlife, maintained by the Secretary of the Interior, and are threatened with extinction at this time:

Southern Bald Eagle	Haliaeetus leucocephalus leucocephalus
American Peregrine Falcon	Falco peregrinus anatum
Humpback Chub	Gila cypha
Colorado River Squawfish	Ptychocheilus lucius

The Kaibab Squirrel, Sciurus kaibabensis, the Spotted Owl, Stirix occidentalis, the California brown Pelican, Pelecanus occidentalis californicus, the Prairie Falcon, Falco mexicanus and the Little Colorado Spinedace, Lepidomeda vittata, are described as Threatened Species in the 1973 "Redbook" on "Threatened Wildlife of the United States." The "Redbook" is now inactive but the species are listed to give a complete picture of areas inhabitants.

In addition, the following species are placed in the "status-underdetermined" category in the "Redbook," because while it has been suggested that they face extinction, not enough information is available for a definite determination:

Ferruginous Hawk	Buteo regalis
American Osprey	Pandion haliaetus carolinensis

Prairie Pigeonhawk	<u>Falco columbarius richardsonii</u>
Humpback Sucker	<u>Xyrauchen texanus</u>
Gila Monster	<u>Heloderma suspectum</u>

Pending the completion of the Resources Management Plan, all plants and animals are protected according to policy guidelines for natural areas. Special programs deemed necessary for the perpetuation or maintenance of plant or animal species will be enunciated in the Resources Management Plan.

3.2.3. Human Environment

3.2.3.1. History and Culture

This information has been discussed previously in Section 3.1.3.1.

3.2.3.2. Public Use

The Colorado River through Grand Canyon is one of eight stretches of recreational rivers on the Colorado-Green River system. It is one of more than 24 stretches of recreational river in the western United States.

The Colorado River through Grand Canyon National Park, however, has characteristics which set it apart from other rivers. It is the longest stretch of recreational river--some 280 miles, all of which are contained within a national park. It is also surrounded by more than one million acres of land with little human development. After launching at Lees Ferry the first place a raft can be removed by road from the river is 225.6 miles along the river at Diamond Creek. The river contains some of the world's most difficult and exciting whitewater. The Colorado's isolation by the mile deep gorge of Grand Canyon also give it desirable wilderness qualities and off river hiking, climbing, and sight-seeing.

Entry from rim to river by hikers occurs at ever increasing frequency. The intricate system of the Grand Canyon offers thousands of miles of hiking trails and off- trail routes to both expert and novice hikers. Most of these trails are also utilized by river users. Horse and mule trips also occur on the trails of Grand Canyon. The wide spectrum of use shows that backcountry and river management must be tied together carefully.

River running

River running through Grand Canyon has accelerated over the past 5 years. River use in 1972 exceeded use during the 100 years from 1870 through 1969. Between 1967 and 1972 annual use increased from 2,099 to 16,432 users. In 1973, an interim management plan held use at 96,600 user days, the same approximate use as in 1972.

Commercial. Commercial river trips have been assigned 92 percent or 89,000 of the user days. (Crew members are not counted in this assignment.) These user days are distributed to 21 authorized commercial companies on a 5-year permit which began in 1972. About 70 to 75 percent of commercial use is by motorized boat. Trip lengths vary from 2 to 18 days and may have as many as 40 passengers on two boats.

Non-commercial. Non-commercial trips are permitted 7,600 user-days which are assigned on an annual basis through a lottery system. Demand exceeds the 7,600 user-day limitation by seven to eight times. Approximately 90 percent of private trips are by oar-powered boat. Private trips average about 15 days in length and the maximum trip size is 15 people.

Educational. Educational trips and scientific trips travel in one of the existing categories of commercial or non-commercial depending upon their status. Educational and scientific demand seems to be increasing in recent years. Some scientific trips are for management purposes.

Camping. Over 300 river beaches are available for river parties. These beaches exist in clusters; certain portions of the river have abundant camps, and other portions have little or no camping areas as the sheer canyon walls meet the river. No structures or facilities are provided for river users. The bottle-neck of camps presents a limiting factor in camping space. Side canyons are also used for overnight camping when river parties hike to view scenic attractions. Most camps along the river are used primarily by boat parties rather than hikers. Conflicts of use only occur when beaches are at the end of a trail (e.g., Hermit) or when river users hike to a scenic spot off the river (e.g., Thunder River, Havasu).

Spelunking. The geologic formations of the canyon, especially the limestone, contain caves. Five caves of major attraction exist along the river, others are known to the avid spelunker. Caves are very fragile systems and potentially dangerous. At this time, caving is not a major recreational activity in the Colorado River use zone.

Fishing. Fishing is not a major attraction within the park. It does occur along the river and in some of the major tributaries (e.g., Bright Angel and Tapeats Creeks), where the major fish caught are channel cat, carp, striped bass, walleye and occasionally Coho Salmon. All these fish have been introduced to the river through stocking or transplant at Lake Mead, Lees Ferry, Diamond Creek, and the major tributaries within the park. Gila cypha is occasionally caught on hook and line.

Wilderness. Some 500,000 acres of land adjacent to the Colorado River have been proposed for consideration as designated wilderness as specified in the Wilderness Act of 1964. Most of the land below the rims offer wilderness qualities to the river traveler with the exception of corridors at Bright Angel and Kaibab Trails, Phantom Ranch and Diamond Creek Road. The river is proposed as potential wilderness until the use or exclusion of motors on the river is determined. In recent wilderness workshops held in cities of the Western United States, 86 out of 105 people participating thought motor use was not acceptable and should be discontinued on the Colorado River in Grand Canyon.

Interpretation and Education

Interpretive and educational use are an important part of the concept of the National Parks. The Colorado River provides a means for utilization of the interpretive and educational resources of Grand Canyon. The geologic and natural qualities of the canyon offer educational as well as interpretive experience to the novice and scientists. The river also offers education in conservation and outdoor activities. Use of the canyon resources have drawn many institutions to the river. Some colleges offer semester credits for participation in a river trip. The educational demand as well as the demand for interpretation are likely to increase in the future.

3.3 Lake Powell and Glen Canyon National Recreation Area

3.3.1 Physical Environment

Glen Canyon National Recreation Area and Lake Powell are located in the heart of the Colorado Plateau, a physiographic area which is drained by the Colorado River and its tributaries. The Plateau covers approximately 150,000 square miles, 90 percent of which lies in the states of Arizona, Colorado, New Mexico and Utah. The Colorado Plateau Region fosters some of the few remaining wild areas of the United States. The rugged deserts, mesas and canyons of the Southwest form a unique experiential resource.

The entire region of the Upper Colorado River Basin and Lake Powell is experiencing attention by politicians, developers, energy experts, and the general public because of it being a land prime for development in terms of population, increased tourism, energy and water resources, abundance of coal for powerplant consumption, and finally, scenic recreation.

The Glen Canyon National Recreation Area covers approximately 1,236,880 acres surrounding Lake Powell including Rainbow Bridge National Monument.

Although the majority of the recreation area lies in Utah, the Glen Canyon Dam and approximately 3 percent of the recreational lands are in northern Arizona. Glen Canyon National Recreation Area is just one component of the system of five National Parks and seven National Monuments, in addition to the National Recreation Area, which are administered by the National Park Service in Utah.

Lake Powell, one of a series of water reclamation projects involving the Colorado River system, began filling with the completion of the dam in 1963. When it reaches its maximum level, the lake will be 186 miles long with 1,960 miles of convoluted shoreline.

3.3.1.1 Physiography

The Glen Canyon National Recreation Area is in the Canyonlands Section of the Colorado Plateau province. It lies athwart the Colorado River from Cataract Canyon at the northeast to Lees Ferry at the southwest, and along the San Juan River west of the Goosenecks.

This part of the Canyonlands Section is a highly dissected plateau surface 5,000 to 7,000 feet above sea level. The broad upwarped surface is transected by two huge upfolds, the Waterpocket Fold and the Echo monocline. The area is characterized by a maze of deep canyons whose walls are nearly vertical. Flat-topped mesas and rock platforms rise in tiers or giant steps away from the main drainages to the upland regions of the Colorado Plateaus.

Bordering the Recreation Area are Navajo Mountain (Elev. 10,880 feet), and the Henry Mountains (Elev. +11,000 feet); that rise several thousand feet above the plateau surface.

The Glen Canyon reach of the Colorado River, now occupied by Lake Powell, is the longest continuous canyon in the Colorado River system. The general trend is northeastward but the specific trace of the canyon is sinuous because it consists of incised meanders several hundred feet deep. The sinuosity is still evident, even though the original canyon is filled with several hundred feet of water. Much of Lake Powell is enclosed by the Navajo Sandstone, which forms rounded and vertical walls as much as 1,000 feet high. In other parts of the area alternating resistant and soft strata erode into a series of irregular benches. Few tributary drainages enter Glen Canyon at grade. These are the Dirty Devil River, North Wash, Trachyte Creek, Ticaboo Creek, White Canyon, Red Canyon, Moqui Canyon, Escalante River, and Navajo Creek. Most of the other tributaries contain hanging valleys before entering the main drainage system.

Dissection by the Colorado River of the rocks in the northeastern part of the area has produced a topography of jagged escarpments, vertical-walled cliffs, rock benches and ledgy slopes. Erosion along faults and joints results in sharp wedge-shaped recesses and spurs upon the canyon walls. San Juan Canyon downstream from Clay Hills Crossing is essentially a box type that characteristically results from erosion of hard and soft strata of the Triassic and Jurassic rocks. The Canyon has a maximum depth of 2,500 feet between Piute Mesa and Nokai Dome. Only four tributary streams, Piute Farms Wash, Copper, Nokai, and Piute Creek enter the San Juan River in the stretch of the Canyon.

Stratigraphy

Rocks of Pennsylvanian to Cretaceous age crop out in the Glen Canyon National Recreation Area. Pennsylvanian and Permian rocks are exposed only in the Cataract and San Juan Canyon areas. Cretaceous rocks are present in the eastern part of the Kaiparowits Plateau between Rock Creek Canyons and Navajo Point.

This part of the canyon lands was marginal to the main seaways during uppermost Paleozoic and Mesozoic time. Marine deposition of late Pennsylvanian and early Permian time was in the Paradox Basin to the east of the Cordilleran geosyncline to the west. The rise of the Uncompahgre Highlands in southwestern Colorado is recorded in the detrital sediments of Pennsylvanian time. These highlands also contributed detritus to the Permian and Triassic Formations. The last advance of the seas from the west was during Permian time and is represented by Kaibab limestone. Erosion was predominant during the Permian-Triassic time interval. During early Triassic time the Moenkopi Formation was deposited along the eastern margin of the seas. Following retreat of the Triassic seas widespread erosion of the pre-Chinle surface marks one of the profound unconformities in the Colorado Plateau. The Chinle Formation was deposited unconformably on the Moenkopi and represents fluvial and floodplain sediments derived from highlands to the east. The Glen Canyon Group of rocks reveal intertonguing between the eolian sands of the Navajo and Wingate Sandstones and the fluvial sediments of the Kayenta Formation. Following regional upwarping during Early and

Middle Jurassic time the San Rafael Group was deposited along seas which transgressed southward within the Rocky Mountain geosyncline. Marine deposition during this period is reflected in the widespread distribution of the Carmel Formation. During the retreat of the Jurassic seas the fluvial Morrison Formation and the eolian Cow Springs Sandstone were deposited. Following the withdrawal of the Jurassic seas the Colorado Plateau was the site of large scale erosion during Early and Late Cretaceous time. The area was again invaded by marine deposition and the presence of continental and nearshore marine sediments of Upper Cretaceous rocks reflects the many advances and retreats of the seas. This depositional environment is represented by the Tropic Shale and Straight Cliffs Sandstone.

Surficial Deposits, overlying the bedrock formations, occur in scattered deposits, located along the river, in the side canyons, on the Navajo baldrock, and on Carmel-capped platform. These are composed of alluvial silts and sands, sand dunes, Pleistocene gravel terraces, talus, rock falls, and minor amounts of soils.

The million of tons of silt brought into the canyon by spring and summer floods added to or replaced mud bars and sand banks at the mouths of tributary canyons along the sides of the river banks, and in the main stream channel. These changed the surface configurations slightly with the yearly surge of snowmelt water from the Rocky Mountains. Older stranded alluvial terraces, now about 25 feet above the river, termed

Moki terraces by some researchers, have been cut from a lower fluvial deposit composed of material laid down by the river and tributary streams. These are capped by a thin horizon principally derived from local fluvial deposits and wind-blown sand.

Sand, weathered from the stark faces of cliffs, the stripped surfaces, and from the river deposits is blown, shifted, and deposited as dunes in the canyons during the afternoon breeze or during regional storms. The larger dunes, holding moisture for relatively long periods of time, offer the most promising and potentially rewarding locations for annual and perennial wild flowers.

Cherty, porphyritic, and quartzitic gravels deposited by the Colorado River remain as terraces chiefly on the stripped Navajo sandstone surface up to 1,000 feet above the riverbed. Weathering of the canyon walls produces talus slopes upward of 500 feet in height.

Soil, the least conspicuous surface condition, is found in alluvial terraces, on hillsides in the inner canyon, and upon the remnant Carmel-capped platform away from the river precipice. It is shallow, mildly alkaline, and lacks developmental horizons.

The soil type in the general area is identified as the Badland-Rock Land Association. (Soil Conservation Service, U.S. Department of Agriculture). Badland describes an area of barren shale or interbedded sandstone and shale. Rock Land generally denotes bare rock outcrops, but also includes some areas of shallow soils over bedrock. The shallow and very shallow soils are on benches and mesas where the topography is undulating or rolling.

The localized soil condition consists almost entirely of coarse-grained wind deposited material over sandstone. However, many different soil patterns can be distinguished. These patterns include deep and moderately deep soils derived from wind deposited materials which are found in the following situations:

Deep to shallow soils which overlie cobble soils

Shallow, very rocky soils

Deep soils of the drainage ways

In general, the majority of the soils exhibit a single grain structure, are well drained, are medium to fine in texture, and are immature with relatively little secondary development. They are alkaline and are low in organic matter. Plant roots predominate in the upper 12 to 18 inches of the soil profile.

The depth of the soil layers varies from 0 to 20 feet. The clay based soils become a nearly impassable quagmire when wet, but dry to a hard surface within one day where the soil is well packed.

The fine desert topsoil, when insufficiently anchored by vegetation, can become airborne with sufficient winds. The "blow sand" condition has a sand blasting effect in some areas and leaves accumulations of sand in others.

The shoreline exhibits textural changes with the water level fluctuation of Lake Powell. A "bathtub ring" forms on the sandstone cliff walls from an increasing intensity of white carbonate deposit.

Glen Canyon lies in the Four Corners Air Quality Control Region. The area has little industry and a relatively low population. Background air quality is generally very good since there is little development and little vehicular traffic in the area. However, emissions from power-generating stations commencing operation (the Navajo Generating Station in June 1964) and possible future generating stations may alter the air quality of the region.

The National Science Foundation sponsored Lake Powell Research Project has conducted studies of background air quality in the general region. Recording first began on September 3, 1972. Analysis of air quality data collected by the Lake Powell Research Project is underway. The report has not yet been completed; however, they have initially determined that:

> "The air quality of the Lake Powell region is excellent, especially in comparison with the air in cities such as Phoenix. For example, the arithmetic annual mean concen tration of nitrogen dioxide in Page is 36 micrograms per cubic meter (Hg/m^3) compared to 168 Hg/m^3 in Phoenix and the annual geometric mean mass concentration of aerosal in Page is 18 Hg/m^3 compared to 108-265 Hg/m^3 in Phoenix. The air around Lake Powell loses some of its excellent character

near local air pollution sources such as automobiles and motorboats. These sources emit carbon monoxide, hydrocarbons, oxides of nitrogen, aerosols, and noise. The last two parameters of the list are the easiest to measure. The background value of aerosol number concentration is about 1300 particles per cubic centimeter (cm^3), while values near the exhaust of a motorboat or automobile exceed 10^5 per cm^3."

Extensive study has been accomplished near Page, Arizona, in order to determine air pollution caused by the Navajo Generating Plant. Measurements have been made within the area for sulfur content utilizing lead peroxide techniques. Sulfur content of air in the region is extremely low, although this in no way indicates the quality of air in terms of the other polluting agents such as carbon monoxide, nitrous oxides, oxides, hydrocarbons, and particulates.

The principal particulate matter found in other air quality analysis is soil dust, due to strong winds which pick up unanchored particles of soil.

Initial studies by the Lake Powell Research Project indicated that it is so quiet in some remote sites in the Lake Powell region, that the recording instruments gave incorrect readings because of internal sounds. Corrected instruments gave readings of less than 30 dbA (decibels weighted on the A scale to simulate the human hearing response). (National Science Foundation, 1973).

Natural noise levels in the high desert are low because there is little wildlife and little rustling vegetation. People, motorboats, vehicles, and aircraft increase the noise levels in this area, where sounds reverberate in canyons and travel unobstructed paths across the vast open spaces (motorboats can produce over 100dbA). Winds may muffle some sound.

3.3.1.2 Water in Lake

Glen Canyon is located in an arid region where precipitation is minimal and the evaporation rate is high. The general area has a deep solid sandstone base and low water permeability is characteristic since there are few geologic features to translocate the water. The location of ground water is discontinuous and the yield from the sandstone strata is variable. Determination has not been made as to whether the ground water being pumped is from a regionally available aquifer or from lake bank storage. Bank storage of water is dependent on the permeability of the base rock and the surface level of Lake Powell. A hypothetical model of the average bank storage situation indicates that the average bank storage zone would be 1 1/2 miles wide at maximum impoundment levels. A detailed study would be needed to determine if high-fracture permeability were causing larger amounts of bank storage.

Lake Powell is a catch basin for variable runoff from the mountains and adjacent mesas and plateaus. The major drainages in the area are: the San Juan River on the southeast, the Escalante River to the southwest and the Colorado River itself. Colorado River water flowing through

Glen Canyon comes principally from the Rocky Mountains. During the months of April, May, June and July, runoff is high and the Colorado River is at maximum flood stage; about 70 percent of the annual runoff occurs in these four months. Springs originate in most tributaries draining into Glen Canyon. This water is clear and comes from springs and seeps in the Navajo sandstone. The quantity varies in most tributaries from less than one gallon to over 100 gallons per minute. Drainage channels are fairly well defined. The larger slickrock ravines are susceptible to temporary flash flooding when regional storms can turn dry sandy stream courses into violently flooded channels, which return to their arid state in a few hours except for brim-full potholes along the water courses. Many of these potholes, especially in the bald-rock, have prehistoric pecked steps leading to them--evidence of their usefulness.

Since Lake Powell is a relatively young reservoir, no long-term limnological studies are available. The biological and chemical content and the mixing patterns of Lake Powell are changing as the lake level rises and as more visitors use the lake. A long-term study, The Assessment of Man's Activities in the Lake Powell Region, is presently being conducted by the Lake Powell Research Project to formulate the baseline indexes for the water-quality of Lake Powell. The study includes:

Diversity indexes on phytoplankton and zooplankton. Lower diversity values indicate less optimal water quality conditions.

Measurement of the primary productivity by the rate of carbon fixation during photosynthesis for use as an index of eutrophication.

Coliform counts in that they signify the possible presence of pathogenic bacteria such as Salmonella and Stypotococci.

A number of tentative conclusions have been reached so far as a result of the study (LPRP 1973).

1. "Lake Powell is midly eutrophic."

2. "Total coliform counts are above acceptable levels for drinking but are safe for body contact."

3. "Intestinal bacteria such as Salmonella sp. do not represent a health hazard," although the presence of Salmonella has been detected in Wahweap Bay.

4. "All major marinas on the lake are possibly affecting the water quality."

5. "Silt and organic load carried into the reservoir by the tributaries significantly increase productivity."

During years of high runoff in the Colorado River watershed and extreme water level fluctuation, enormous amounts of silt and organic loads are carried into the reservoir, mainly by tributaries at the upper end. Tests have shown that the period from May to August is the most productive biologically. In 1972-73, tests showed that in the water directly below the Hall's Crossing Marina, the mean production rates were high compared to other test locations on the lake. At both Hite and Halls Crossing, high productivity rates show the effects of a greatly fluctuating reservoir with the high silt and organic loads. Other test sites throughout the lake at locations above and below each marina led the study to conclude that "all major marinas on the lake are possibly affecting the biological water quality."

Analysis of physical limnology is complex because of all the tributary waters. Tests suggest that the tributaries supply the major evaporative surfaces and that there are inflow turbidity currents occurring all year. (National Science Foundation, LPRP, 1973).

Lake Powell is a sulfate/bicarbonate/chloride lake with an average salinity of approximately 500 parts per million (PPM) total dissolved solids. The composition of the waters is controlled primarily by the contributions from the Green, Colorado, and San Juan Rivers, but is modified by the precipitation of calcium carbonate. The precipitation of calcite in Lake Powell has been described as "the most quanitiatively important chemical process that alters water quality as a result of impoundment." (LPRP, 1973) Precipitation is probably most intense in the lower reaches of the lake. Precipitation may be responsible for lowering the salinity by as much as 19 to 29 ppm.

The thermal regimen and convective mixing characteristics of Lake Powell are warm monomictic. However, Lake Powell is meromicitc to the extent that seasonal convective mixing does not carry to the bottom. At its present volume and configuration, the circulation of Lake Powell is dominated by advective transports and mixing. In this respect, Lake Powell is still very much a river despite its impressive volume of water impounded in the form of a lake. Advective flows of cold saline waters have, to date, effectively forestalled the development of an anaerobic condition in the bottom waters.

The amount of dissolved oxygen in the waters varies throughout the year. In the summer when the surface water temperatures are higher, the water has the least ability to hold oxygen in solution. Oxygen content is a key to maintaining water quality. Oxygen is necessary to support the bacterial action which decomposes wastes and deep plants in the water. Oxygen levels in the lake decrease rapidly between depths of 50 to 70 feet where the temperature change per unit is the greatest. This contributes to the creation of two layers of water, each with its own density, circulation characteristics, and fish inhabitants.

A study on the control of pollution from outboard engine exhaust found that exhaust products separated rapidly from the water and accumulated in pools on the surface. Very little exhaust material was found to be retained in the water below the top few inches. Both fuel and exhaust products were found capable of supporting microbial growth with adequate oxygen supply.

Analysis of metals indicates that mercury concentration in fish is safe for the most part, but reaches levels above the allowable amount in some large carnivores, especially bass and walleye. Muscle tissue accumulates the highest mercury concentrations in most fish. Metal content of the waters attributable to man's use of the lake includes the presence of concentrations of zinc which is associated with the use of portable chemical toilets on boats. (National Science Foundation 1973) Zinc is diluted by the lake waters but remains in solution.

3.3.2 Biological Environment

3.3.2.1 General

The southern central portion of the Colorado River Basin considered in this report presents three grading climatological zones. Most of the region is desert ranging in altitude from 3,000 to 5,000 feet and characteristically has the Upper Sonoran floral and faunal assemblage. The intermediate mesas and high plains, here considered as Transitional, range in altitude from 5,000 to 7,000 feet. The area includes the slopes of Navajo Mountain, the summit of Cummings Mesa, and most of the Rainbow Plateau. Plant life is dominated by scrub oak, juniper, and grasses. The third zone, the cool-humid Alpine, occurs only on Navajo Mountain from 7,000 feet to its summit, near 10,000 feet. The Transitional zone is found at 7,000 feet on the Kaiparowits Plateau, north of the river.

The evaporation rate in this region is high, owing to the low humidity, high temperatures, dry winds, and sunny skies. The precipitation deficiency of the region below 7,000 feet results from its inland location far from the Gulf of Mexico and from the mountain barriers along the Pacific Coast. Summer rainfall occurs primarily in July and August and is associated with moist air from the Gulf of Mexico. These are the months of maximum precipitation; April, May and June are the driest months. Winter rains are sometimes a slow drizzle accompanied by snow flurries. The average annual precipitation for the plateau country is near 10 inches per year with a range of 6.5 to 13 or more inches. The amount of precipitation increases with elevation, but is governed to some degree in this increase above the canyon by exposure, prevailing winds, and the proximity to mountains.

Short thundershowers in the summer, lasting less than an hour, can cause heavy runoff often resulting in flash floods in the tributary canyons. These storms may bring down in one rain most of the monthly average. Gentle soaking rains are less common; when they do occur they are associated with a Nevada low pressure area. The cool humid zone receives more than 16 inches of precipitation annually, one-third of the total being snow. Snowfalls in the higher elevations occur primarily between September and May. At the lower elevations snowfalls are scattered and melt soon after reaching the ground. Lees Ferry, Arizona, receives less than four inches of snow annually and this is concentrated in the months of November, December and January. Temperature changes between day and night are varied, particularly above 5,000 feet. During the summer months, hot days often exceeding 100° F., are accompanied by relatively cool nights at the lower elevations. Winter maximums average in the upper 40's or low 50's; winter minimums average well below freezing, but rarely sub-zero.

Prevailing winds are from the southwest, but vary seasonally. Strong gusty winds can be expected during much of the year. From December to

April, winds are associated with the passage of active storm fronts. Preceding the front, winds are from a southerly direction; following the frontal passage, winds shift and originate from a northerly direction. From April to September, strong gusty winds are common as part of active thunderstorms and may reach velocities of 70 miles per hour. From October to December, winds are calm except when associated with storm fronts.

Frost-free periods in Glen Canyon are relatively long. The average length of the growing season at Lees Ferry (elevation 3,141 feet) is 229 days with average dates for the last spring frost and first fall frost being March 24 and November 8 respectively.

Sunny days in the canyon lands range from 70 to 80 percent of the year. Direct sunlight in the canyon coupled with high reflectivity from the smooth canyon walls results in searing intensity to the novitiate's eyes and exposed skin.

Dry moderate surface winds are generally westerly in the winter and southwesterly in the summer months of June, July and August. These winds begin about noon, reach their maximum intensity about three, and generally subside by nightfall. Strong winds, usually occuring in a succession of gusts, are not uncommon. These high winds carry blowsand throughout the canyons and over the rock terraces and occasionally scatter pebbles from the canyon rim.

3.3.2.2 Flora

Glen Canyon NRA is situated in the botanical overlap between the cold desert of the Intermountain Basin and Range Province and the hot desert of the Southwest. The vegetation consists primarily of xerophytic (drought resistant) shrubs, including sagebrush, Mormon tea, saltbush, ricegrass, and blackbrush. A limited number of annual plants grow in the normal years of low precipitation, but when precipitation is above average, annuals are more abundant. Because of the small amount of available moisture, desert plants compete strongly for survival. Evolutionary anatomical adaptations including spines, heavy bark, smaller leaf surface area and thicker cutinous layers on leaves, serve to abate plant desiccation. Competition is somewhat reduced by a stratification of root systems; some plants have shallow root systems and others deep. Usually spaces between plants with shallow root systems are large because of the moisture required to support each plant. Therefore, communities of black brush and related plants cannot produce a complete soil cover; exposed soil, open for wind erosion, will always remain between plants.

All plants in this area have adapted to withstand drought, high summer temperatures, below freezing winter temperatures, and wind. However, the native vegetation is fragile in its ability to absorb man's impact.

Within the Recreation Area marked changes in vegetation are recognizable and reflect differences in available moisture, aspects of exposure, altitude, soil differences, topography and temperatures. In the canyons the distribution of plants is regulated by the availability of water and the adaptions of plants that fit them to make use of the quantity available at any particular site. Three habitat types, streamside or river bank, terrace, and hillside, generally occur in an ideal cross-section of plant distribution in the inner canyon.

Streamside vegetation of phreatophytes, which use large amounts of water, is found on alluvial deposits bordering terraces, along water courses, ponds, seeps, and springs. This community of tall shrubs and small trees ranges from 10 to 60 feet, in width and occasionally is as much as 200 yards wide.

The dominant species at the streamside community are the sandbar willow, Salix exigua; Gooding willow, Salix goodingii; baccharis, Baccharis emoryi; tamarix or salt cedar, Tamarix pentandra, and arrowweed, Pluchea sericea. Associated with these five major species are others which are occasionally found mixed with them. Local stands of the Gambel oak, Quercus gambellii; hackberry, Celtus douglasii; and rarely the Fremont cottonwood, Populus fremontii are found with this community on narrow alluvial terraces, steep slopes near the river, and in glens. Other shrubs, herbs, and grasses are found either scattered or in local dense stands.

Terrace vegetation ranges from 10 to 300 feet in width. It includes xerophytic perennial herbs or desert shrubs growing on dry surface soil which use intermediate supplies of water beyond precipitation, usually receiving it by capillary action from a subterranena water source. The terrace community grows primarily on old flood plains and includes arrowweed, Pluchea sericea; grease wood, Sarcobatus vermimulatus; rabbit-brush, Chrysothamnus viscidiflorus; four-winged saltbush, Atriplex canescens; squawbush, Rhus trilobata; narrow-leaved yucca, Yucca angustissima; shadscale, Atriplex confertifolia; and other shrubs. Trees including Fremont cottonwood, hackberry, and Gambel oak, occur with grasses, vines and other trees, shrubs and herbs to make up the community in the main and side canyons.

Hillside vegetation of xerophytic plants adapted to the sparing amounts of water provided by precipitation is found on hillsides, ledges, talus slopes and cliffs, sand dunes, and on higher terraces and mesas above the canyon rim. In this zone the low desert shrub vegetation includes shad-scale, Atriplex confertifolia, and saltbush, Atriplex cuneata, with Garrett salt bush, Atriplex garrettii locally abundant. Other plants including joint firs, Ephedra, sp.; dropseed, Sporobolus, sp.; bottle-stopper, Eriogonum inflatum; and cacti, Opuntia spp. Blackbrush, Coleogyne ramosissima; are conspicuous at the higher elevations. In general, this community varies in numbers and distribution by locality, with the herbaceous plant being quite abundant in species but few in number.

An assortment of plants ranging from larger trees to mosses is found in the stream channels. Cottonwood, Gambel oak, hackberry, red bud, Cercis occindentalis; reed cane, Phragmites communis; cattail, Typha latifolia; willow; and secondary phreatophytes occur along the stream courses not scoured by flash floods. They are mixed with streamside and hillside vegetation or both. Monkey flower, Mimulus eastwoodiae; cardinal flower, Lobelia cardinalis; ferns, and mosses along with other semi-aquatic plants, and grasses cling to the wet seeps, aquifers, moist sand and some talus slopes. Lichens and mosses are found on bare northerly-facing cliffs in patches or coats varying in thickness and coverage.

The vegetation of the region can be characterized by arbitrary altitudinal zones ranging from the lake's edge to the summit of Navajo Mountain. In general, vegetation below 5,000 feet is sparse except along watered tributaries. Between 5,000 to 7,500 feet occur pinyon pine and juniper. Above 7,500 feet a spruce-fir forest mixed with aspen flanks the upper slopes and summit of Navajo Mountain.

3.3.2.3 Fauna

In order to ascertain a quantified account of the existing wildlife habitats, a complete inventory developed from continuous observation and study would be required. No such known inventories have been conducted; however, much generalized information can be presented to satisfactorily describe the environment.

The rising waters of Lake Powell have continually restricted the habitat of terrestrial forms of wildlife (birds, mammals, amphibians and reptiles), and expand available habitat for fish. Ultimately, if lake levels become more stable than they are now, a greater amount of shoreline will exist than did previously at the original river level. At this interface, between the water and the land, there is an area which allows for a great variety of wildlife due to increased ground cover, larger variety of food organisms (plant and animal), and availability of water. However, before such a situation can become established, plants will need to colonize the shoreline area.

With the changing habitat found around Lake Powell, the following habitat categories can be defined:

Fluctuating Lakeshore Edge

Projected Stabilized Shoreline

Flat Lands

Canyonlands

Slope Areas

Lake

Within these major areas are many other habitat situations such as the blow sand and slickrock areas.

a. Fluctuating Lakeshore Edge

The present shoreline area, with its increasing shoreline elevation, does not lend itself to a stable flora or fauna community. Within this area, there does exist a continually displaced animal community. Kangaroo rat, antelope ground squirrel, pack rats, deer mice, ring-tailed cats, weasel, snakes and lizards are found in this area. For the most part, the amphibians have disappeared from the scene due to the lack of a protective habitat. Bird life in this range, because of its mobility, is not significantly affected by the water level changes. An increase in insect life due to the various levels of vegetation decay is possible.

b. Projected Stabilized Shoreline

The lake will continue to fluctuate even after it is filled and the existence of a relatively stable shoreline with a conducive area for permanent plant growth is only a matter of speculation at this time. The animal species diversification in this area is dependent on the plant cover. This potential area would have the greatest diversification and abundance of wildlife species of any area. With new cover available at the lakeshore - land interface, the following species would probably establish themselves in the area once more:

bullfrogs	Rana catesbeiana
gopher snakes	Pituophis catenifer
garter snakes	Thamnophis sp.
milk snakes	Lampropeltis triangulum
rock squirrels	Citellus variegatus
chipmunks	Eutamias sp.
cottontail rabbits	Sylvilagus sp.
beaver	Castor canadensis
coyote	Canis latrans
fox	Urocyon sp.
ring-tailed cats	Bassariscus astutus
weasel	Mustela frenata
badger	Taxidea taxus
striped skunks	Methitus maphitus
spotted skunks	Spilogale putorius
bobcat	Lynx rufus
sparrow hawk	Falco sparverius
red-tailed hawks	Bueto jamaicensis
lizards	
snakes	
variety of mice	
variety of bird life	

Mammals are more limited here than on bench lands, but include rodents, such as the antelope ground squirrel, jack rabbits, and an occasional coyote. Some lizards and snakes frequent this area, although their numbers are generally low.

Birds are represented by a multitude of song birds and predators. The desert shrub community contains populations of black-throated sparrow, Brewer's sparrow, pinyon jay, loggerhead shirke, horned lark, common nighthawk, Say's phoebe, ash-throated flycatcher, mocking bird, mourning dove and house finch.

Some of the more common transient waterfowl are the shoveler, and cinnamon teal, all of which may be observed regularly on the lake during the spring; the great blue heron, snowy egret, merganser and several species of grebes frequent the area during the winter.

The topographic diversity and abundance of prey provide a suitable habitat for numerous species of predatory birds. These include the golden and northern bald eagles; ferruginous, red-tailed, Swainson's, Cooper's, sharp-shinned, and marsh hawks; prairie and peregrine falcons; and great horned, burrowing, screech and long-eared owls. The peregrine falcon is officially classified as "endangered," the prairie falcon as "threatened" and the ferruginous hawk as "status undetermined" by the Office of Endangered Species and International Activities (Department of the Interior, Fish and Wildlife Service, Office of Endangered Species and International Activities, 1973).

c. Flat Land

This area is characterized by numerous benches and flat-bottomed valleys. The mammals of this area include ground squirrels, kangaroo rats, jack rabbits, and the coyote. Birds characteristic of this area include larks, finches, crows, ravens, hawks and the golden eagle. The lower valley areas would have the greater number of birds and mammals.

Brushy sagebrush flats and low mesas are inhabited by the leopard lizard, northern side-blotched lizard, the Great Basin sagebrush lizard, northern whiptail lizard, and Great Basin skunk. The Great Basin gopher snake, Hopi rattlesnake, desert striped whipsnake, western striped racer, midget faded rattlesnake, California king snake, and Utah black-headed snake range widely over the recreation area and occur at least occasionally in almost all of its terrestrial habitats.

Typical residents would include:

ground squirrels	Citellus leucurus
kangaroo rat	Dipodomys ordii
black-tailed jack rabbit	Lepus californicus
horned lark	Eremophila alpostris
house finches	Carpodacus mexicanus
foraging crows	Corvus brachyrhynches
ravens	Crobus corax
golden eagle	Aquila chrysaetos
lizards	
snakes	
hawks	

d. Canyon Lands

This area is often vertical, largely rock with intermittent water seeps and springs. The vertical cliffs provide nesting areas for birds such as swifts, crows, ravens, red-tailed hawks, and golden eagle. The cliffs also provide habitat for pack rats, deer mice, rock squirrels, as well as snakes and lizards.

swifts	Aeronautes saxatalis
crows	Corvus brachyrhynches
ravens	Corvus corax
red-tailed hawks	Buteo jamaicensis
golden eagle	Aquila chrysaetos
pack rats	Neotoma lepida
deer mice	Peromyscus sp.
rock squirrels	Citellus variegatus
ring-tailed cats	Bassariscus astutes
snakes	
lizards	

e. Slope Areas

These areas may be intermediate between the water and steeper cliffs, or between various bench areas. They are often characterized by blow sand areas, slickrock and extensive soil erosion.

Bird life here is limited to a few nesting species such as horned larks, Eremophila alpostris; ravens, Corvus corax; crows, Corvus brachyrhyches; and golden eagle, Aquila chrysaetos.

The majority of the mammals are nocturnal, and remain within burrows during the day. The diurnal animals become less active during the hotter hours of the day and even some of the nocturnal species delay their time of emergence from their burrows until later hours of the evening as daily summer temperatures increase. One may expect to encounter antelope ground squirrel, Citellus leucurus; black-tailed jack rabbits, Lepus californicus; coyote, Canis latrans; lizards, snakes, and various hawks.

Most of the fishes now found in Lake Powell have been introduced. Only six species are native to this portion of the Colorado River. The dominant sport fish are the largemouth bass, Micropterus salmoides; black crappie, Pomoxis nigromaculatus; and rainbow trout, Salmo gairdneri. Other sport fish are the brown trout, S trutta; striped bass, Roccus saxatillus; bluegill, Lepomis macrochirus; green sunfish, L. cyanellus; walleye, Stizostedion vitreum; channel catfish, Ictalurus punctatus; black bullhead, I. melas; and yellow bullhead, I. natalis. Some of the non-sport fish are carp, Cyprinus carpio; flannelmouth sucker, Catostomus latipinnis; and thread-fin shad, Dormosma petenense.

Three species appear on the 1974 United States List of Endangered Fauna. These are Colorado River squawfish, Humpback sucker, and Bony-tailed chub, which are endemic to the Colorado River system.

3.3.3 Human Environment

The relatively untouched natural condition of the area surrounding Glen Canyon provides several uncommon, if not unique, experiences for the visitor. The most outstanding experience would be a result of the unparalled scenery of canyons, mesas, deserts and, of course, the lake. With the paradoxical interface by the blue waters with the arid reds and browns of the desert, Lake Powell would have to be noted as the most singularly recognizable scenic feature. The waters of Lake Powell are the resource.

The strangely unfamiliar expanse of scenery intrigues and invites exploration. Those who heed the call are presented with a dramatic frozen history of unfathomable geologic forces. The remains are cast in a strange pattern of extremes and contrasts. From within the seclusion and intimacy of the side canyons, a person can climb to a plateau and discover vast barren regions of desert of slickrock framed by distant mountain peaks. Boaters have an equal experience available from the high speed cruising on broad expanses of lake water to the careful navigation between the labyrinth-like curved vertical sandstone walls of the many glens and canyons.

With all of the experiences that the area has to offer, a great deal of the appeal to the visitor comes from that which it does not have, namely the crowding, excessive noise, and foul air and water which all too frequently are a part of man's habitat. The opportunity to escape for a time from all that is man-made is often overwhelming. The subsequent freedom provides a unique occasion for refreshment and relaxation.

The area has the ability to excite and challenge in that it removes the safe, familiar mean of normal existence. This is particularly true when the barren extremes of the desert do not readily provide comfort and protection.

3.3.3.1 Regional Perspective

Glen Canyon National Recreation Area is located in a region of outstanding scenic, scientific, and historic interest. In general, the region extends from Grand Canyon National Park northeast to Arches National Monument, from Zion National Park east to Mesa Verde National Park and from Canyon de Chelly National Monument northwest to Capital Reef National Monument.

The area surrounding Lake Powell is extremely desolate and sparsely populated. The closest centers of population in Utah are Blanding, Monticello, Hanksville, and Mexican Hat. Population estimates (1970 census) for these towns range from 100 to 2,250 people. Page, Arizona, center for the Glen Canyon National Recreation Area administration complex, has a population of 7,529 and is located approximately 135 land miles north of Flagstaff.

The surrounding highways in the Glen Canyon area offer spectacular views of breathtaking scenery, glimpses of Indian life and exposure to local historical and archaeological sites. U.S. Highway 89 provides major access to Page, Arizona, and Wahweap Marina on the southern shore of Lake Powell. It intersects with U.S. Highway 24, providing access to Hanksville, Utah and Utah State Highway 95, leading from Hanksville with access to Utah State Highway 276 and Hite, Utah. Bullfrog Basin is 46 miles south of the intersection of Highways 276 and 95. Halls Crossing lies directly across Lake Powell from Bullfrog Marina. Access is gained by way of Highways 95, 15 miles south of Hite, or 40 miles northwest of Blanding, Utah.

3.3.3.2 Concession Facilities

Recreation and visitation. Halls Crossing is accessible by U.S. Highway 263 and the unpaved gravel access road within the Glen Canyon National Recreation Area boundary. Many services are provided for visitors to the Halls Crossing Development Area. The National Park Service operates a launching ramp and campground for tents and trailers and other facilities. A ranger is on duty for visitor consultation and safety convenience. The Lake Powell Ferry Service, Inc., concessioner at Halls Crossing since 1964, presently operates a trailer village of 43 spaces, dry storage for 300 boats, 56 slips, 50 buoys, a floating dry dock and wet slip, a general store at the marina, a general maintenance facility and an administrative office.

Halls Crossing also caters to fly-in visitors. The airstrip, located east of the development area is 4,000 feet long and 60 feet wide. Facilities at the airstrip include a warm-up pad, a windsock and tie-down facilities for smaller, prop-driven aircraft.

Halls Crossing is a destination point rather than a point that draws visitors from through traffic. Vacationers enjoy such recreational activities as swimming, fishing, boating, water skiing, picnicking, backpacking, spelunking, and sightseeing. Visitation usually falls off in the hot summer months, rises again in the fall and decreases thereafter until the end of the year with the late spring months attracting the most visitors. Ultimately, the area will be provided with a motel, restaurant, village-center complex and a new 200-unit trailer village and a housing area.

Bullfrog Basin, accessible by an all-weather route via U.S. Highway 95 to U.S. Highway 276 from Utah 24 near Hanksville, Utah, is located northwest of Halls Crossing, across Lake Powell. National Park Service facilities include a ranger station, airstrip, launching ramp, campground and picnic area. Bullfrog Resort & Marina, Inc., provides lodging, service station, a restaurant, a marina and a trailer village with utility facilities.

Wahweap is located 11 miles northwest of Page, Arizona on the southern edge of Lake Powell and is accessible by U.S. Highway 89. Besides National Park Service administration offices, facilities include an information center, picnic shelters, launching ramp and a beach for swimming. The concessioner, Canyon Tours, Inc., operates boat rentals, boat tours, boat repair facilities, a marina, a restaurant, a motel, a trailer village with utility hookups, and a service station. The Wahweap campground provides 178 campsites for tents and trailers with picnic tables, restrooms, charcoal grills and drinking water also furnished.

Hite is located 28 miles northwest of Natural Bridges National Monument on U.S. Highway 95. The concessioner, Hite Marina, Inc., operates a boat fuel service, limited camping supplies and small primitive camping facilities.

3.3.3.3 Cultural Resources

The canyon country of southeastern Utah was inhabited by a branch of the prehistoric Pueblo Indians who have been called the "Anasazi," a Navajo word meaning "ancient ones." The Anasazi lived primarily in the upland areas where they irrigated and farmed the land, rather than in the remote and nearly inaccessible canyons. However, in the tenth century they began to inhabit the deeper canyons. The canyon dwellers were nomadic and left signs of their presence everywhere--pictographs, chipping areas, and remains of houses. By 1300 A.D. the Anasazi left the canyon country, abandoned their dwellings and moved south. The specific reasons for the move are not known.

In 1958, before the waters of Lake Powell began to rise, the Utah Department of Archeology conducted an archeological field survey of the lands to be inundated (up to elevation 3700 feet). The sites investigated were attributed to the Anasazi culture dated 900 A.D. to 1100 A.D. These sites consisted mainly of chipping areas, a few mud cists, and scattered pictographs on sandstone projections next to the river. Conclusions suggested that extensive investigation was not warranted. Almost all of these sites have since been inundated.

The area above the 3700 foot elevation has not been thoroughly investigated for archeological sites. The Utah State Historic Preservation

Officer recommends that this area be investigated before any construction is begun.

Little is known about the canyon country from after the Anasazi left until the Spanish arrived in 1776. Modern Indian tribes, the Navajo and Utes, were occupying some of the area when Fathers Dominquez and Escalante began to explore the canyon country and crossed the Colorado at the Crossing of the Fathers. There was further Spanish exploration, and slave traders and fur trappers from New Mexico established a few trails in the Grand Canyon area during the following 50 years. In the 1850's, the U.S. Topographical Engineers spent time mapping the Utah canyon country in order to establish new routes across the then hostile Mormon country.

John Wesley Powell's exploration of the Colorado in 1869 and 1871-72 helped complete the regional topography, gave permanent names to many of the features, and solved some of the mysteries of the Colorado River canyons. In 1879, a party of Mormons set out from northwest Utah to settle along the San Juan River in hopes of expanding the Mormon frontier of settlement. Among them was Charles Hall, who built the ferryboat which transported these settlers across the Colorado at Hole-in-the-Rock. The difficult Hole-in-the-Rock crossing point was chosen because the vertical canyon walls presented more difficult access at all other locations in the vicinity. Hall remained at Hole-in-the-Rock for about a year operating the ferry and then moved north to Halls Crossing where it was much easier to approach the river. Hall operated a ferry service based at the mouth of Halls Creek on the west bank of the river from late 1880 to 1883.

Prospectors searching for gold, oil, copper, coal and uranium came to the Glen Canyon area from 1880 through the present. During World War I a number of people were beginning to appreciate the natural beauty of the river canyons, and commercial tours at Glen Canyon were initiated.

Visitation to Glen Canyon National Recreation area has surpassed projected estimates for recent years. In 1970, actual visitation was 788,480 while estimates projected only 556,000. Visitation was 970,922 in 1972 and 1,209,116 in 1974.

The late spring months attract the most visitors. The 1974/1975 figures show that December, January and February received the smallest number of visitors, between 28,203 and 44,279 and visitation increased between 63,375 and 135,156 in March, April and May. Visitation falls off somewhat again in September and decreases thereafter until the end of the year. The average length of stay is 2 to 3 days.

Detailed information about the visitor make-up is available. However, some generalization can be made from concessioner and National Park Service observations. Visitors come to Glen Canyon principally to participate in water related activities - primarily fishing and water skiing. Exploring by boat and swimming are also popular. A few also camp, hike and tour the area by vehicle and on foot.

Types of visitors vary seasonally. From January to April, 80 percent of the visitors are male fishermen. From May to September, fishermen, young families on vacation and off-season snow skiers comprise the visitor make-up. From September to November many retired people visit the National Recreation Area. The largest number of visitors come from Utah, Colorado, Arizona and New Mexico. But many come from California and Texas. (Visitors tend to come from the north in the winter seeking warmer weather and from the south in the summer seeking cooler weather). At the present time the entire economics is represented by the visitors. However, because of the expense of access to the surface of Lake Powell and the expense of boat storage, the middle and higher economic ranges have greater representation.

The four Utah counties surrounding the recreation area (San Juan, Wayne, Garfield, and Kane) make up one of the most sparsely settled areas of the country. The total population of the four counties is 18,000 (Garfield - 3,157, Kane - 2,421) which brings the areas mean population density to less than 1 person per square mile.

The few small population centers in the region are located on the fringe areas where the land is more habitable and suitable for economic pursuits.

Agricultural activity in the four counties region has been experiencing a continuing decline. Presently Garfield County employees 10 percent of its workforce in agriculture and Kane County only 7 percent. The lumber industry in Kane and Garfield Counties represent an important and stable sector of the economy. It comprises the second largest source of employment in Kane County. However, this and government employment appear to be the only significant exceptions to the general rule of economic uncertainty in the region.

Median family incomes for 1970 in the four county region are below the national figures by the following amount: Wayne County $4,638; San Juan County, $4,870; Garfield County, $3,358; and Kane County, $2,539. In 1973, unemployment figures for the four county area, the range was from 12.8 percent to 18.2 percent while the national rate was about 5 percent.

Some of the economic troubles of the area can be attributed to higher paying jobs and broader opportunities outside the region. This is depleting the younger age group that should be providing the most promise for the socioeconomic future of the area. In Garfield County, for example, only 9 percent of the total population is between the ages of 20 to 29, as compared to the more than 16 percent for the State and 14 percent for the nation.

Although the uranium boom of the 1950's significantly stimulated the regions mineral industry at the time, uranium mining has been on the decline since the 1960's. Renewed interest in this mineral may take place, however, as higher quality ores are consumed and industrial users turn to lower grade ores as an energy source.

During the 1950's, the search for uranium brought many prospectors to Glen Canyon. A number of claims were filed, but few mines are still operating.

The Glen Canyon area is potentially valuable for coal, gas and oil. There are many scattered oil and gas leases in the area; primarily in the Orange Cliffs portion of the National Recreation Area. The nearest coal deposits lie in the Kaiparowits Plateau adjacent to the southwest boundary and the Henry Mountains about 30 miles north of Bullfrog Basin.

Public Law 92-593 which established Glen Canyon National Recreation Area provides that leasable and non-leasable minerals can be removed from the recreation area provided that such removal does not have significant adverse effects.

Currently there is no evidence of sufficient quantities of minerals or fossil fuels to warrant any mining operation.

3.3.4 Lake Powell Fishery

Fish populations in Lake Powell developed from three sources. Some species were stocked directly into the reservoir, others were introduced into the Colorado River drainage before impoundment, and others were native to the river itself. Game species stocked in Lake Powell include largemouth bass (Micropterus salmoides), black crappie (Pomoxis nigromaculatus), rainbow trout (Salmo gairdneri), kokanee salmon (Oncorhynchus nerka), and striped bass (Morone saxatilis). Threadfin shad (Dorosoma petenense) were stocked to provide forage for other species. Other fishes originally exotic to the drainage but now found in the lake include bluegill (Lepomis macrochirus), green sunfish (Lepomis cyanellus), brown trout (Salmo trutta), walleye (Stizostedion vitreum), channel catfish (Ictalurus punctatus), black bullhead (Ictalurus melas), yellow bullhead (Ictalurus natalis), carp (Cyprinus carpio), fathead minnow (Pimephales pronelas), mosquito fish (Gambusia affinis), Utah chub (Gila atraria) and white sucker (Catostomus commersoni). Species endemic to the drainage include flannelmouth sucker (Catostomus latipinnis), Colorado squawfish (Ptychocheilus lucius), humpback sucker (Xyrauchen texanus), bonytail chub (Gila robusta elegans), round tail chub (Gila robusta), humpback chub (Gila robusta), humpback chub (Gila cypha), bluehead sucker (Catostomus discobolus) and red shiner (Notropis lutrensis).

Largemouth bass were first stocked in Lake Powell in 1963 and have since been the most important game fish in the lake. Annual creel census has shown largemouth bass make up 40-50 percent of the total fish harvested each year. Bass grow rapidly and 5-6 pound fish are not uncommon.

Black crappie have become an increasingly important fish in Lake Powell. Crappie were introduced into the southern end of the reservoir in 1964 and 1965. By 1967 crappie had become well established in the southern half of the lake and by 1968 crappie were found reservoir wide. Percentages of crappie in the creel increased each year and by 1973 and 1974 crappie made up approximately 50 percent of the total catch. Much of the popularity of black crappie is due to their exceptional size. Most of the fish entering the creel are 3 years old and weigh approximately 1 pound. Four and five year old fish are common and approach 2 pounds in weight.

Both bluegill and green sunfish are abundant in Lake Powell. Bluegill are most numerous, but neither species attains a large enough size to attract great attention from anglers. Both species combined have made up 5-12 percent of the annual harvest.

Since impoundment of Lake Powell, walleye have steadily increased in abundance. Although walleye are commonly taken in biological samples, few are taken by fishermen. Fish weighing 4-9 pounds have become numerous and a potentially excellent Fishery exists.

Cold water species found in Lake Powell include rainbow trout, brown trout, and kokanee salmon. Occurrence of brown trout and kokanee salmon is rare. Brown trout have not been stocked, but are recruited from the drainage and are seldom caught by fishermen. Kokanee salmon were stocked in 1963 and 1964 and it is unlikely that any now remain in the reservoir. Rainbow trout have been stocked periodically since impoundment and provide a sport fishery in a 10 mile radius of the dam. Chemical-physical conditions of the reservoir during summer largely restricts the distribution of cold water species. Growth of rainbow trout is rapid and although they have contributed only 1.0 percent of the total annual harvest, many caught are in the 8-12 pound class.

Three different species of catfish occur in Lake Powell. Channel catfish are abundant, while black bullheads and yellow bullheads are rare. The contribution of bullheads to the sport fishery is insignificant. Channel catfish have accounted for approximately 5-20 percent of the annual creel.

Striped bass were first introduced into Lake Powell in 1974 and 1975. Introductions continue in an attempt to better utilize pelagic areas of the reservoir which are frequented by an abundance of threadfin shad. Potentially, striped bass could grow to be the largest game fish in Lake Powell. Fish stocked as fingerlings average 12 inches at the end of one year.

Threadfin shad were introduced into Lake Powell in 1968. By 1970 it was evident that shad had become a very important forage species, dominating the diets of largemouth bass, black crappie, walleye, and rainbow trout. Shad were also found to be an important item in the diets of bluegill and green sunfish. Subsequent to shad introduction, rainbow trout and black crappie growth rates increased.

Carp are numerous in Lake Powell, but not over abundant. The reservoir topography being dominated by steep canyon walls and deep water offers little littoral area preferred by carp and may limit their abundance. Individuals generally run 1-2 pounds.

Species endemic to the Colorado River and occasionally found in Lake Powell include flannelmouth sucker, humpback sucker, bonytail chub, and Colorado River squawfish. These fish are of insignificant value to the sport fishery and with exception of the flannelmouth sucker are rarely seen. The flannelmouth sucker is somewhat more abundant, but is only taken infrequently in biological sampling. It appears that these highly specialized fish are dependent upon the Colorado River and its tributaries, rather than a lentic environment in completing their life cycle.

The effects of the Glen Canyon impoundment on these fish are not clearly understood at this time but their numbers are generally on the decline with the Colorado River sqawfish, and humpback chub being listed as endangered species.

For the most part, gross changes in the operation of Glen Canyon Dam would have immediate influence on several of the fish populations. Populations that could be directly affected include the most important game and forage species. Furthermore, it should be understood that complex interactions between species and long-term trends could change as a result from alternating past patterns of water regulation. Effects of this nature are complicated and nearly impossible to predict without long-term studies..

3.3.4.1 Spawning and Survival

Largemouth Bass

Natural reproduction has occurred each spring with subsequent strong year classes. Peak spawning occurs between mid April and early June. Spawning begins when water temperatures reach approximately 60° F and lasts until temperatures are approximately 75° F. Nests are built in gravel or on rock shelves scattered with rubble. Mean depth of nests at time of construction is 6 feet and ranges from 2-12 feet. Eggs hatch in about 6 days. After hatching, fry school in the vicinity of the nest and are often guarded by the adult male for a short time. Young-of-the-year bass remain in shallow, littoral areas throughout the summer. Rising water levels in the reservoir during spring and early summer is considered beneficial to largemouth bass reproduction and fry survival. Stable levels or 1-2 feet drawdowns during spawning would probably not significantly affect reprodcution. Drawdowns beyond 2 feet would likely be detrimental and should be avoided. Losses could result from bass failing to spawn, adults abandoning nests, and decreased survival of young fish.

Black Crappie

Spawning and reproduction of back crappie closely resembles largemouth bass. Nesting sites and times are almost identical. Like largemouth bass, crappie reproduction could seriously be reduced by dropping reservoir levels during spring months. The rate of reservoir "drawdowns" will influence the severity of the impact on spawning.

Bluegill and Green Sunfish

Spawning begins in late May at about 65° F and lasts throughout much of the summer in water as warm as 80° F. Nests are fanned out on sandy bottoms and guarded by males. Water depth is usually 1-2 feet. Eggs hatch in 70° F water in 30-60 hours. These highly prolific fish would probably be little affected by moderately fluctuating water levels.

Walleye

Walleye spawn on rock wind-swept shorelines during March at temperatures of 40-50° F. Eggs are broadcast at 1-10 feet depths and hatch in approximately 10-20 days. Drawdowns of 1-2 feet in early spring would likely be of little consequence. However, decreases in water levels beyond 2 feet could impair walleye reproduction and should be avoided.

Rainbow Trout, Brown Trout and Kokanee Salmon

Lack of a suitable coldwater inlet and rapidly warming spring temperatures keep rainbow trout from reproducing naturally. Water level fluctuations would probably have little direct affect on coldwater species. Large releases from penstocks during summer while fish are restricted to deep water layers in the immediate vicinity of dam could carry a substantial percentage of the population into the river below.

Catfish

Channel catfish spawn when surface water temperatures reach 70-80° F. Nest sites are generally in protected areas under or near rocks or logs. Naturally reproducing populations are also found in the Colorado and Green Rivers above Lake Powell. Recruitment to the reservoir from upstream could be considerable. It is unlikely that annual changes in discharge from Lake Powell would directly influence catfish populations.

Striped Bass

It remains uncertain if striped bass in Lake Powell will be able to sustain themselves by natural reproduction. Adults normally ascend large, moderately slow moving rivers to spawn. Semibuoyant eggs are broadcast and must be suspended off the bottom by river currents until hatching. Eggs hatch in approximately 60 hours after fertilization. Spawning could occur in either the Colorado or San Juan Rivers above Lake Powell. Nevertheless, fingerling stocking may be necessary in order to maintain a sport fishery. Future water level fluctuations should not influence spawning of striped bass. Stable or increasing water levels would tend to maximize areas of food production and cover, and are recommended.

Shad

Shad reproduction occurs in late May or early June when water temperatures reach approximately 70° F and may continue throughout the summer and fall. This highly prolific species spawns on floating debris or in open water where the eggs remain semibuoyant. Changes in reservoir levels should not directly affect threadfin shad.

Carp

Spawning occurs in spring, beginning when temperatures read 60° F and continuing until the water warms to approximately 80° F. Females concentrate in groups and broadcast their eggs in shallow water where they adhere to debris or rubble. Hatching occurs in 4-8 days. Carp, notorious for their adaptability, are common else where in the drainage and would unlikely be affected by changes in water level regulation. Any adverse impact on carp populations would be desirable from the standpoint of a sports fishery.

3.3.5 Historical, Archeological, and Cultural*

As indicators of time, major reliance has been placed by most scholars on distinctive ceramic wares. These wares are broken into numerous types, types which seem to have either a restricted geographic range, or were limited to a few years' (or centuries') span of manufacture and use. Such index types have been very useful, providing clues to age not inferrable from any other of the arts and crafts, which seem to be maddeningly complacent (R. Woodbury, 1954). Ceramic type usefulness in telling time has much diminished as research has shown that many types were manufactured over a much longer timespan than was originally credited to them. (Breternitz, 1963; Ambler, *et al*., 1964; Lindsay, *et al*., 1965, Sharrock, *et al*., 1961b).

As for the Glen Canyon itself, occupancy was, as has been implied, not continuous nor equally heavy throughout the area. For one thing, not all parts of the area were equally attractive. Of the many tributaries (see Fig. 2) Moqui, Navajo and Lake Canyons show the longest, as well as the heaviest use in the Canyon Lands. An exception is the Escalante River-Boulder Creek system. In fact, the Escalante system is a special case, almost duplicating in miniature the Glen Canyon. The Escalante is a long perennial stream, fed by long right bank tributaries containing numerous aboriginal sites in the areas of broad alluvial flats and perennial or seasonal streams. Its left bank tributaries are shorter and less frequently contain streams and aboriginal sites are rare.

Away from the canyons the heavy occupancy of Boulder Creek Valley (Lister, various; Gunnerson, 1959b) as well as the dense settlement of the Kaiparowits

* Anthropological Papers, Glen Canyon, a summary, Number 81 June 1966, University of Utah Press, Salt Lake City, Utah.

Plateau (Gunnerson, 1959a; Fowler and Aikens, 1963), falls late in the occupation sequence, and is probably best to be explained by greater resources of the higher elevation (up to 7,200 ft.), i.e., richer biota, better soils, and apparently heavier precipitation. In the same way plateaus south of the Glen--Paiute and Cummings mesas, and Rainbow Plateau were probably more desirable for the same set of favorable environmental reasons (Ambler, et al., 1964).

If one considers the full area one does find the entire chronological sweep of the Anasazi occupancy represented, but the distribution is spotty and discontinuous until Pueblo II and III times. No evidence of the big game hunters of 5000-8000 B.C. was discovered. The Desert Archaic (Daifuku's Elementary stage) is probably represented by the several non-ceramic sites, but none yielded diagnostic artifacts. Nonetheless Lindsey, et al. (1965) and Long (1965), Lipe, et al. (1960) and Sharrock, et al. (1963, 1964) found and assigned nonceramic sites on the mainstem, on most of the tributaries and in Castle Wash to a pre-Basketmaker III stage. Nearly all sites so assigned were buried and the pre-ceramic ascription is probably correct. The use of the sites would appear to at least precede the Tsegi period of aggradation with which the Pueblo II sites are associated.

In Castle Wash, two non-ceramic sites were dug and more noted. These are all assigned to the Basketmaker stage but more on faith than evidence. Later, the Lone Tree Dune site (42Sa-363) (Sharrock, et al., 1963) was C-14 dated at A.D. 250±80, a date consistent with the Basketmaker II assemblage of artifacts at the site. In the canyons, it is in Moqui

Canyon that the best documented Basketmaker occupancy occurs. Here, there were sites rich enough to attract three expeditions from 1897 to 1929 (Adams, 1960; Sharrock, et al., 1963). In 1961, excavation of the leavings from earlier Bernheimer Expeditions yielded a good and varied collection of materials ascribed, typologically, to the Basketmaker II stage, presumed, of course, to have been derived (migrant) from the Basketmaker center to the east. One Basketmaker II site was noted in Oak Canyon. On Cedar Mesa numerous Basketmaker sites are rumored to exist. One (42Sa313) excavated site (Sharrock, et al., 1964) on Cedar Mesa is interpreted as late Basketmaker III.

The Moqui Canyon sites—Rehab Center and Bernheimer Alcove—were stratified with Pueblo remains over, and mixed with, the Basketmaker type containing mummified bodies with no cranial deformation (Reed, 1963a). Artifacts associated with the burials were scant but of diagnostic kinds of basketry, yucca cloth and flexible bags, but there was no pottery. No heavy deposits of midden or debris were apparent anywhere, so this first infiltration is presumed to have been of short duration. With the departute of this early population, the entire area seems to have been without permanent occupancy.

Basketmaker III is not represented in any canyon except Navajo where it is reported from a tributary. Pueblo I is claimed for Navajo Canyon on the lower Glen (Long, 1965). It was only in Pueblo II times that heavy settlement of the lowland canyon system is reported. This time it was more general and complete. Although some canyons were not continuously occupied, some were used until Late Pueblo III.

On the plateaus, about the same pattern can be charted archeologically except that one cave--Sand Dune--shows strong Basketmaker use, and an earlier Desert Archaic deposit dated at perhaps 3000 B.C. was also reported. Occupancy seems to have continued until the abandonment of the northern Anasazi regions in the late 13th century.

Cultural Lines of Communication

As Glen Canyon research progressed, authors tended more and more to speak of the canyon dwellers as being an overflow population pushed into a marginal environment. While this view is defensible, it is at best only a partial explanation of the distribution of the settlements. In fact, the evidence is that, far from being marginal, the canyons were desired spots, with the uplands--Cummings Mesa, Boulder and Escalante Valleys, Kaiparowits Plateau--being occupied later than the lowlands in the face of improved climate and possible population increase. The Mesa Verde influences in the canyon system are confined to the Colorado and its east bank tributaries, largely upstream from Moqui Canyon. The remains in the lower part of the triangle and the lower Glen Canyon downstream from Moqui Canyon are heavily Kayentan. Moreover, the Kayenta appear to have made two upstream thrusts, one about A.D. 900 and the other, more extensive, ca. A.D. 1100 (Lipe, et al., 1960). Also, the Kayenta crossed the Glen Canyon and followed up the Escalante River and Boulder Creek to establish a long communication line, and a large, distant outpost deep in Fremont country (Lister, various). They also dominated the Kaiparowits. The ceramic and architectural evidence is that the Kayenta and Fremont populations blended, or were in intimate contact, at the Coombs site. All this looks less like marginality than like aggressive colonization by Kayentans, a process somehow different from casual, unorganized drift of excess population into the nearby canyons where the potential for agriculture existed, but limited in both arable acreage and water resources. At Point of Pines (Haury, 1958), there is a later evidence of Kayenta colonization (at both Coombs and Point of Pines, the Kayenta villages were destroyed by fire during occupancy). To ascribe the spread of traits of Kayenta origin to any specific colonial plan is probably rediculous, but it must be remarked that Kayenta-inspired ceramic traits, at least, extend far west and north of the hartland along the left bank of the Glen Canyon stretch of river. Whatever the explanation, the Kayentans were clearly a viable and wide-spread people with extensive contacts after A.D. 1100.

Although the canyon complex is the focus of our concern, it can be understood as having no unique cultural contribution of its own; its history reflects what went on in the highlands to the north and south, and readily fitted into the broader frame of Southwestern prehistory.

The Glen can be thought of as no great barrier to communications but it actually does appear to serve as an often crossed boundary between several named cultural subprovinces of the Southwest (see Fig. 23). To the south lies the Kayenta Anasazi group, to the east, Mesa Verde Anasazi, and touching the river on the north is the Fremont culture which covers eastern Utah but is not very well understood in its relationships to the Anasazi (see Aikens, 1966a). West of the Glen, and north of the Colorado, is the Virgin area, which can be included with Kayenta (Aikens, 1966b). All these "branches," as they are sometimes called, are local variants of the

Pueblo tradition that is recognized over parts of four states, having achieved a maximum distribution before A.D. 1300. They are still extant in remnant form in the modern towns of the Rio Grande and the western Pueblo towns.

The several branches show marked differences in minor crafts and variations in locale and population density but these local differences should not obscure, for the student, the great uniformity of the Anasazi sub cultures. All are characterized by small scattered settlements, with the larger settlements apparently being little more than aggregations or clusters of several small units. In these later situations the small units, in their separation from one another, effectively preserve the earlier scattered settlement pattern. (See especially the Kayenta - in Lindsey, et al., 1965). All depend primarily on a mixed gardening and collecting subsistence, with the hardy annuals, beans, corn and squash providing part of the diet. Cotton is common also in the later time period; empty bolls and carefully preserved caches of seed probably imply that cotton was raised locally. All Anasazi show great technological skill in utilizing available materials for tools, utensils, ornaments, and clothing. In particular, ceramics of good technical quality and usually great artistic merit characterize all the area. No evidence of concerted political or military action exists; archeological evidence buttressed by ethnologic data, suggests the autonomy of every little settlement, with confederation or union only seen in the face of some grave shared threat. The Pueblo uprising in the 17th century might exemplify united action in stress situations. There seems little doubt that communication and exchange of ideas was extensive and continuous over the Southwest for most of Pueblo dominance (Reed, 1964b).

By almost any geographic standard, other than European, the area where Pueblo remains are common is very small. Portions of only four states are involved. Few readers will realize how small the entire Southwest is or that Glen Canyon Dam lies about in the center of the area where Southwestern cultures are represented. Using the dam as a center, a 300-mile radius describes a circle which includes Ogden, Utah, Las Vegas, Nevada, Phoenix and Tucson, Arizona, Reserve, Albuquerque and Santa Fe, New Mexico, and Alamosa and Artesia, Colorado. Placing Glen Canyon Dam at the center of the Pueblo area has no validity except as doing so succeeds in showing something that is more important. The dam lies only 269.5 air miles from the western Pueblo area and 171.5 miles from Mesa Verde. The headwater of Lake Powell at Hite is only 69.6 miles from the Fruita-Emery axis where the Fremont culture dominates. The Colorado River, for most of its length, is believed to separate the "real" Pueblo area from the "peripheral" northern half of the imaginary circle, although the expansion to the north is believed to have occurred during Pueblo II times or is at least thus credited by most authors.

Recent Historical and Cultural events have already been covered in section 3.1.3.1 and 3.2.3.1. They will not be repeated in this section.

3.3.5.1 Petroglyphs

Petroglyphs are a recurrent feature of prehistoric habitation on the lower San Juan and are found in direct association with sites or in areas which are known to have been inhabited. Some may be associated with prehistoric trails.

The small size and often haphazard distribution of lower San Juan petroglyphs elsewhere are in keeping with Anasazi petroglyphs elsewhere (see especially, Kidder and Guernsey 1919:192-196; Steward 1929:155-158, 215-223, Colton 1946a:7) and in marked contrast to the so-called Fremong petroglyphs and pictographs which are found to the north and west (Morss 1931:34-42). Most of the common elements found on the lower San Juan are illustrated by Colton (1946a:7) in his panel of representative Kayenta petroglyphs.

Closer study of the San Juan material may reveal some consistent differences among petroglyph groups. So far, for example, meandering lines have been found to be prevalent only on the north side of the river.

Painted pictographs were found in only one location. On the lower side of an overhanging ledge at site 44, three large, crude footprints were painted red. From the length of the sole and the number of toes it is fairly certain that they were intended to represent human footprints. The surface which they adorned was apparently originally part of a ceiling.

4. Environmental Impacts of Present Operation

4.1 Impacts on Glen Canyon Tail Water to Lees Ferry

4.1.1 Physical Environment

4.1.1.1 Physiography

Alluvial Morphology

The regulation of flow in the Colorado River by Glen Canyon Dam has resulted in significant environmental changes which continue to occur along the Colorado channel. Since the construction of Glen Canyon Dam in 1963, the flow of the Colorado has been almost completely dependent upon the release of water from Lake Powell. Virtually all the sediment that formerly passed through the canyon is now trapped in the reservoir, and the frequent flash flooding that is associated with such rivers in the southwest is now controlled by Lake Powell. Previous to the construction of Glen Canyon Dam, flash flooding and spring snowmelt would produce peaks in river flow which would transport large quantities of sand and silt through the canyon, scouring the channel. As the water receded in the summer the river lost both its ability to carry suspended silt loads and the volume to push it along. Much of this silt and sand load was then deposited along the channel. This created numerous river bars and terraces which were periodically eroded away and replenished with the annual sedimentation.

With the present controlled flow, the higher terraces are no longer inundated and occasionally swept clean. The lower terraces are eroding at a more rapid rate. Quantification of erosion rates and of the balance between sediment erosion and deposition is difficult. Baseline studies have not been made; however, detailed comparison of photogrammetic data from aerial photography is now being compiled.

The Bureau of Reclamation in Denver, Colorado, has made studies and has compiled data into a report entitled "Channel Changes in the Colorado River below Glen Canyon Dam." A 1957 degradation study based on a detailed bottom sediment sampling program and an analytical approach to sediment transport and armor resulted in a prediction that about a 1.22-meter (4 foot) degradation immediately below the dam and 8.26 million cubic meters (6,700 acre-feet) of erosion would take place in the reach above the mouth of the Paria River in about 14 years.

To verify changes since closure of the dam, resurveys of cross sections in the approximate 24-kilometer (15-mile) reach of the Colorado River were made in 1959, 1963, 1965, and 1975. Bottom sediment samples were also collected in 1966 and 1975 to analyze the changes in material size as a result of the degradation and armoring process. The resurveys confirmed the 1957 predictive study by noting that sufficient armoring material remained to control excessive degradation with about 9.87 million cubic meters (8,000 acre-feet) of material scoured from channel bottom by 1975.

A National Park Service-funded intensive study of man's impact on the Colorado River in the Grand Canyon is now being carried out. Although the study is not yet complete, a summary of data was published in the July-August 1974 issue of The American Scientist, Volume 62, in an article entitled, "Man's Impact on the Colorado River in the Grand Canyon" by Messrs. Dolan, Howard and Gallenson. Their article points out that pre-dam flood terraces were deposited in zones of reduced river velocity such as in the mouths of tributary canyons, in alcoves along the bank, on bars in the side section of the river, and as narrow deposits bordering especially wide, straight stretches of the river.

4.1.1.2 Water in the River

The Colorado River in its natural state often discharged more than 80,000 cubic feet/second (cfs) and carried an average of 0.38 million tons of sand and silt a day through the Grand Canyons. The high water scoured the bottom of the canyon and eroded and redeposited material on the river shores. Since impoundment, the water released at Glen Canyon Dam is a turbid-free, powerful erosive agent. Daily discharges vary from 4,000 cfs to about 30,000 cfs. The sediment free water erodes the existing beach areas but does not resupply the sands lost either to the wind or directly into the river. The increased light penetration through the sediment free waters has produced variations in the flora and fauna make-up of the Colorado River above Lees Ferry.

4.1.2 Biological Environment

4.1.2.1 General

The controlled flows released from Glen Canyon Dam have contributed to a rapid change in the biological make-up of the inner canyon. Changes are apparent in the vegetative make-up along the terraces as well as vegetative growth in the river proper. Faunal differences are noted in the fish population now found in the Colorado River and may exist in rodent populations on the terrace banks.

4.1.2.2 Flora

Pre-dam conditions included a conspicuous line of hardwood vegetation associated with the higher terraces along the banks of the Colorado

River. Below them there was little permanent vegetation because of the cycle of erosion and deposition during floods presented an unstable growing surface which either uprooted or buried seedlings. Furthermore, the growth of phreatophytes on the higher terraces was discouraged by the isolation from the water table during summer low water.

After closure of Glen Canyon Dam, previously unvegetated areas now grow cattail, Russian thistle, mesquite, arrowweed, and willows. In addition to the rapid development of new plant communities along the banks, the shallow water areas of the river channel are becoming covered with thick green algal growth resulting from reduced water pressures and reduction in the scouring action coupled with increased light penetration through the now sediment-free waters.

4.1.2.3 Fauna

The fish population of the Colorado River between Glen Canyon Dam and Lees Ferry is changing drastically in both its species composition and numbers. Many endemic species such as the squawfish and boney-tailed chub which were adapted to the turbulent, turbid waters are rapidly disappearing. The marked reduction in water volume as well as the loss of suspended sediment load has in effect created an entirely new ecological habitat.

The State of Arizona has begun a pilot program of stocking Rainbow trout in this stretch of the river. The clear cold waters are conducive to rapid growth of trout; however, the daily fluctuation inhibits a successful reproducing population due to the covering and uncovering of gravel bars which are suitable nesting sites.

With the increase of vegetation along the banks, there has been an accompanying increase in cover for smaller rodents and mammals. While no baseline records have been established it may be presumed that the populations are increasing. There is also an increase in nesting habitat for avian species such as mourning dove which nest in the dense thickets on the higher terraces.

The controlled releases from Glen Canyon Dam have proved favorable to the beaver (Castor canadensis). Beaver population is estimated to be significantly higher during post-dam period than pre-dam period. This is probably a direct relationship to the ability of the animal to maintain bank dens throughout a season without the danger of inundation and extreme fluctuations in seasonal water levels. The drawback associated with beaver is that as unpalatable vegetation such as tamarisk crowds out a more favored food type, such as willow and poplar, there is severe competition for food sources.

4.1.3 Human Environment

4.1.3.1 Recreational Use of the River

Recreational use is limited to people launching shallow draft boats at Lees Ferry and proceeding upstream to the dam. At low water (4,000-6,000 cfs) boats drawing more than 24 inches of water cannot travel upstream past Three-Mile Bar. Releases of this nature are approximated during the early morning hours and on weekends when power demand is less. Recreational use is limited to boating for pleasure, fishing, and camping. Campsites must be located where a steep bank allows a close in-shore approach by boat without the danger of becoming stranded by low water in the morning. These campsites continue to receive heavy visitation and public use. In addition to the need for a campsite adjacent to a steep bank, the encroaching tamarisk vegetation limits the number of sites available; consequently, a few sites receive the majority of public use. An associated problem is the lack of available firewood which, in pre-dam days, was deposited annually during periods of peak runoff. Now, with controlled flow, there is no replenishment of this natural wood supply and as the existing supplies are exhausted, recreationists may turn to destroying live vegetation in order to obtain wood for campfires.

4.1.3.2 Commercial Use of the River

Commercial use of the river is limited to a single concessioner, Fort Lee Co., which provides a one-day raft trip from the base of the dam to Lees Ferry. The controlled flow of the Colorado River has enabled this trip to be instituted. As Fort Lee Company holds sole commercial right to egress and ingress through the two-mile tunnel leading to the base of the dam there is no other commercial activity. These shallow draft rafts, capable of carrying up to 30 persons, are not affected by daily fluctuations in river elevation. The raft provides a scenic method for the visitor to get a representative sampling of the Glen Canyon experience as it may have been prior to the inundation by the waters of Lake Powell. The impacts of the operation of Glen Canyon Dam and the controlled releases of the Colorado River on commercial traffic below Lees Ferry is more properly the subject of the discussion appearing under Colorado River through Grand Canyon National Park.

4.1.4 Water Quality

Sediment

Prior to construction of the storage units of the Colorado River Storage Project, most of the larger tributaries and the main stem of the Colorado River carried large loads of sediment, particularly in their middle and lower reaches.

For example, in 1957 the suspended sediment load of the Colorado River at Lees Ferry, Arizona, gaging station was recorded at 143 million tons. This sediment was detrimental to water diverters for consumptive use as well as to high-type fishery and other recreational uses. In 1959 the cofferdam utilized in the construction of Glen Canyon Dam was finished and diversions began through the tunnels. Sediment was deposited behind the cofferdam in 1959 and 1960 at a sufficient rate to gradually fill the cofferdam lake with the result that by 1962 the annual sediment load at Lees Ferry had increased to 67 million tons. This load dropped to 2.2 million tons in calendar year 1963 with the closure of Glen Canyon Dam and initial storage in Lake Powell. Lake Powell and other Colorado River Storage Project reservoirs are now effectively trapping and storing almost all of the sediment originating in the Upper Colorado River Basin. Lake Powell and the other Upper Basin Reservoirs trap approximately 75 to 80 percent of the sediment that normally would flow into Lake Mead. By storing the sediment in the Colorado River Storage Project reservoirs, the streams immediately below the dams have been changed to relatively clear trout water fisheries as well as desirable boating and recreational areas. Daily sampling at Lees Ferry was discontinued beginning in water year 1966 because of the lack of sediment.

Temperature

The Colorado River Basin water temperatures vary widely, reaching the greatest difference during the summer months when they vary from near freezing in the high mountains to above 90° F. in the lower reaches. Warmer temperatures may increase the rate of growth and the decomposition of organic matter and of chemical reaction, resulting in bad odors and tastes, and also decrease the dissolved oxygen concentration available to sustain a fishery.

Changes in water temperature in the basin result primarily from natural climatic conditions. The large reservoirs, however, may affect the stream temperatures for a considerable distance below the reservoir. Lake Powell appears to warm the winter temperatures of the Colorado River below the dam by up to 10° F and cool the summer temperatures by about the same amount. Flow depletions and changes in stream channel characteristics may also increase the effects of natural climatic conditions causing cooler or warmer water temperatures.

Total dissolved solids in the river below Glen Canyon Dam have become more constant from releases rather than low flow in the winter with high concentration and high flow from spring runoff with a low concentration.

4.2 Impacts on Colorado River Through Grand Canyon National Park

All of the impacts on the Colorado River through the Grand Canyon National Park are essentially the same as those discussed in Sections 4.1 and will not be repeated here.

Commercial traffic on the river as mentioned in Section 4.1.3.2. is more appropriately discussed in this Section.

Trips on the Colorado through Grand Canyon are made year-round. (Table 4-1) The major season of river use is from March through October. Use is concentrated through this period during the months of May through September. Most trips leave Saturday, Sunday, Monday, or Tuesday. Departures the rest of the week are about 60 percent lower than on these days.

Release schedules from Glen Canyon Dam allow for enough water to float the river, with some reliability, from May to September. Low water during the remaining months creates difficulty for scheduled commercial trips and can cause delays of private or commercial trips. High minimum rather than maximum flows is the limiting factor in these trips; many rapids cannot be run on the Colorado by a raft at low flows.

4.2.1 Physical Environment (See 4.1.1)

4.2.1.1 Physiography (See 4.1.1.1)

4.2.1.2 Water in the River (See 4.1.1.2)

4.2.2 Biological Environment (See 4.1.2)

4.2.2.1 General (See 4.1.2.1)

4.2.2.2 Flora (See 4.1.2.2)

4.2.2.3 Fauna (See 4.1.2.3)

4.2.3 Human Environment (See 4.1.3)

4.2.3.1 Recreational Use of the River (See 4.1.3.1)

4.2.3.2 Commercial Use of the River (See 4.1.3.2)

Table 4-1

Total Traffic Leaving Lees Ferry

Passengers and Crew

1974	Sun	Mon	Tue	Wed	Thur	Fri	Sat	Total
March	33	43	56	0	0	32	10	174
April	125	301	140	58	61	18	177	880
May	361	526	438	90	69	148	567	2,199
June	545	719	714	171	203	215	711	3,278
July	469	742	594	210	215	221	560	3,011
August	442	824	628	94	342	229	474	3,033
September	338	366	300	35	90	63	288	1,480
October	2	0	80	37	0	0	32	151

At current use level, sanitation is a problem along the Colorado River. The 110,000 user days per year along its narrow beaches has created difficulties in disposal of human waste. Containerization of waste by use of portable toilets has limited the spread of toilet paper and human feces burial of the containerized waste along the narrow banks of the river creates a potential health hazard as campers camp on burial sites. High fecal coliform counts have been reported 60 to 90 days after burial, (Knudsen, 1975). Since some beaches are used over 50 nights a season and burial areas are limited, camper-burial site interaction potential is high. Park Service regulations require that all river trips "shall carry a portable toilet or other means of containerization of human waste for burial, be in a hole 2 feet deep, 6 feet above normal high water fluctuation, at least 50 feet fromt he river bank and at least 200 feet from any area normally used for camping." There are at least 18 popular camps where this disposal is impossible. A research program is in process to determine the scope of sanitation hazards presented by present waste disposal methods.

At current use level disposal of refuse is also a problem. Disposal of "kitchen garbage" has created offensive odors on beaches.

The use of trees for firewood, the dumping of sewage on beaches, the use of soap in side streams and food scrap dumping also have been shown to have an effect on the organisms within the canyon, as well as visually altering the ecosystem.

4.3 Impacts on Lake Powell and Glen Canyon National Recreation Area

4.3.1 Physical Environment

4.3.1.1 Physiography

A 1975 report by the U.S. Geological Survey staff, prepared for the Glen Canyon National Recreation Area Master Plan, set forth certain geologic hazards associated with the filling of Lake Powell. It is pointed out that the waters of Lake Powell have produced unstable conditions along segments of the reservoir shoreline. When water encroaches on sandpiles, former landslides, talus slopes and rock falls, instability results. Sandpiles, as much as 100 feet high, accumulate to the leeward of vertical cliffs formed by the Navajo, Wingate and Entrada Formations. When such piles become undermined and waterlogged, the entire pile can slide into the water in a matter of minutes. These unstable areas are hazards to users to the lake inasmuch as they are favorite camping and mooring spots.

Dormant landslides and talus slopes are common along Chinle outcrops. When their toes become lubricated by the rising waters, large segments can become activated and slide into the deep near-shore waters. Such slides can be detected beforehand by observing fresh "breakway" scars.

Another physiographic impact is associated with the fall of large slabs of Wingate and Navajo Sandstones. These falls occur where the lake waters have either removed or lubricated the upper part of the supporting rocks. Large slabs can be released along near vertical joints and topple suddenly into the water. The fall of a single slab 300 feet long and

150 feet high has been documented. Several smaller falls are known to have occurred.

Fluctuating lake water elevation strips away the mantle of unconsolidated alluvial deposits on the higher terraces, leaving the slickrock core. The loss of alluvial terraces and beaches further restricts camping and mooring sites along the shoreline.

The most singular eye-catching feature of a fluctuating water elevation is the presence of a white ring on the sandstone cliffs reaching from the water surface to the high water mark. This is created by the deposition of calcium carbonate present in the water of Lake Powell. This may be a secondary aid to navigation inasmuch as the calcium carbonate ring is reflective and at night, aids the visual demarkation between dark water and dark cliffs.

The rich organic load of the lake waters is concentrated and deposited at the heads of the many tributaries to Lake Powell. The rapid growth of algae and diatamacious organisms coupled with this deposition of vegetation produces an annual accumulation of up to one-half inch of coagulated clay and silt enmeshed with a mass of diatomes, blue-green and green algae. As the water retreats, there is a reduction action and a black sand and silt layer is produced with hydrogen sulfide being emmitted.

4.3.1.2 Water in the Lake

Chemical studies of Lake Powell by the Bureau of Reclamation and by the Lake Powell Research Project indicate that its waters are moderately saline (500 parts per million Total Dissolved Solids), and that their composition is controlled by the relative proportions of contributions from the Green, San Juan and Colorado Rivers. Surface waters are oversaturated with respect to calcium carbonate. Salt flux calculations and comparisons of pre- and post-dam bicarbonate concentrations of river water at Lees Ferry suggest precipitation of calcium carbonate in Lake Powell. Tentative values for salinity reduction due to this process are 19 to 29 ppm. Calcium carbonate precipitation is probably most intense in the lower reaches of the lake.

Samples of organic and inorganic components of the Lake Powell ecosystem were collected during 1971 and 1972 by the Lake Powell Research Project. Bulletin No. 1, June 1973, suggests that the restriction of outflow in the impounded Colorado River leads to mercury accumulation in the ecosystem. Bio-amplification of the mercury is found to occur, and it results in mercury levels in the larger predatory fish that approach or exceed current safe-consumption standards. It is estimated that from 1360 to 5440 kilograms of mercury may be released annually by natural weathering in the Upper Colorado River Basin, and that impoundment of the river may lead to the accumulation of approximately 800 kilograms of mercury in the lake system each year. It is further hypothesized that concentrations of mercury released by natural weathering may be augmented by coal-fired power-generation developments proposed for the Lake Powell region. The extent of this augmentation and its effect on Lake Powell principally depends on the actual mercury content of coal used; the degree to which this mercury enters the lake drainage; and the movement and bio-amplification of the mercury within the system.

The Bureau of Reclamation has conducted sedimentation studies in Lake Powell in 1968, 1970 and again in 1973. Generally, the maximum accumulation of sediment has occurred between Dark Canyon and the Dirty Devil River with concentrations in the area of Sheep Canyon and Hite. Depth soundings for the Dirty Devil River indicate that large quantities of sediment have been carried downstream and deposited into the reservoir at the Dirty Devil confluence with the Colorado River. There has been a total accumulation of approximately 90 feet of sediment at the mouth of the Dirty Devil River since the construction of Glen Canyon Dam.

The sedimentation pattern for the reservoir is not usual; however, it is subject to shifting somewhat during flood seasons as floods entering the reservoir from tributaries have tendencies to wash out the sediment deposited and rearrange the sedimentation pattern at the confluence of the tributaries with the reservoir.

As the water surface elevation for the reservoir continues to rise, marinas now existing on the reservoir should be able to maintain operations without problems resulting from sedimentation; however, as the reservoir water surface elevation decreases, operation of the marinas in the upper reaches of Lake Powell may become critical depending upon the pattern with which the sediment has been deposited within the reservoir. Bullfrog, Halls Crossing and Wahweap marinas will not be endangered by the decrease in the reservoir water system. An investigation into the formation of a sediment delta at the head of Lake Powell is based on historical flow and sediment discharge record and probable operating conditions of Lake Powell. A study done in 1961 and confirmed in 1974 estimated that the probable useful life of a development located near Hite would be 20 to 25 years, before reasonable access to the main channel of the Colorado River is cut off by the delta.

A similar situation is developing in the San Juan arm of Lake Powell. A sediment delta is building up in the vicinity of Piute Farms and Clay Hills Crossing which, during periods of slack water drawdown, severely hampers access to and egress from the San Juan River which becomes deeply channelized in sediments deposited during higher water levels.

4.3.2 Biological Environment

4.3.2.1 General

There is evidence to support the theory that pre-dam biological and ecological investigations and relationships within Glen Canyon were, of necessity, meager and little understood. A report by the Fish and Wildlife Service in the early 1950's concluded that the Glen Canyon reservoir would inundate 153,000 acres of poor quality wildlife habitat. The report further stated that the losses would be "highest in the mountainous areas and lowest in the relatively inaccessible canyon of the Colorado River where the wildlife only consisted of those animals which live in the muddy waters of the Colorado River, or are able to subsist on the sparse vegetation among the cliffs." Since little attention was given to the impact of the creation of the dam on biological processes, it is difficult to assess these impacts at this date without full knowledge of that portion of the environment which was inundated by the waters of Lake Powell.

It is sufficient to say that the impacts were most heavily noticed in regards to the aquatic and terrestrial fauna and riparian flora established in pre-dam conditions.

4.3.2.2 Flora

Lake Powell has inundated floral relationships which occurred along the streamside of the Colorado River of Glen CAnyon. As waters of Lake Powell rose, this inundation spread to the side canyons with a resultant loss of willow/cottonwood associations in the upper canyons. Fluctuating water levels result in the loss of many plant communities from streamside to upper terrace. There has been an increased ease of dispersal of exotic plant species such as tamarisk, Russian olive and Russian thistle. The establishment of phreatophytic vegetation such as tamarisk can be controlled by water fluctuation resulting in inundation of post-emergent seedlings. While the lake elevation continues to rise, the establishment of such vegetation is kept under control. When lake elevations fail to exceed that of previous years and there is no post-emergent inundation of sprouts and seedlings, a very rapid establishment and growth of tamarisk will result. With a reported growth rate of 14 inches per week having been recorded and an annual growth of 12 feet per year being not uncommon, the annual spread is exceedingly fast.

Water consumption is one of the most common features associated with phreatophytic vegetation such as this. Evapotranspiration varies with the depth to the water table. Tamarisk has a deep root system which can exceed 30 feet or more. A plant with free access to water can evapotranspire a volume of water equal to or greater than evaporation of free water from the lake surface. A large tree can eliminate as much as 200 gallons of water per day. A stand of tamarisk can consume three to four acre-feet of water per acre per year. Tamarisk reproduces rapidly by seed or by cutting. Seeds are extremely small (280,000 seeds per ounce) with each plant producing many thousands of seeds over an extended flowering period. Such an explosive growth of vegetation along a retreating shoreline will vastly change the visual appearance of the reservoir within a few years following establishment. In addition to the loss of water which can be expected, the rapid growth of tamarisk groves will further reduce suitable camping and mooring sites along the shoreline of the reservoir. Most visitors find groves of tamarisk to be undesirable for camping inasmuch as they harbor pestiferous flying insects and, due to the high rate of transpiration, create localized areas of high humidity.

4.3.2.3 Fauna

Establishment of Lake Powell has changed the aquatic faunal affiliations remarkably. The native endemic fish species have suffered in the change from a heavily sedimented river to a less turbid lake system with an anaerobic water condition near the bottom. The recognized endangered species, Colorado squawfish and humpback chub, have had their populations curtailed dramatically and their continued existence put in question.

The cold midly turbulent waters have proved to be highly favorable to the production of certain species of game fish, including the walleyed pike, largemouth bass, black crappie, and most recently, the striped bass. The introduced forage fish, threadfin shad, provides an ample food source for all of the above predatory species.

The larger mammalian and reptilian species of fauna have encountered drastic changes in their customary travel and distribution patterns due to the encroachment of the lake into previous habitat.

There is the possibility of genetic drift resulting from isolation of gene pools in remnant populations of small mammals and rodents occurring on islands or box canyons above the lake surface. It is difficult to assess the impact on habitat losses due to the fluctuation of Lake Powell; however, it may not be incorrect to assume that for every habitat lost another is gained through a change in topography and availability of water.

With the lack of stabilized lakeshore, it is unlikely that large populations of amphibians will become established due to the continual change in habitat features.

4.3.3 Human Environment

4.3.3.1 Recreational Use of the Lake

Creation of a large reservoir in a heretofore dry, albeit aesthetically attractive, portion of southern Utah and northern Arizona has created a recreational facility that is primarily water-oriented.

Lake Powell's boating public is primarily non-resident. Fluctuating lake elevations pose a special problem to these people who are unfamiliar with changes which may have occurred since their last visit. The shoreline topography changes in response to fluctuating elevations and submerged pinnacles and slickrock islands come and go as the lake rises and recedes during seasonal fluctuations. In addition to the danger of running aground or striking submerged obstructions, the presence of driftwood following the spring runoff is heightened in the upper end of the lake and in the backs of tributary canyons. Driftwood can be encountered throughout the length of the lake year around and when water-logged to the point where it floats just below the surface it presents a special hazard. Cruising at night, or at high speed in canyons increases the danger of striking such floating material.

Talus slopes reaching into and below the lake surface in addition to sand banks adjacent to the shoreline offer a serious hazard for the visitor who chooses these for a camping or mooring area. Similarly, sheer cliff walls which have been eroding away for millions of years may in some locations collapse suddenly, causing landslides or rock falls. In addition to the danger of direct hits from such falling debris, there is the danger of a tidal wave set up by the displacement of lake waters by large masses of falling rocks. This can be especially hazardous when it occurs in the confined channels of tributaries to the main body of Lake Powell.

Studies by the Lake Powell Research Project have shown that there is little change in the percentage composition between beaches and cliffs along the shoreline of Lake Powell. Regardless of lake elevation between 3620 feet and 3700 feet, the percentage remains approximately 55 percent in cliff face, 22 percent in domed terrace, 18 percent in talus and 2-3 percent in sand shoreline. The rest is shelfy terrace, alluvium and rockslide.

4.3.3.2 Recreational Use of Adjacent Areas

Creation of Lake Powell has opened up thousands of acres of previously inaccessible land to exploration by a boat-in public. In addition, the secondary and tertiary roads surrounding Lake Powell receive increasing use from four-wheel drive enthusiasts seeking access to the highlands above the reservoir. There is an increasing use and informal establishment of primitive campsites and backcountry camping both by the boat-in and the drive-in public.

Increasing public use of the surrounding area has resulted in an increasing incidence of vandalism and theft of archeological resources. Due to the remoteness of the area many archeological sites have not been adequately explored and recorded by scientific investigation. The nine known occurrences in 1974 no doubt represent only a small fraction of the actual violations which occurred during the same period.

In addition to the increasing illegal off-road use, primarily motorcycle and specialized 4-wheel drive vehicles, resulting from increased public use of surrounding areas, there is an increasing problem with transporting motorcycles and trailbikes to remote areas of the lake by houseboat. Thus, previously inaccessible areas are becoming increasingly exposed to human impact resulting from correspondingly easier lake and road access.

4.3.3.3 Commercial Enterprise

Commercial enterprise is regulated within Glen Canyon National Recreation Area in accordance with the Concessions Policy Act of October 9, 1965 (PL 89-249). Concession facilities exist at Hite, Halls Crossing, Bullfrog, Rainbow Bridge and Wahweap. The impacts of operation of Lake Powell on each facility are given in the following section.

Hite--Hite Marina, Inc. is operating under a concessions permit to the National Park Service providing marina and camp store facilities near the north end of Lake Powell. The rising lake level caused complete relocation from the west bank of Lake Powell to the east bank in 1974, in order to utilize more available land. Another move is contemplated for the fall of 1975 or spring 1976, necessitated by increasingly higher lake elevations and the resultant loss of the current land assignment. This will require the complete relocation of residential facilities, gas utility lines, marina and boat rental slipps, parking area, boat storage area and associated facilities.

A major problem is the great amount of driftwood which accumulates in the concessioner's facility each spring during the high runoff. This creates not only a hazard to boaters but a physical impediment to the launching and operation of boats within the marina proper. There is a further problem associated with the Hite location as outlined under the discussion of sediment loads in Lake Powell. It is expected that this facility may have to be modified by 1990 if sedimentation continues at the present rate.

Halls Crossing—Lake Powell Ferry Service, Inc. operates the concession at Halls Crossing under concession contract with the National Park Service. It provides marina facilities, trailer village, camp store and related visitor services. Here the primary impact consists of the need to, almost daily, reposition the marina facility in response to lake elevation rises during the months of May and June in the order of 0.25 to 0.40 feet per day increase. While not a seemingly large rise in vertical distance, this is reflected disproportionately in a horizontal reach especially on slopes such as launch ramps and marina approaches which are commonly at 10 or 12 percent slope.

Bullfrog—Bullfrog Resort & Marina, Inc. operates under concession contract to the National Park Service and provides a trailer village facility, a restaurant, boat service department, gas station, marina, and tour service and boat rental. In recent years fluctuating level of Lake Powell has necessitated the relocation of the marina facility three times in as many years. In addition, a continuing basining and marina enlargement program has been started by the concessioner in order to provide adequate turning and docking facilities year around. Again, there have been many continual problems associated with moving marina equipment docks, etc. in response to a daily fluctuation.

Rainbow Bridge—Rainbow Bridge Marina is operated by Canyon Tours, Inc. as an ancillary facility to the Wahweap development. Marina fueling facility and camp store are provided for the visiting public. Actual marina operations in response to a fluctuating water level are confined to repositioning of the entire floating unit which comprises both Park

Service and concessioner housing and use facilities by means of taking up or letting out additional cable which ties the entire floating development into the sandstone walls below the surface.

Wahweap--Wahweap Marina is operated by Canyon Tours, Inc. which also operates Rainbow Bridge Marina under concession contract to the National Park Service. Services provided include motel accommodations, dining room, service station, camp stores, tour boats and full range of marina and boat service. Here as elsewhere on the lake, primary response to a fluctuating water level is the daily maintenance and repositioning of floating marina facilities. In addition, there is the added expenditure of moving utility lines, servicing the lakeshore developments and the necessity for reconstructing access roads, parking lots and other visitor accommodation features.

For any marina development on Lake Powell, there is a common impact. The potential for an elevation range of 210 feet exists, having a great effect on any facilities constructed for use with the lake. Fluctuating lake levels make access to the water difficult. Lengthy launch ramps must be constructed to accommodate the changing lake levels and paths connecting the marina with land facilities must allow for filling and drawdown of the lake. All marina facilities located on the water must be movable as the coves become larger or smaller. The main portion of the fluctuation zone is unusable for permanent construction.

4.4 Impacts on Lake Mead

4.4.1 Description of Lake Mead

Lake Mead, a reservoir of the Lower Colorado River drainage system created in 1935 by the construction of Hoover Dam, is located approximately 30 miles east of Las Vegas, Nevada. The lake when full is 110 miles long; has an available storage capacity of 26.2 million acre-feet; and has a maximum depth of 580 feet. The shoreline is 847 miles long and covers 157,900 acres. Lake Mead is a multiple-purpose reservoir providing water for flood control, municipal use, irrigation and power, and recreation.

4.4.2 Fish and Wildlife Associated with Lake Mead

4.4.2.1 Fish

Numerous fish species inhabit Lake Mead's aquatic environment. Major game species in the lake are rainbow and cutthroat trout, largemouth bass, striped bass, crappie, bluegill, and channel catfish. Nongame species include threadfin shad, shiners, minnows, carp, green sunfish, mosquito fish, and razorback sucker.

Impacts on Largemouth Bass—Before the construction of Glen Canyon Dam and the filling of Lake Powell, annual water level fluctuations in Lake Mead were extreme, but usually only responsive to downstream water use and the melting of snowpack in the extensive watershed of the river system. Occasionally, flood situations pushed water levels to new heights during spawning seasons providing above normal spawning and survival conditions that were followed by several boom years of largemouth bass fishing.

During the initial years of filling Lake Powell, the water level in Lake Mead declined. Subsequently, the success rate of largemouth bass reproduction in Lake Mead diminished.

Since early 1965, when the water elevation in Lake Powell was stabilized, Lake Mead water levels have remained fairly constant with the lake being held level or only small declines during the spring months with the exception of 1973 which experienced a rise in the level of approximately 20 feet from January 1, 1973 to July 30, 1973.

Creel census studies reveal the success rate of largemouth bass fishing on Lake Mead has continued to decline since the construction of Glen Canyon Dam. Consequently, the Nevada and Arizona game and fish agencies expressed their concerns to the Bureau of Reclamation's Lower Colorado Region about the declining quality of the largemouth bass fishery. The agencies felt the decline of the largemouth fishery was due primarily to receding water levels during the bass spawning and survival season. Because of the concern expressed by the responsible state agencies, the Bureau of Reclamation agreed to participate in an intensive largemouth bass study being conducted on Lake Mead with Nevada Department of Fish and Game, Bureau of Reclamation, Arizona Game and Fish Department and National Park Service participating.

Lake Mead Bass Study

The major objectives of the study were designed to provide information needed to better manage the largemouth bass fishery.

1973 and 1974.--Data obtained from this portion of the study revealed that various factors influenced largemouth bass spawning and survival.

Spawning: (1) Gradient.--Some nest failures could be attributed to steep gradients composed of loose material. This factor was particularly noticeable during the 1974 spawning period when receding water levels and extreme wind conditions caused excessive bank erosion and resulted in the burial and/or suffocation of several nests. (2) Weather and temperature variations.—Cold weather and wind during the spring months have an adverse effect on spawning bass. Wind action results in the movement of colder water from the open basins into exposed littoral zones where bass are spawning. A drop in water temperature of 4° to 6° F. and wave action caused bass to display erratic spawning behavior, often abandoning their nests. This type of behavior was documented. Chilling is also suspected for early egg die-off and fungus invasion. Cooler temperatures prolong the period of nest development and expose eggs or sac-fry to extended predation.

Survival: Cover relationship.—Considerable attention has been given to the quantity and the quality of available bass cover in Lake Mead.

It has been recognized during the many years of fish management in Lake Mead that good cover conditions are a function of seasonal and annual water levels. Blanket statements which have been made prior to this study relating good bass production to the single factor of annual increases in water levels are misleading. The statements disregard the many variables of cover that can be produced by water level manipulation.

Two major types of cover involved in proper bass management on Lake Mead are flooded terrestrial vegetation and established aquatic plants (including emergent types).

The construction of Glen Canyon Dam and the filling of Lake Powell have recently produced relatively stable water levels in Lake Mead resulting in the establishment of aquatic vegetation. Dense and open plant communities of pondweed, cattail, and spiney naiad were present in coves and shallow areas during 1972.

Observation of large numbers of Class I (yearling) bass during 1973 was attributed to well-established zones of aquatic plants observed in 1972. Subsequent rapid increase of water level during 1973 flooded the aquatics to excessive depth and nullified the aquatic cover value.

Conversely, the good bass production of 1973 was coincident with the flooding green terrestrial vegetation which had become established in a well-defined shoreline zone during the minor annual fluctuations of the preceeding 2 years.

Terrestrial cover lost considerable value after only 1 year of flooding. The loss of tamarisk fronds and finer stem material resulted in less desirable escape cover for fry and fingerling.

Although the term "cover" often implies "escape cover," it has other values which are probably of equal importance to bass fry and fingerling survival. Food organisms of various types are stimulated and concentrated by good cover conditions. Cover is a major component of acceptable bass habitat and figures prominently in the population dynamics of the largemouth bass in Lake Mead.

Future Study.--Future study of the Lake Mead bass fishery is important to obtain pertinent data that were not accumulated during 1973 and 1974.

Tag - Reward Study.--This study was initiated to provide the following information: (a) angular success, (b) fishing pressure, and (c) movements of largemouth bass.

Planting of 2,000 Marked Bass.--Stocking of 2,000 marked bass will provide the following information: (1) survival of stocked bass, (2) susceptibility and availability to fishermen, (3) movements, and (4) overall contribution to the bass fishery.

Aquatic and Terrestrial Vegetation Related to Lake Mead Water Levels.--The significance of both types of vegetation in relation to food and cover will be studied thoroughly.

Predation.--Some predation work has been performed in the 1973 and 1974 studies. More information will be obtained in 1975 and 1976 to provide conclusive data.

Summary: The principal impacts on the Lake Mead bass fishery are caused by three major factors induced by man and/or nature. These factors are: (1) fishing pressure, (2) water level fluctuation, and (3) weather, primarily water temperature fluctuations and wind.

Ideal conditions on Lake Mead for the enhancement of the Lake Mead bass fishery would be either stabilized water levels during the spring and early summer months, or a combination of the two covering odd years depending on availability of water and various biological conditions existing on Lake Mead.

Impacts on Nongame Fish Species.--No negative impacts.

There are no known endangered species in Lake Mead. The razorback sucker is listed as "undetermined" in the 1973 edition of "Threatened Wildlife of the United States," published by the Fish and Wildlife Service, U.S. Department of the Interior.

4.4.2.2 Wildlife

Many species of wildlife utilize Lake Mead, its shoreline, and land directly adjacent to the lake. Major species utilizing this habitat are rabbits, small rodents, coyotes, quail, dove, birds of prey, wild burros, desert bighorn sheep, a variety of snakes and lizards, and various species of waterfowl.

Impacts to Wildlife.--Stabilization of Lake Mead water levels by the construction of Glen Canyon Dam, eliminating extreme water level fluctuations, possibly has enhanced wildlife habitat on the periphery of the lake's shoreline by providing an abundance of vegetation for food and cover that was not available when shoreline and peripheral vegetation were inundated by water level increases up to 100 feet yearly.

4.4.3 Recreational Impacts

Thousands of local residents and out-of-state visitors take advantage of Lake Mead's many recreational opportunities, i.e., camping, boating, water skiing, and fishing. The many visitors attracted to the Lake Mead area also benefit the area's local businesses associated with recreational needs (oil, gas, boats and accessories, fishing tackle, etc.).

4.4.3.1 Camping

Before the construction of Glen Canyon Dam, constant Lake Mead water level increases during the spring and summer months inundated many ideal beach areas which would have otherwise been available to weekend and holiday campers. Stabilization of the lake's water levels eliminated this yearly pattern.

4.4.3.2 Boating

Fluctuating reservoirs exposing islands and rocks at various times of the year are hazardous to boaters, especially those who are unfamiliar with the lake's physical features. More stable water levels have eliminated this past characteristic making the lake safer for boating.

4.4.3.3 Marina Operations

Before the construction of Glen Canyon Dam, concessionaires were plagued with the problem of constantly lowering and raising their marinas and docks to conform with the water level patterns of Lake Mead. This was a difficult and expensive task to perform the many times a year in order to follow the fluctuating water levels. Stabilization of the lake essentially eliminated this problem creating a beneficial economic impact and less expense to the concessionaire.

4.4.3.4 Fisherman Use

Because of the population increase in the southern Nevada and southern California areas, the establishment of a salmonid and striped bass fishery, and the overall increase in popularity of fishing by the public, fisherman use on Lake Mead has increased significantly over the past 10 years. Although angler use has increased and more species of fish are being caught, angler success for largemouth bass, the major fishery of Lake Mead, has decreased from .45 to .26 per angler hours since the filling of Lake Powell. Because fisherman success for largemouth bass has declined, there apparently has been a reduction in angling pressure for largemouth bass. This reduction has resulted in a negative impact to the overall economy of the area which is partially affected by the quality of the Lake Mead bass fishery. A more productive bass fishery would eliminate this negative impact.

4.4.4 Sedimentation

Construction of Glen Canyon Dam has reduced the rate of sediment inflow into Lake Mead. Original estimates predicted a useful life of over 300 years for Lake Mead. Present estimates predict that the useful life has been extended to about 500 years. Reduced turbidity both in the Colorado River and in Lake Mead improves the aesthetic and biological values of these bodies of water.

4.4.5 Operation

The nearly uniform annual water release from Glen Canyon Dam assures a more dependable although diminished water supply for municipal, industrial, and agricultural uses in the Lower Basin. The probability of requiring flood control releases from Lake Mead is expected to be reduced in both frequency and magnitude.

4.4.6 Water Conservation

Although there have been no studies to predict the quantity, the reduced fluctuation on Lake Mead is expected to conserve a small amount of water by reducing the evaporation from the wetted shoreline and from less water surface. There is also expected to be a twofold beneficial impact on the water quality of Lake Mead. In addition to reducing the concentrating effect of evaporation, the reduced fluctuation should minimize the leaching of salts from the surrounding soil profile when the ground water level is raised and subsequently lowered.

4.4.7 Power

Upstream storage creating a more stable water level on Lake Mead is beneficial to power operations. Stable conditions afford more accurate determination of availability of dependable capacity and energy. Under certain conditions, the upstream storage could also prevent the necessity of releasing water from Lake Mead which would be used to generate secondary energy as opposed to storing water for generating firm energy at a later date.

5. Alternatives

5.1 Alternative Operations

5.1.1 Modification of Long-Term CRSP Power Operations

5.1.1.1 Renegotiation of CRSP Power Contracts

CRSP has executed contracts with preference customers in the Colorado River Basin Area for the sale of all of the Project power and energy available. These contracts have a remaining life of approximately 15 years and provide for delivery of power and energy in accordance with the hourly requirements of each particular customer. Renegotiation of this aspect of the contracts in order to level out or modify the releases from Lake Powell would require that other alternative power sources be obtained and would idle about 500 MW of Glen Canyon Powerplant installed capacity. Alternative sources of power to replace the present peaking capacity of Glen Canyon Powerplant would probably be in the form of fossil fuel burning steam electric plant.

5.1.1.2 Construction of Alternative Peaking Plants

Several alternatives to provide replacement peaking capacity at Glen Canyon Powerplant in order to facilitate a release more oriented to recreation and boating are available in the form of pump storage, turbine and conventional generating equipment. Most of the viable alternatives would require the use of fossil fuel burning plants to replace the hydro capacity foregone at Glen Canyon. Although the peaking plants, particularly turbine, may be located adjacent to the area where the load requirements are greatest, they would contribute to the degradation of the surrounding area and require fuel storage facilities. All available pumped storage sites that appear to be economically and environmentally feasible for development are being studied for use in serving future additional loads.

With the increased costs of fuels to generate the energy for the pump-back operation, the economics of such an alternative are questionable. Normally the ideal pumped storage sites are not adjacent to the area of maximum power and energy use and would require considerable transmission system to deliver the power to the users.

Additional Capacity could be included in a normal conventional fossil fuel generating or nuclear powerplant. However, these alternatives would require considerable advance planning and would have the environmental impacts associated with such plants. Although recreational activities below Lake Powell would be somewhat enchanced by modifying release patterns, a review of the costs of other resources would need to be considered in pursuring such alternatives.

Losses in revenue to the Storage Project would greatly endanger the ability of the Project to repay the costs and would affect the participating projects' repayments as CRSP revenues are used to repay the already constructed water projects. The overall plan for CRSP repayment would need to be revised, thus requiring the power rates to be increased to the point required to assure repayment in accordance with the CRSP Authorization Act.

5.1.1.3 Purchase of Alternative Peaking Capacity

Limited amounts of existing peaking capacity may be available from public or private utilities to replace peaking capacity at Glen Canyon. The amount available in the future would depend on the ability of the utilities to construct fossil fuel burning plants and to obtain financial support for such construction. Utilities in the area who are contracting with new wholesale customers have delayed in making the contracts for firm commitment before 1980. Any contracts entered are on a nonfirm basis. The lack of finances for new generating equipment had delayed or canceled the construction of several powerplants required to satisfy their normal power and energy growth.

5.1.2 Alternative Monthly Operations

5.1.2.1 Renegotiation of Customer Loads

In order to renegotiate customer loads it would require extensive energy conservation efforts by the customers in the marketing area. This might be accomplished to some extent by educating the ultimate power users not to waste electrical energy and teaching them the economics in the purchases of certain types of appliances and the installation of ideal equipment to minimize energy use. In addition, manufacturers of electrical equipment would need to review the types of electrical components used in appliances and the electrical efficiency of the equipment.

To renegotiate the amount of energy delivered by the Storage Project during the winter and summer seasons would otherwise require the customers to purchase their energy requirements from other sources. These sources would normally be fossil fuel fired generating equipment. Although contractually it is possible to force customers to take energy in a predetermined manner although not compatible with their requirements, it would be merely a matter of economics to continue to use CRSP energy.

5.1.2.2 Purchase of Alternative Peaking Power

a. On a Seasonal Basis

During certain months of the year, utilities normally have capacity in excess of their requirements due to the nature of their power system loads. This capacity could be purchased on a short-term basis in lieu of generation at Glen Canyon Powerplant. The cost of this capacity would probably be about the same as firm capacity on an annual basis due to the fact that the utilities usually use their idle capacity for maintenance of generating facilities. The purchase of such capacity would normally be from plants that would deplete fossil fuels.

b. Long-Term but Interruptible

Although purchase of interruptible peaking capacity is available, it would be difficult to use this capacity to maintain any uniformity in the releases below Lake Powell as the interruption of capacity may be fairly frequent particularly if it is produced from fuel fired steam plants.

5.1.3 Alternative Daily Operations

The release rate from Lake Powell may vary as much as 20,000 c.f.s. daily. This is primarily due to the system power requirements. Loads are usually much less on weekends and holidays than during the weekday periods. Usually releases will vary from a minimum in the early Monday morning hours to a maximum on Wednesday or Thursday evening hours. To change this pattern would require a change in the customers power and energy requirements as outlined in Section 5.1.2.1. In addition, on occasions interchanges have been made with utilities in the Western United States to allow flexibility in operations. Present plans include economic interchange transactions with utilities. These transactions include but are not limited to making on-peak, off-peak energy trades with other power systems to the extent system conditions will permit. Economic savings which result from these transactions are normally split between the United States and the other parties affected. These transactions are not generally predictable in advance, but on occasions are prearranged to assist in providing adequate flows for recreational purposes during holidays and Sundays. However, normally economic transactions would not have an adverse effect on the multi-purpose operation of the Project. Interchange between hydros and adjacent thermal generation facilities often make possible the storage of surplus energy in the form of water in one of the reservoirs for use in supplying customer loads at a later time.

5.1.3.1 Week Days

During week days, Glen Canyon releases start to increase about 7:00 a.m. to satisfy power demands around the Upper Colorado River Basin. Demand for power reaches its peak by 1:00 or 2:00 p.m. Releases then start to decrease reaching a low between 12:00 midnight and 7:00 a.m. To the extent system conditions permit, purchased energy is obtained during light-load or off-peak hours. An alternate operation might be to release a uniform flow during the week. Such an operation would eliminate buying energy in the Colorado River Storage system during off-peak hours.

a. Daytime

Daytime consumer demands for power start about 7:00 a.m. Peak demands occur about 2:00 p.m. and then slowly decrease to minimum flows about 12:00 midnight. The alternate operation for Lake Powell might be a uniform release throughout the day. This type of release would not satisfy the peak power demands of consumers. An alternate source of peak power would have to be supplied by upstream reservoirs or by private power companies.

b. Nighttime

Consumer demands decrease in the early afternoon and are at a minimum from 12:00 midnight to 7:00 a.m. under the present operating plan. If a base load or uniform release was used, large quantities of low value power would be generated and even spills would occur during the nighttime operation.

5.1.3.2. Weekends

During weekends, demand for power is less and, therefore, releases from Glen Canyon Dam with the present operation are less. Flows on weekends in the winter months often reach a minimum of 1,000 ft^3/s. and a maximum of about 8,000 ft^3/s. The alternate operation for Lake Powell would be uniform releases throughout the weekend. The uniform release operation would likely cause excessive spilling due to low power demands from consumers on weekends. No interchange into the CRSP power system would be needed, but a market for surplus energy would be essential to minimize the amount of spill during weekends.

5.1.3.3 Holidays

Holiday demand for power is similar or even less than on weekends since power demands are at a minimum. With a uniform or constant release, spills would have the same magnitude as spills during weekends.

5.1.4 Alternative Maintenance Schedules

Normally generating units are maintained during periods when power system requirements are light. The only alternative to maintaining units during these off-season energy requirements that might be more compatible with recreational use of the river system would be to reserve sufficient capacity in the system to allow maintenance at any time. Such a procedure would be very costly and uneconomical, and would put additional demands on the fossil fuel plants. Coordinated maintenance schedules with other utilities may be a possibility. However, the light load requirement of other utilities normally coincides with those of the United States, thus requiring maintenance concurrently.

5.1.5 Alternative Operations to Maximize Recreation on Lake Powell

At its normal long-term operating level, Lake Powell provides about 130,000 acres of surface for swimming, boating, water skiing and fishing. For the sightseer and explorer, it provides over 1,700 shoreline miles of canyons carved from rocks of varied description and color. To maximize recreation, Lake Powell should remain at a constant elevation throughout the recreational season. The alternative operation for lake-oriented recreation would cause low releases during the early spring and late summer months. This type of operation is not compatible with a power operation and probably would cause the generators to be taken off line under low release conditions. Downstream fishing and enhancement, as well as river boating, would also be seriously impaired by such low and erratic flows.

5.1.6 Alternative Operations to Maximize Recreation on Tailwater and River

Releases from Lake Powell are normally so planned that a minimum continuous flow of at least 1,000ft^3/s will be maintained in the river. Alternative operation to maximize the recreation downstream would be to release water at a sufficient level and at a uniform rate. This would be the best operation to enhance fishing and boating downstream and not strand any boaters on the river. This type of operation would not be good for power operation in terms of power for peaking. Glen

Canyon Powerplant would operate as a base loading powerplant with other upstream reservoirs supplying peaking power and other CRSP power. Recreational activities on Lake Powell will suffer by a fluctuating reservoir being lowered during the winter and raised in the runoff season.

5.2 Other Alternatives

5.2.1 Renegotiation of Compacts and Treaties

The Colorado River is governed by Colorado River Compact and the Mexican Treaty. By renegotiating these two documents, Glen Canyon release patterns could be maximized for power, reservoir fishing, wildlife and recreation or to some degree for any combination thereof.

5.2.1.1 Colorado River Compact

The Colorado River Compact, among other things:

a. Divides the Colorado River Basin into the Upper Basin and Lower Basin at Lee Ferry, Arizona;

b. Divides the beneficial consumptive use of water between the Upper and Lower Basins;

c. Provides for a minimum delivery to the Lower Basin of 75,000,000 acre-feet every 10 years at Lee Ferry; and

d. Provides for sharing equally, by the Upper and Lower Basins, the burden of delivery of any deficiency in water available in the Colorado River to satisfy the water Treaty with the Republic of Mexico.

By renegotiation the Upper and Lower Basin could be divided below Hoover Dam. Therefore, Lake Mead could act as a regulatory reservoir for irrigation and water for domestic uses leaving Glen Canyon Dam to utilize releases. (1) The southern part of the basin has demand for power in the summer months for cooling homes. The Upper Basin could execute power contracts on a long-term basis with the southern part of the basin with maximum power benefits. (2) The power releases would be high in the summer months to give near maximum benefits to boaters planning trips through the Grand Canyon. (3) Surplus power could be interchanged into the system from the northwest in the springtime and, therefore, cut back on releases at Glen Canyon Dam. Glen Canyon Powerplant could generate the heavy demand for power needed in the southern part of the region during the summer months.

5.2.1.2 Mexican Treaty

This article provides:

> "(a) A guaranteed annual quantity of 1,500,000 acre-feet...
>
> "(b) ...in any year in which, as determined by the United States Section, there exists a surplus of waters..., the United States undertakes to deliver to Mexico...additional waters of the Colorado River System to provide a total quantity not to exceed 1,700,000 acre-feet a year ....In the event of extraordinary drought or serious accident...making it difficult to delivery the guaranteed quantity,...the water allotted to Mexico...will be reduced in the same proportion as consumptive uses in the United States are reduced."

A renegotiated treaty might be such as to not specifically define a period in which water would be delivered to Mexico. Water in storage at Lake Powell could be released to Mexico at a time when power demands are the highest. Extra water could be given to Mexico in the form of spills duirng high runoff years at Glen Canyon. In the event of an extraordinary drought, water allotted to Mexico will be reduced on the same basis as the present treaty.

5.2.2 Amendment of Federal Laws and Regulations

Amendments of Federal Laws would change the operation at Lake Powell to maximize recreation, both above and below the dam, fishing, wildlife and power demand.

5.2.2.1 Boulder Canyon Project Act

5.2.2.2 Colorado River Storage Project Act

The Colorado River Storage Project Act provides for the development of water for consumptive use within the Upper Basin, control of floods, and production of electrical energy. Under an amended law, Glen Canyon could be operated to maximize fishing and boating above and below Glen Canyon Dam. In most cases, new criteria under an amended law would not be compatible with the other laws that presently govern the Colorado River.

More of the project costs would have to be allocated recreation, fish and wildlife, and would be nonreimbursable and nonreturnable.

5.2.2.3 Colorado River Basin Project Act

The object of this act is to provide a program for further development of the water resources of the Colorado River Basin. However, the act is subject to all laws that have governed the Colorado River in the past.

Operation of Glen Canyon for fishing, recreation and boating both above and below the Dam would require a need to amend the Colorado River Basin Project Act. Parts of the act that govern releases at Glen Canyon Dam would have to be omitted.

5.2.2.4 Criteria for Coordinated Long-Range Operations of Colorado River Reservoirs

The annual plan for operating the Upper Basin Reservoirs would have to be modified to provide for recreation, fishing and boating in the vicinity of Lake Powell. Article II(2)(b) has an objective of maintaining a minimum release of 8.23 million acre-feet. Article II(3)(b) limits the filling of Lake Powell by releasing water from Lake Powell to maintain equal storage in Lake Powell and Lake Mead. These criteria could remain in the long-range operation, but would be secondary to the recreational objectives around Glen Canyon Reservoir.

5.2.3 Water Importation from Other Drainage Areas

Water importation into the Colorado River Drainage System as an alternative would be very benficial to the Colorado River Basin. The water could be used to benefit the Glen Canyon Reservoir's boating and fish and wildlife activities with Colorado Basin drainage water used to satisfy the Law of the River requirements. However, Title II of Public Law 90-537, dated September 30, 1968, states that for a period of ten years from the date of this act, the Secretary shall not undertake reconnaissance studies of any plan for the importation of water into the Colorado River Basin from any other natural river drainage basin lying out of the States of Arizona, California, Colorado, New Mexico, and portions of Nevada, Utah and Wyoming, which are in the natural drainage basin of the Colorado River.

5.2.4 Precipitation Modifications

The Colorado River Basin Act of 1968 directed the Secretary of Interior to conduct investigations to augment water supply of the Colorado River by means of weather modification. Results of these investigations show that weather modification is a definite possibility for increased runoff of the Colorado River. The incremental increase of water would be used at Glen Canyon primarily to enhance fishing, boating, and lake recreation. The Colorado River Basin Project Act of 1968 also directs the Secretary to satisfy the requirements of the Mexico Water Treaty from the Colorado River as a first obligation of any water augmentation project. This section would be amended to give Lake Powell recreation the highest priority and the Mexican Treaty obligation as a secondary priority.

5.2.4.1 Cloud Seeding

The technique of cloud seeding in the Upper Colorado River Basin is a promising source of new water supply. Some of the advantages of using cloud seeding to augment the Upper Basin water supply are (1) a source of high-quality water that does not reduce water supplies in other areas. (2) no known major ecological disadvantages. (3) Increased water at high elevations permitting hydropower generation. (4) Water supply enhancement at a relatively low cost. Runoff from incremental precipitation in the Upper Colorado River Basin could cause additional runoff to average approximately 1.3 million acre-feet annually.

5.2.5 Water Conservation Measures

Watershed Management

Manipulation of begetative cover and other water yield improvement techniques can result in increased stream flow without damage to the watershed or to areas downstream if the activity is carefully planned and executed as part of a coordinated land and resource management program.

Farm Management

On-farm water management should prevent excessive use of water runoff, deep percolation, water logging, soil erosion, and loss of plant nutrients. It also has a direct effect on the water quality in the irrigation return flows with efficient distribution systems to minimize water use.

Seepage and Conveyance Loss Control

In order to conserve water, conveyance systems should be concrete lined or covered for the most efficient system use. Evaporation will be less with a covered-type system as well as less weeds and other growth along ditches to deplete the water. Water saved from seepage and conveyance loss could be applied within each state as another consumptive use and the state would have the benefits.